Problem Chosen	2022 MCM/ICM Summary Sheet	Team Control Number
F		2210118

How to Realize Global Equity: Payday of Asteroids

Asteroids are hoards of abundant precious metals resources forming in the core of Earth far from Earth crust where most mining take place. However, attempts to gain individual profits from selling these rare metals without universal regulations would eventually evolve to political competition against the UN's goal of maintaining global peace. Considering the rapid development of asteroid mining industry, UN needs to modify Outer Space Treaty aiming to promote global peace and reduce inequalities.

For problem 1, we define Global Equity as the rational and fair allocation. Next, to quantify asteroid resources in a standard manner, we develop a **Quantification of Asteroid Resources Model**. And then, a **Resources Allocation Score Model** is constructed to rationalize the allocation of resources. Then we use **WGI Aggregation Methodology and Entropy Weight Method** to process the data and calculate the weight. Based on our analysis, we assume: in the process of mineral resources allocation, a country with more economic resources, governance, scientific and technological resources should enjoy more allocation of mineral resources.

For problem 2, we begin with describing the pattern of asteroid mining in the future. Then we develop a **Principal Component Analysis Model** and take into consideration of mining capacity, per capita resource demand, number of technicians, and ore and metals imports and exports (% of merchandise imports). After that, t**he Global Equity Index(GEI)** is constructed with the use of principal components. Last but not least, the Global Equity Index is applied to the United Kingdom from 2005 to 2015, where its effectiveness is verified. From the time series figure in the text, it can be seen that the GEI of the UK has exceeded 0.25 by 2015.

For problem 3, in order to explore how changes in the asteroid mining factors mentioned in problem 2 could impact the Global Equity Index differently, a **GEI prediction model** is developed. And the **Expert Modeler** selects the most appropriate time series model for per capita resource demand, ore and metals imports and exports. From the time series diagrams, there is no denying that the predicted data of per capita resource demand has a linear downward trend, ore and metals imports and exports have a smooth trend. The specific impact on global equity is seriously analyzed.

For problem 4, we propose reasonable strategies in order to resolve the conflicts between existing Outer Space Treaty and developments of asteroid mining in the future. We take the contribution degree of each country to global equity into consideration and establish a non-profit **SMOC** (Space Mining Oversight Committee) organization to solve the problem of equitable distribution of resources. By granting ownership of resources to organizations for equitable distribution, making the technology available to all countries after the expiration of patent, and providing R&D funds to countries at different levels of development to promote global equity and reduce inequality.

Finally, we analyze the accuracy and sensitivity for judging our proposed models, proving that our model is accurate and stable for different parameters.

Contents

1 Introduction

1.1 Problem Background

It was not until Japanese Hayabusa probe snatched first asteroid sample that human unveiled the mystery of the elemental composition of asteroids. Asteroids are hoards of abundant rare metals resources like platinum group metals (ruthenium, rhodium, palladium, osmium, iridium and platinum). These precious metals form in the core of Earth far from Earth crust where most mining take place. Therefore, these metals are difficult to exploit which leads to high price of rare metals. "I'll make a prediction right now. The first trillionaire will be made in space." Ted Cruz's words reveal people's pursuit to acquire huge profits on asteroid mining.

However, based on Outer Space Treaty, "the exploration and use of outer space shall be carried out for the benefit and in the interests of all countries and shall be the province of all mankind", corporation's attempts to gain profits from selling rare metals violates treaty because it's a commercial activity for individual benefits. Since such activity would be modelled after by other country's corporations, competition for resources would evolve to political competition eventually which runs counter to UN's goal to maintain global peace. Considering the rapid development of asteroid mining industry, UN feels the urged need to modify Outer Space Treaty aiming to promote global peace and reduce inequalities.

1.2 Restatement of the Problem

Considering the background information and restricted conditions identified in the problem statement, we need to solve the following problems:

- Give a definition of global equity and build a mathematical model to quantify global equity based on the definition.
- Asteroid mining is still in its very much infancy that the prospects of conditions relating to asteroid mining are so much. Therefore, assume and demonstrate one possible vision of asteroid mining in the future, using appropriate justification to explain it. Moreover, analyzing how asteroid mining influencing global equity model.
- Consider how global equity model changes accordingly when altering different conditions selected for the future of asteroid mining visions.
- For the sake of promoting global peace and reduce inequality, taking results of global equity model as evidence of policy making, proposing some ideal modification of Outer Space Treaty and create a rational pattern for asteroid mining in the future.

1.3 Our Work

We establish four models to solve the problem in our paper.

First, we divide elements in asteroids to industrial elements and PGM and unify the unit of each element in asteroid in order to get the knowledge of the total value of mineral resources. We use the spot price of gold as the standard of value conversion. If we get the ratio of resources on any asteroid, we can calculate the total value of mineral resources in that asteroid. Equitable distribution of resources is an embodiment of global equity.

Secondly, we define F as resource allocation. Then, we divide influence factors to three aspects, economics, politics, and science and technology. We select appropriate sub-factors and calculate the weight of them by applying Entropy Weight Method to get the score of each factor in resource allocation. Given equal weight to these three factors, we determine the proportion of resource allocation in the form of scores.

Thirdly, we apply the method of principal component analysis (PCA) to determine three parameters that have the greatest impact on global equity index. Then, we use per capita resources demand, import of ores and metals, export of ores and metals, three calculated parameters to determine global equity index which demonstrates how these parameters impact global equity.

Finally, we use the data of per capita resources demand, import of ores and metals, export of ores and metals from previous years to predict how these factors would change over time. By analyzing the development trend of these three factors, we propose the possibility of how these factors affect global equity and give specific suggestions from the perspective of international organizations. We should reserve a minimum number of mineral resources for each country, set reasonable patent expiration time, provide scientific research funds to country in need, and set different loan interest rates according to the development of science and technology in different countries.

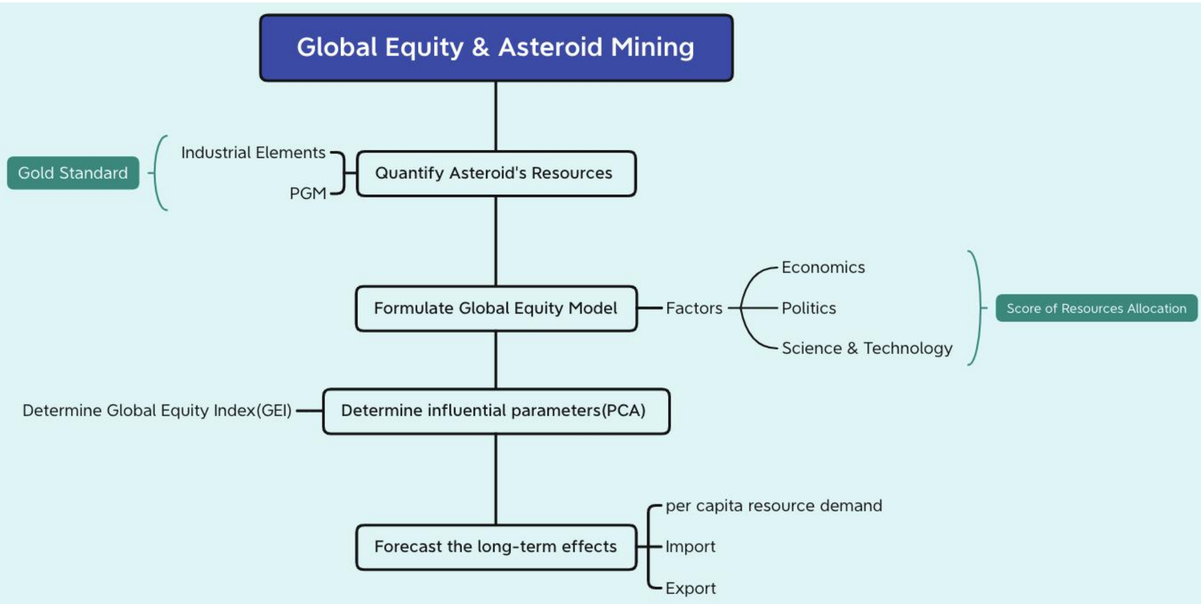

Figure 1: whole modeling process of the paper

2 General Assumptions

- Assume that the value of asteroids' mineral resources could be measured. Generally speaking, we just focus on the abundant elements to quantify the resource value;

- It is assumed that the comprehensive national power to the resources allocation score are equally important, which could be reflected on economical, political, and scientific and technological aspects;

- Assume that there is simple linear relationship between $\mathrm{F_i}$ and its sub factors $\mathrm{F_i^{(j)}}$ on the model. In order to make the selected factors describe the model more accurately, it is necessary to unify the standards of different factors;

- We assume that the statistics we collected from the websites and reports are reliable and accurate. The data we use in our model is mainly collected from some databases, such as UN data, UIS.Stat, WGI.

3 Notations and Signs

Table 1 shows the main notations and signs used in this paper. Other notations and signs will be declared or defined when using.

Table 1: Declaration of notations and signs

Symbol	Description
RV	the total value of asteroids' mineral resources
F	resources allocation score
x_1	mining capacity(measured by CIP index)
x_2	per capita resource demand
x_3	number of technicians
x_4	ore and metals imports (% of merchandise imports)
x_5	ore and metals exports (% of merchandise imports)
GEI	global equity index

4 Task 1: Measurement of Global Equity

4.1 Definition of Global Equity

Global Equity is the rational and fair allocation, based upon global economic interests, political interests, and scientific and technological interests and other interests. It embodies the impartial and reasonable allocation of rights and responsibilities. Every country participating in global cooperation should shoulder its corresponding responsibilities and get the benefits it deserves.

In the process of mineral resources allocation, a country with more economic resources, governance, and scientific and technological resources should enjoy more allocation of mineral resources. Why do we allocate resources according to the comprehensive national power of a country to achieve equity? Neil Armstrong was the first to set foot on the moon, but stepping on the ground doesn't mean he owns it. We must admit that every citizen of the earth including our children has the right to enjoy the huge resource wealth of universe. It's not possible to carefully assign to each individual from realistic considerations. However, global equity may be achieved at a certain extent by comprehensively allocating the quantified mineral resources from the macro perspective of countries and regions.

4.2 The Quantify Model of Global Equity

4.2.1 Introduction to Asteroid Resources

At present, all commercial space activities are carried out in geosynchronous orbit (GEO), the vicinity of Earth. However, with the mature of technology more attention would be paid to asteroids farther away.

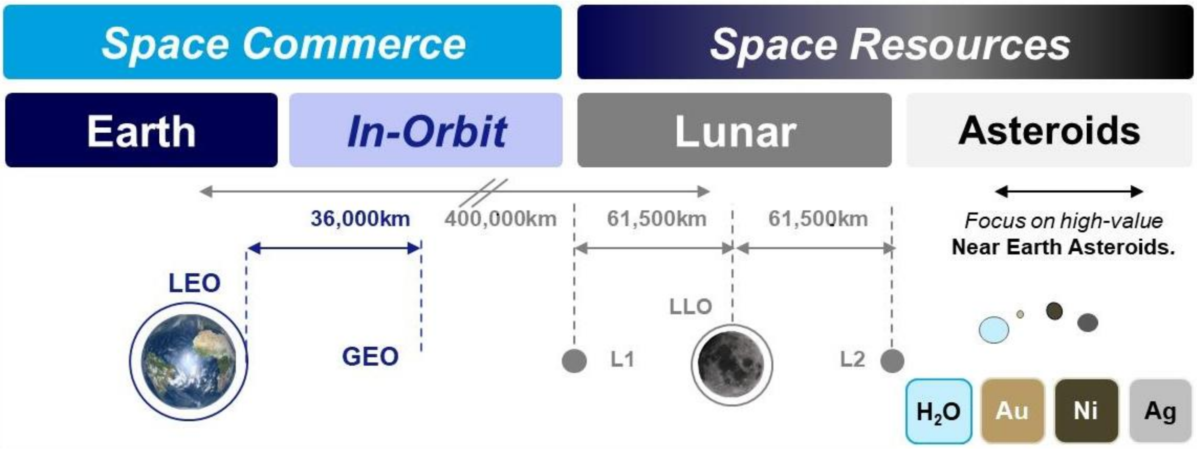

Figure 2: Almost space activities used to carry out in geosynchronous orbit (GEO). However, with the mature of technology, more attention would be paid to asteroids farther away where more valuable space resources stored in there.

Literature indicate that these asteroids may contain valuable elements, like platinum group metals (PGMs), gold, and germanium. Identified natural resources include also industrial elements, such as nickel, in the form of metallic nickel-iron, and cobalt.

Table 2:Abundance (ppm) of PGMs and precious metals in asteroids

Metals	LL chondrite asteroid	Earth Crust
Industrial elements		ppm^3
Cobalt	1.57%	25
Nickel	34.3%	120
Iron	63.7%	55,000
Germanium	1,020	1.8
PGM	*ppm*	*ppm*
Rhenium	1.1	0.0004
Ruthenium	22.2	0.001
Rhodium	4.2	0.0002
Palladium	17.5	0.0006
Osmium	15.2	0.0001

Sources: Cited from Sommariva, Andrea. "Rationale, strategies, and economics for exploration and mining of asteroids." Astropolitics 13.1 (2015): 25-42.

4.2.2 Model I: Quantification of Asteroid Resources

In order to get the knowledge of the total value of asteroids' mineral resources on a uniform basis. First, we define the total value of asteroids' mineral resources as $\boldsymbol{RV}$, measured by an equation that standardizes the value of cobalt, nickel, iron, germanium, rhenium, ruthenium, rhodium, palladium and osmium on gold standard. Then, we choose coefficient $\boldsymbol{\alpha_i}$ as equivalent conversion rate to convert the average market price of each metal to spot price of gold.

$$\mathbf{RV} = \alpha_1\mathrm{Cobalt} + \alpha_2\mathrm{Nickel} + \alpha_3\mathrm{Iron} + \alpha_4\mathrm{Germanium} + \alpha_5\mathrm{PGM} + \alpha_6\mathrm{R}h\mathrm{enium} + \alpha_7\mathrm{Rut}h\mathrm{enium} + \alpha_8\mathrm{R}h\mathrm{odium} + \alpha_9\mathrm{Osmium} \tag{1}$$

Where, RV represents resource value of asteroids, α_i is equivalent gold conversion rate.

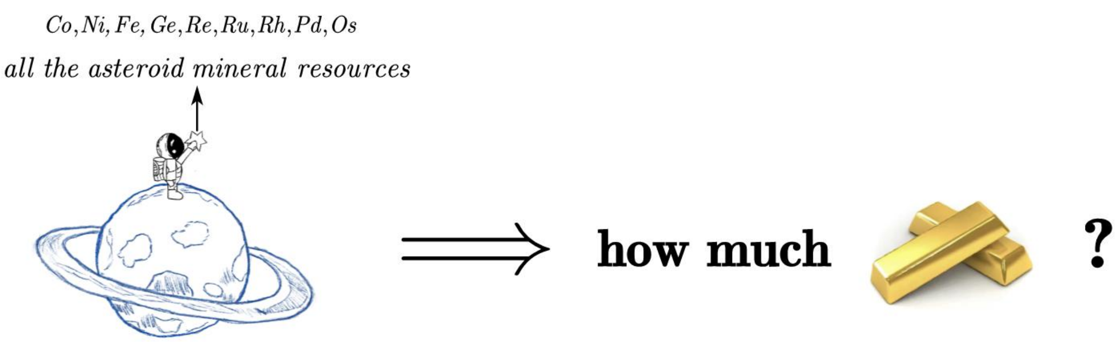

Figure 3: Equivalent conversion based on the gold standard

4.2.3 Model II: The Resources Allocation Score Mode

Global Equity is the rational and fair allocation, so we define the resources allocation score as F. Then, we consider the economic influence factors of the resources allocation score. In the process of mineral resources allocation, a country with more economic resources, governance, and scientific and technological resources should enjoy more allocation of mineral resources. Therefore, we define F_1, F_2 and F_3 as economical, political, and scientific and technological factors.

Firstly, we consider the economic influence factors of the amount of resources allocation. We believe a country with more economic resources deserve more mineral resources during allocation. F_1 represents resources allocation based upon various economic factors with different weights. Firstly, the economic factors on resource allocation, which include Gross Domestic Product (GDP), Consumer Price Index (CPI), Unemployment Rate and Producer Price Index (PPI), are significant.

$$F_1 = f(F_1^{(1)} + F_1^{(2)} + F_1^{(3)} + F_1^{(4)}) \tag{2}$$

$F_1^{(1)}$ means Gross Domestic Product.

$F_1^{(2)}$ means Consumer Price Index.

$F_1^{(3)}$ means Unemployment Rate.

$F_1^{(4)}$means Producer Price Index.

As a broad measure of overall domestic production, GDP functions as a comprehensive scorecard of a given country's economic health. And the stability of CPI is often the most important Social-Economic goal. Keeping the stable growth of CPI is often the most important Social-Economic goal. In addition, the unemployment rate and economic growth rate have a negative correlation. As the economy grows, the unemployment rate will decrease. What's more, the producer price index is an index used to measure the average change of manufacturers' factory prices. If the producer price index is higher than expected, it indicates that there is a risk of inflation.

According to the Assumption 1, there is a linear relationship between resources allocation and economic factors. Therefore, F_1 can be expressed as

$$F_1 = \alpha_{11}F_1^{(1)} + \alpha_{12}F_1^{(2)} + \alpha_{12}F_1^{(3)} + \alpha_{14}F_1^{(4)} \tag{3}$$

where, $\alpha_{1i}(i = 1,2,3,4)$ is weight of each sub factor to economic factor.

Then, we use **Entropy Weight Method** to process the data and calculate the weight. The result is showed as follows.

$$F_1 = 0.2795F_1^{(1)} + 0.6762F_1^{(2)} + 0.0334F_1^{(3)} + 0.0108F_1^{(4)} \tag{4}$$

Secondly, as for political impacts on allocation, we believe a country with healthy political atmosphere, effective government and responsibility could receive more resources during allocation. We evaluate political equity from 6 aspects, including the voice and accountability, the political stability and absence of violence/terrorism, the government effectiveness, the regulatory quality, the rule of law and the control of corruption.

$$F_2 = g\left(F_2^{(1)} + F_2^{(2)} + F_2^{(3)} + F_2^{(4)} + F_2^{(5)} + F_2^{(6)}\right) \tag{5}$$

$F_2^{(1)}$means Gross Voice and Accountability.

$F_2^{(2)}$means Political Stability and Absence of Violence/Terrorism.

$F_2^{(3)}$means Government Effectiveness.

$F_2^{(4)}$means Regulatory Quality.

$F_2^{(5)}$means Rule of Law.

$F_2^{(6)}$means Control of Corruption.

The Worldwide Governance Indicators report on the above six broad dimensions of governance for over 200 countries and territories over the period 1996-2020. Governance consists of the traditions and institutions by which authority in a country is exercised. This includes the process by which governments are selected, monitored and replaced; the capacity of the government to effectively formulate and implement sound policies; and the respect of citizens and the state for the institutions that govern economic and social interactions among them. Countries with great capacity of governance spare more efforts in maintaining social stability. By comparing governance, we could measure how much responsibility has a country shouldered. More resources need to be allocated to country with greater capacity of governance for the sake of equity.

According to the Assumption 1, there is a linear relationship between resources allocation and political factors. Therefore, F_2 can be expressed as

$$F_2 = \alpha_{21}F_2^{(1)} + \alpha_{22}F_2^{(2)} + \alpha_{23}F_2^{(3)} + \alpha_{24}F_2^{(4)} + \alpha_{25}F_2^{(5)} + \alpha_{26}F_2^{(6)} \tag{6}$$

where, $\alpha_{2i}(i = 1,2,3,4,5,6)$ is weight of each sub factor to political factor.

Then, we use **WGI Aggregation Methodology** to process the data and calculate the weight. Using an Unobserved Components Model (UCM) to construct a weighted average of the individual indicators for each source. A statistical tool known as an Unobserved Components Model (UCM) is used to make the 0-1 rescaled data comparable across sources, and then to construct a weighted average of the data from each source for each country. The UCM assumes that the observed data from each source are a linear function of the unobserved level of governance, plus an error term. This linear function is different for different data sources, and so corrects for the remaining non-comparability of units of the rescaled data noted above. The resulting estimates of governance are a weighted average of the data from each source, with weights reflecting the pattern of correlation among data sources. The result is showed as follows.

$$\begin{aligned} F_2 = 0.1368F_2^{(1)} + 0.1789F_2^{(2)} + 0.1158F_2^{(3)} + 0.1053F_2^{(4)} + 0.3579F_2^{(5)} \\ + 0.1053F_2^{(6)} \end{aligned} \tag{7}$$

Thirdly, several scientific and technological factors also have a certain impact on resource allocation. Countries that invest more resources in scientific research should share more benefits in resources allocation. Among all factors, what contribute most to the development of technology are Education and Research Expenditure. Thus, we pay much attention to these two aspects.

In the model, we choose four factors, including GERD as a percentage of GDP, Government Expenditure on Education as a percentage of GDP, Gross Graduation Ratio from First Degree Programs in Tertiary Education, both sexes, Total Research & Development personnel (FTE).

$$F_3 = h(F_3^{(1)} + F_3^{(2)} + F_3^{(3)} + F_3^{(4)}) \tag{8}$$

$F_3^{(1)}$ means GERD as a percentage of GDP.

$F_3^{(2)}$ means Government Expenditure on Education as a percentage of GDP.

$F_3^{(3)}$ means Gross Graduation Ratio from First Degree Programs in Tertiary Education, both sexes.

$F_3^{(4)}$ means Total Research & Development personnel (Full-time Equivalent)

Gross Domestic Expenditure on research and development (GERD) as a percentage of GDP is the total intramural expenditure on research and development performed in the national territory during a specific reference period expressed as a percentage of GDP of the national territory. The ratio of Government Expenditure on Education reveals its economic strengths and scientific strengths. Gross Graduation Ratio from First Degree Programs in Tertiary Education is an index to measure the quantity of reserves of scientific research talents. The more higher education talents, the greater the potential for the development of science and technology. Total Research and Development personnel who engage in scientific research for a full-time workweek indicates both time and the number of people put into scientific research activities.

According to the Assumption 1, there is a linear relationship between resources allocation and scientific and technological factors. Therefore, F_3 can be expressed as

$$F_3 = \alpha_{31}F_3^{(1)} + \alpha_{32}F_3^{(2)} + \alpha_{33}F_3^{(3)} + \alpha_{34}F_3^{(4)} \tag{9}$$

where, $\alpha_{3i}(i = 1,2,3,4)$ is weight of each sub factor to scientific and technological factor.

Then, we use **Entropy Weight Method** to process the data and calculate the weight. The result is showed as follows.

$$F_3 = 0.2612F_3^{(1)} + 0.1250F_3^{(2)} + 0.1066F_3^{(3)} + 0.5072F_3^{(4)} \tag{9}$$

Resource allocation (F) is determined by economic, political, scientific and technological factors. Causality is as follows.

$$\begin{gathered} F = v(F_1 + F_2 + F_3) \\ F = \alpha_1F_1 + \alpha_2F_2 + \alpha_3F_3 \end{gathered} \tag{10}$$

We assume that political, economic and scientific and technological factors are equally important, which means

$$\alpha_1 = \alpha_2 = \alpha_3 = 1 \tag{11}$$

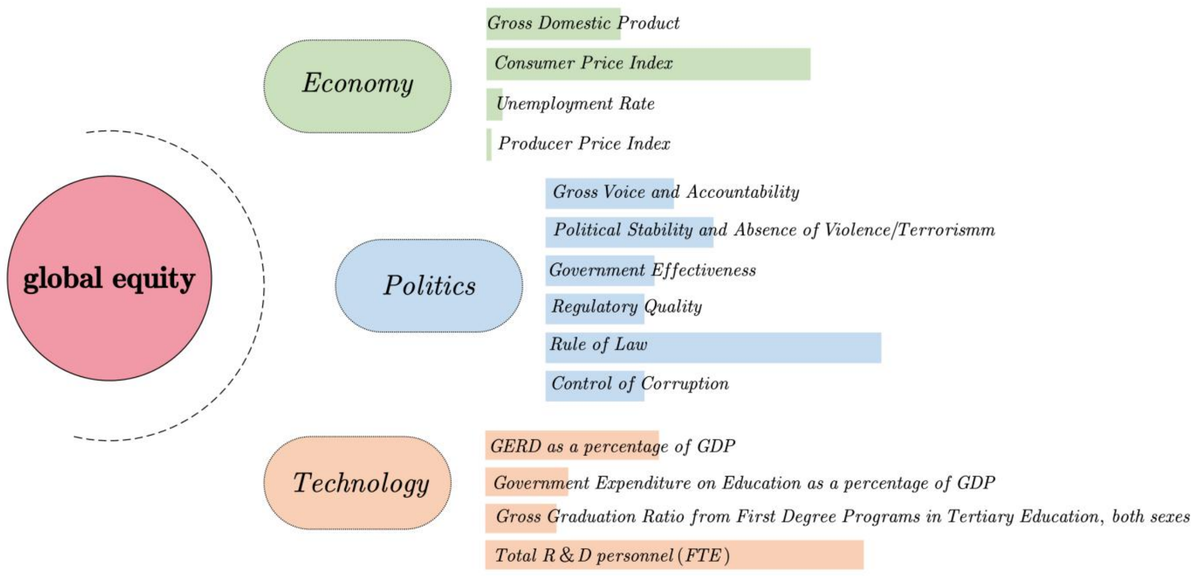

Figure 4: We chose 14 indicators of 3 factors based on the principle of macro-perspective and the actual situation of Comprehensive National Power. The shaded part is the proportion of each indicator.

5 Task 2: Prospect Asteroids Mining Sectors

5.1 Description of the Operation of Asteroids Mining

Attracted by rich mineral resources contained in asteroids, human beings engage in developing technologies of asteroid mining. With the prospect to develop bigger mineral market and alleviate the earth's depletion problem, all countries and regions in the world lay great emphasis on competing mineral resources in asteroids which against original goal of UN to promote peace and reduce inequality. Due to the urgent appeals to solve the allocation of resources with global equity, an international institution named as The Space Mining Oversight Committee (SMOC) established.

SMOC is a permanent international organization which is composed of representatives who dedicate to research global equity in allocation of mineral resources from countries all over the world. It is not only the organizational foundation of the asteroid mining industry, the manager of the asteroid mining trade, the supervisor of the allocation of resources among its members, but the venue for resolving equity issues in the asteroid mining industry.

With the goal of global equity, combining far-reaching law of sea, SMOC estimates the value of available asteroid mineral resources in the gold standard. According to reliable and transparent estimation methods, SMOC allocates and exploits resources rationally for every country and region in the world. Taking the reality of the small number of countries and regions may not acceding to the organization into account, mineral resources should be retained in order to ensure global equity. Only those which belong to the member states will be allowed to mine.

Proportional membership fees shall be collected by SMOC from all member countries in order to fund, operate, manage and supervise orderly execution of asteroids mining. One thing to note that all commercial or non-commercial asteroid mining activities must be conducted under the supervision of the organization. Institutions, companies or enterprises with technical support and licenses from member countries will be authorized to conduct asteroid mining operations after paying a certain license fee. At the same time, SMOC will also fund mining operations in the form of loans. Although asteroid mining becomes a reality at present, all mining products are not owned by individuals due to its particularity and global equity. In other words, mining enterprises have no right to sell the minerals themselves for profits. All mining products would be traded by SMOC. According to the idea of optimizing the allocation of resources, SMOC will give priority to the countries in greater need of trade among mineral purchasing countries in the trade market. The part of trade income will be paid to mining enterprises as commission.

Enterprises could apply for loan from SMOC and the interest of loan could be reduced in proportion according to enterprise’ s KPI which aims to promote positive development of asteroid mining industry. Excluding the cost of mining enterprises, the remaining trade proceeds will be distributed to each member country after deducting essential daily operating expenses of SMOC in strict proportion to the global equity model.

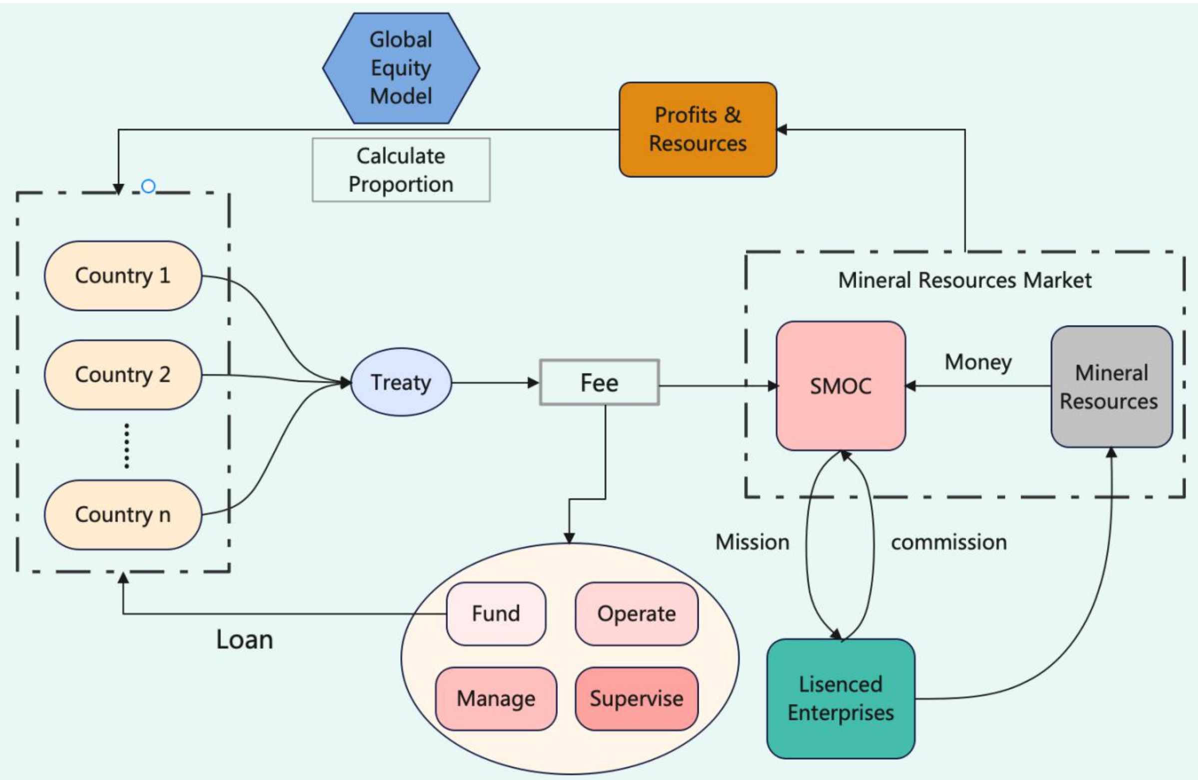

Figure 5: The Pattern of Space Mining Oversight Committee

5.2 Model III: A Principal Component Analysis Model

Principal component analysis (PCA) is a multivariate statistical method often used for reducing dimensionalities. It transforms a group of variables with possible correlation into linearly unrelated ones through orthogonal transformation, and the converted variables are called principal components. These principal components are linear combinations of original variables and are not related to each other.

Since this global equity problem involves multiple variables and there is a strong correlation between variables, we decided to use principal component analysis to figure out several factors that have a relatively great influence on global equity.

5.2.1 Model Results and Construction of the Global Equity Index (GEI)

Here, we employ PCA to construct the global equity index $\mathrm{GEI_i}$.

We select seven developed countries (USA, UK, Canada, Japan, Germany, France, Italy) and seven developing countries (China, India, Thailand, South Africa, Egypt, Mexico, Brazil) as the evaluation objects. And then, when we choose the mining factors affecting global equity as the evaluating indicators, we take mining capacity, per capita resource demand, number of technicians, ore and metals imports and exports (% of merchandise imports) into consideration. Thus, the sample matrix is as follows,

$$\mathrm{x} = \begin{bmatrix} \mathrm{x_{11}} & \cdots & \mathrm{x_{1p}} \\ \vdots & \ddots & \vdots \\ \mathrm{x_{n1}} & \cdots & \mathrm{x_{np}} \end{bmatrix} = (\mathrm{x_1}, \mathrm{x_2}, \cdots, \mathrm{x_p}) \tag{12}$$

where, n is the number of countries (n=14) , p is the number of mining factors (p=5) .

Step1: we standardize the data by:

$$\mathrm{X_{ij}} = \frac{\mathrm{x_{ij}} - \overline{\mathrm{x_j}}}{\mathrm{S_j}} \tag{13}$$

$$\overline{x_j} = \frac{1}{n}\sum_{i=1}^{n} x_{ij} \tag{14}$$

$$\mathrm{S_j} = \sqrt{\frac{\sum_{i=1}^{n}\left(\mathrm{x_{ij}} - \overline{\mathrm{x_j}}\right)}{\mathrm{n} - 1}} \tag{15}$$

where $\overline{\mathrm{x_j}}$ is the mean, $\mathrm{S_j}$ is the standard deviation, and $\mathrm{X_{ij}}$ is the standardized data.

Step2: calculate the covariance matrix of standardized samples.

$$r_{ij} = \frac{1}{n-1}\sum_{k=1}^{n}\left(X_{ki} - \overline{X_i}\right)\left(X_{kj} - \overline{X_j}\right) = \frac{1}{n-1}\sum_{k=1}^{n} X_{ki}X_{kj} \tag{16}$$

where $\mathrm{r_{ij}}$ is the covariance.

Step3: Calculate the characteristic values and feature vectors.

Characteristic Value: $\lambda_1 \geq \lambda_2 \geq \cdots \geq \lambda_p \geq 0$

$$\text{Feature Vector: } a_1 = \begin{bmatrix} a_{11} \\ a_{21} \\ \vdots \\ a_{p1} \end{bmatrix}, \ a_2 = \begin{bmatrix} a_{12} \\ a_{22} \\ \vdots \\ a_{p2} \end{bmatrix}, \ \cdots, \ a_p = \begin{bmatrix} a_{1p} \\ a_{2p} \\ \vdots \\ a_{pp} \end{bmatrix}$$

Step4: Calculate the principal component contribution rate and cumulative contribution rate.

$$\text{Contribution Rate} = \frac{\lambda_i}{\sum_{k=1}^{p} \lambda_k} (i = 1,2,\cdots,p)$$

$$\text{Cumulative Contribution Rate} = \frac{\sum_{k=1}^{i} \lambda_k}{\sum_{k=1}^{p} \lambda_k} (i = 1,2,\cdots,p)$$

Step5: The results of principal component analysis.

Generally, we select the cumulative variance contribution rate of the first few principal components as the analyzed principal components. In other words, most information can be described by these comprehensive evaluation indicators. Here, we select the principal components whose cumulative variance contribution reaches 90%. The PCA results are shown in Table 3.

Table 3: eigenvalue, eigenvector, contribution rate of correlation coefficient matrix

Character vector	a_1	a_2	a_3	a_4	a_5
x_1	0.1748	-0.6505	-0.5195	-0.4834	-0.2065
x_2	0.5149	0.0975	-0.5380	0.6577	-0.0572
x_3	0.6006	-0.1925	0.2935	-0.1403	0.7046
x_4	-0.1201	-0.7096	0.4200	0.5288	-0.1611
x_5	0.5737	0.1636	0.4220	-0.1855	-0.6570
Characteristic value	2.2026	1.4205	0.9590	0.2876	0.1304
Contribution rate	0.4405	0.2841	0.1918	0.0575	0.0261
Cumulative contribution rate	0.4405	0.7246	0.9164	0.9739	1.0000

$$\begin{cases} Z_1 = 0.1748x_1 + 0.5149x_2 + 0.6006x_3 - 0.1201x_4 + 0.5737x_5 \\ Z_2 = -0.6505x_1 + 0.0975x_2 - 0.1925x_3 - 0.7096x_4 + 0.1636x_5 \\ Z_3 = -0.5195x_1 - 0.5380x_2 + 2935x_3 + 0.4200x_4 + 0.4220x_5 \end{cases} \tag{17}$$

Step6: Use the results of principal components to analyze the global equity index(GEI).

We can calculate the global equity index by

$$GEI = 0.4405Z_1 + 0.2841Z_2 + 0.1918Z_3 \tag{18}$$

and then we put the value of Z into Eq.(18) and get

$$GEI = -0.2074X_1 + 0.1513X_2 + 0.2662X_3 - 0.1739X_4 + 0.3801X_5 \tag{19}$$

Here, Eq.(19) represents the influence of main information on the global equity index.

5.2.2 Effectiveness and Application of the Global Equity Index

To verify the effectiveness of the global equity index, we calculate the global equity index of the United Kingdom from 2005 to 2015. And the time series diagram is shown in Figure 6.

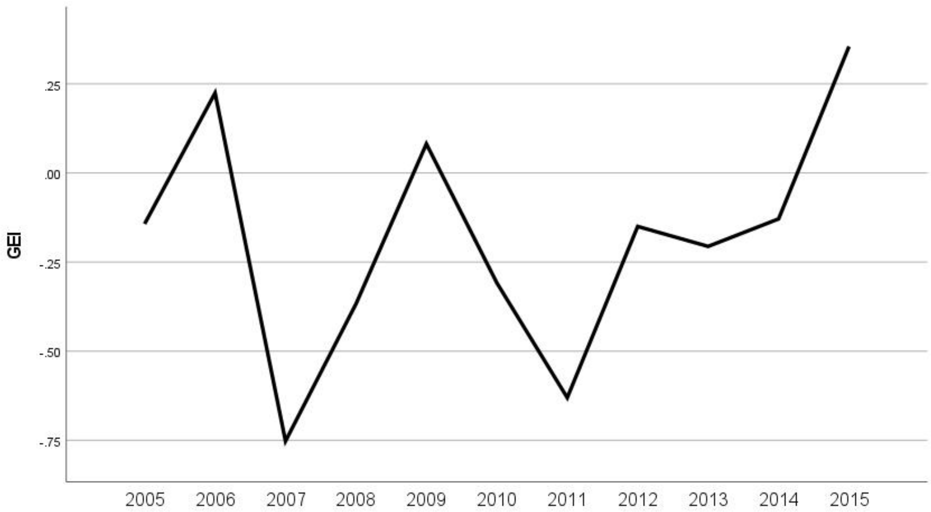

Figure 6: the time series diagram of the global equity index

As Figure 6 indicates, between 2005 and 2011, the global equity index fluctuated significantly. And from 2012 to 2015, the global equity index increased steadily.

Combined with reality, on the one hand, the United Kingdom suffered the worst flood in a hundred years in the summer of 2007, causing heavy losses to the economy. Additionally, in 2001, a series of social riots took place in its capital London. These have led to the decline of the global equity index. On the other hand, from 2012 to 2015, strong economic growth, low inflation, low unemployment and improved fiscal situation have become the reasons for the stable growth of the global equity index.

Thus, the global equity index's effectiveness is verified.

6 Task 3: Changes of Mining Influential Factors

6.1 Model IV: The GEI Prediction Model

Time series, also known as dynamic series, refers to the numerical series formed by arranging the index values of a certain phenomenon in time order. **Time series analysis** is the theory and method of establishing mathematical model through curve fitting and parameter estimation based on the time series data obtained from systematic observation. (*)

6.1.1 The relationship between per capita resource demand and global equity index

Step1: Make a time series diagram of mining capacity to describe the dynamic changes of time series, and determine the most appropriate time series model. Since there are no missing values in the data, time series diagrams can be made in Figure 7.

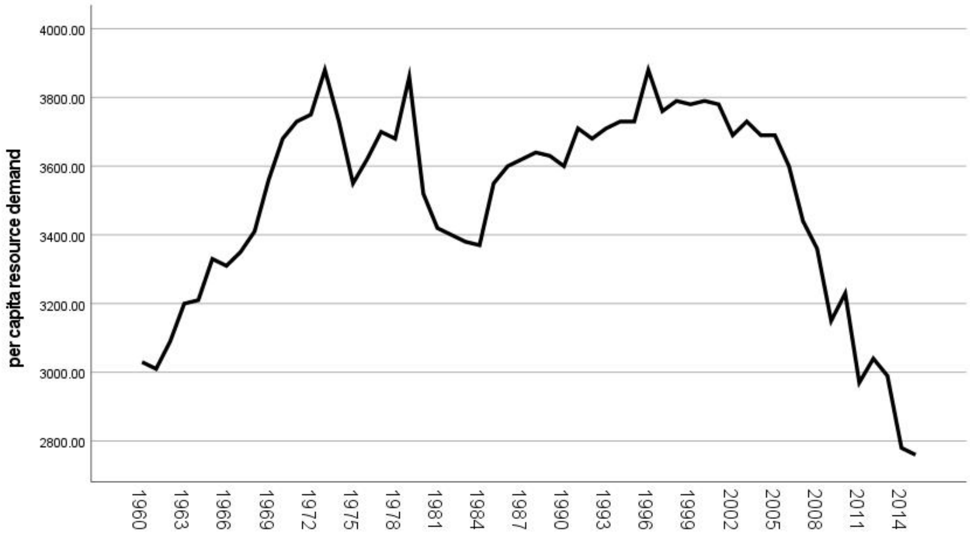

Figure 7: the time series diagram of per capita resource demand

Using the expert modeler of SPSS (The expert modeler automatically finds the best fit model for each dependent sequence), it can be concluded that the most suitable model is ARIMA (0,1,0).

$$\begin{cases} y_t^{'} = \alpha_0 + \varepsilon_t \\ y_t^{'} = \Delta y_t = (1-L)y_t \end{cases} \tag{20}$$

Step2: Residual test was performed for white noise. As can be seen from the ACF and PCAF graphs of residuals in Figure 8, the auto-correlation coefficients and partial auto-correlation coefficients of all lag orders are not significantly different from 0.

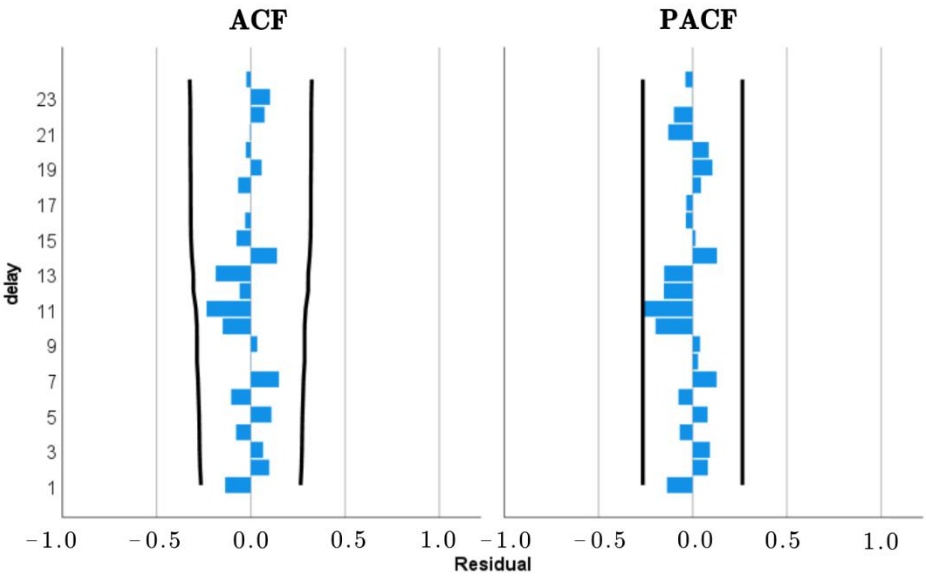

Figure 8: the auto-correlation coefficients and partial auto-correlation coefficients

In addition, the P-value obtained by Q test of residual error is 0.593, which means we cannot reject the null hypothesis and believe that residual error is white noise sequence. Thus, the Autoregressive Integrated Moving Average Model can identify data well.

Step3: Prediction results and renderings at the 95% confidence level. Stationary R-squared is 0.350 and Normalized BIC is 9.099, so we can conclude that the model fits well.

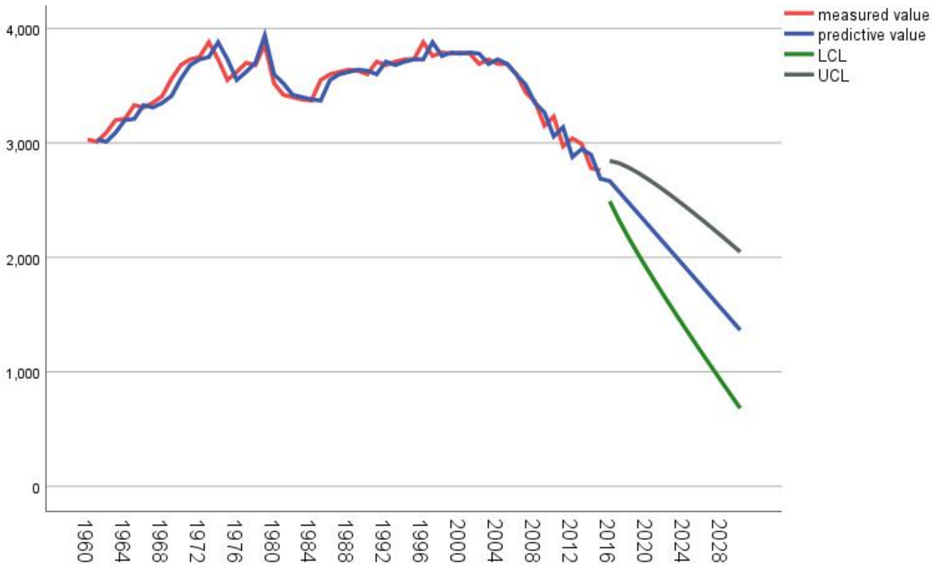

Figure 9: the time series prediction of per capita resource demand

It can be seen from the figure 9 that the time sequence diagram of real data and fitted data almost overlaps, which indicates that the model has a good fitting effect on the original data. In addition, the predicted data have a linear downward trend, which suggests that the demands for mineral resources per capita have declined significantly after 2019.

It can be predicted that this decline is more likely to happen in developed countries. The developed countries have advanced technology and abundant funds, so the actual demands for mineral resources in these countries are large. As a result, most of the mineral resources sold are likely to go to these countries. As gradual maturity of industry, the demand for such minerals is likely to reach the stage of saturation, so companies in the country would reduce activities of mining asteroids leading to the declining supply of mineral resources on the mineral market. So developing countries have limited resources to purchase.

6.1.2 The relationship between ore and metals imports and exports and global equity index

Step1: Make a time series diagram of mining capacity to describe the dynamic changes of time series, and determine the most appropriate time series model. Since there are no missing values in the data, time series diagrams of ore and metals imports and exports can be seen in Figure 10 and 11.

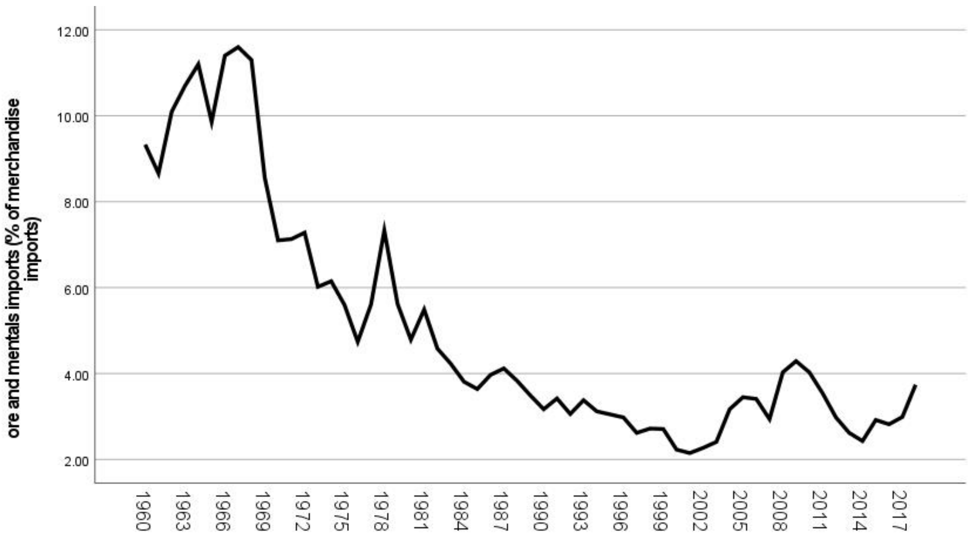

Figure 10: the time series diagram of ore and metals imports

Using the expert modeler of SPSS, it can be concluded that the most suitable model for ore and metals imports is ARIMA(0,1,0).

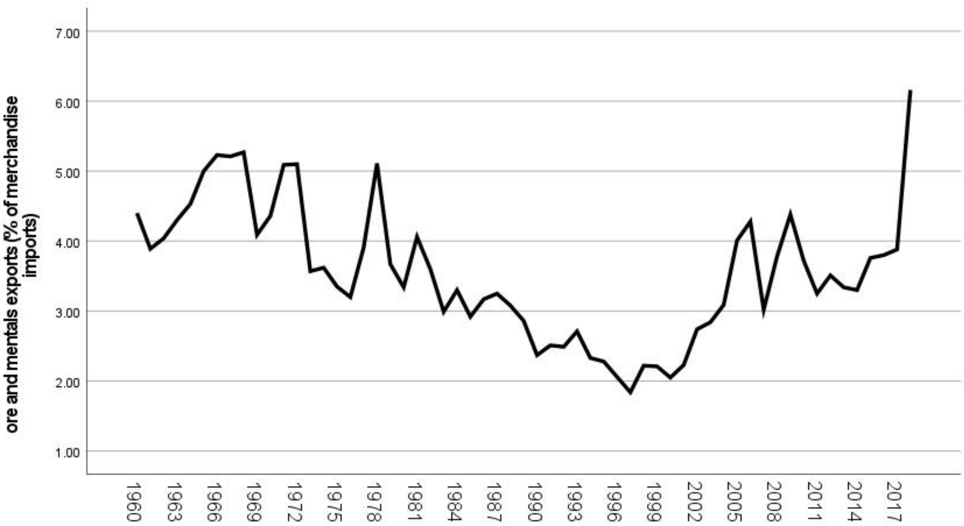

Figure 11: the time series diagram of ore and metals exports

Using the expert modeler of SPSS, it can be concluded that the most suitable model for ore and metals imports is ARIMA(2,1,0).

$$\begin{cases} y_t^{'} = \alpha_0 + \sum_{i=1}^{2} \alpha_i y_{t-i}^{'} + \varepsilon_t \\ y_t^{'} = \Delta y_t = (1-L) y_t \end{cases} \tag{21}$$

Step2: Residual test was performed for white noise. As can be seen from the ACF and PCAF graphs of residuals in Figure 12 and 13, the auto-correlation coefficients and partial auto-correlation coefficients of all lag orders are not significantly different from 0.

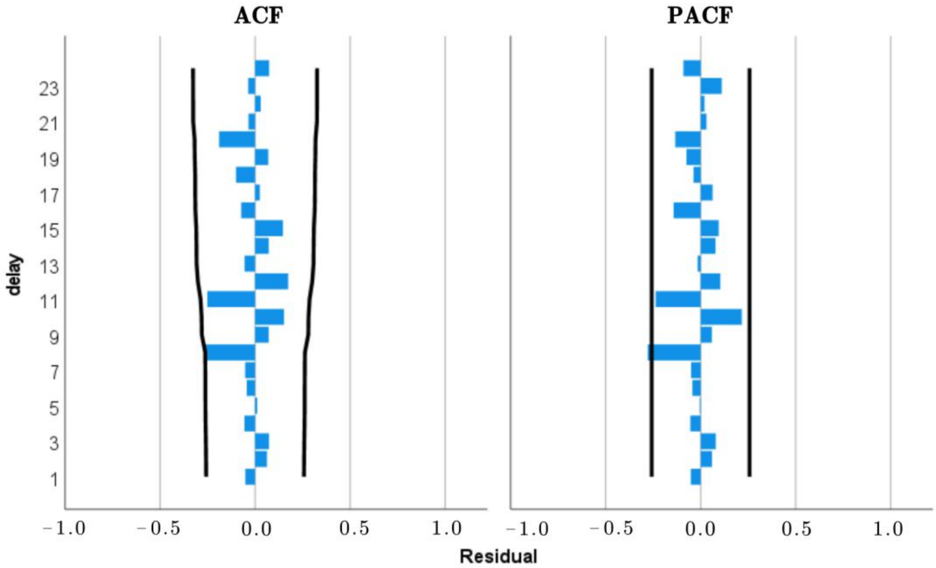

Figure 12: the auto-correlation coefficients and partial auto-correlation coefficients

In addition, the P-value obtained by Q test of residual error is 0.385, which means we cannot reject the null hypothesis and believe that residual error is white noise sequence. Thus, the Auto regressive Integrated Moving Average Model can identify data well.

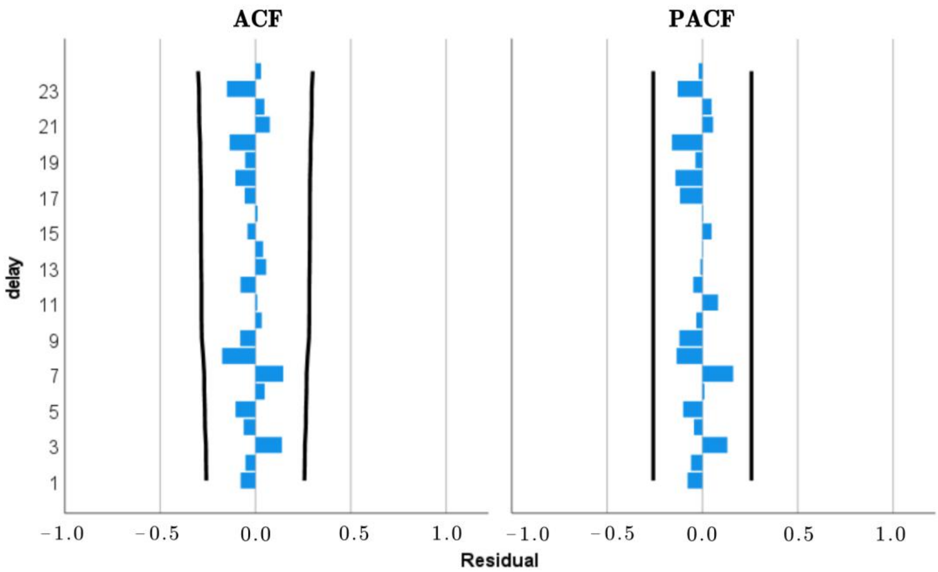

Figure 13: the auto-correlation coefficients and partial auto-correlation coefficients

What’s more, the P-value obtained by Q test of residual error is 0.933, which means we cannot reject the null hypothesis and believe that residual error is white noise sequence. Thus, the Auto regressive Integrated Moving Average Model can identify data well.

Step3: Prediction results and renderings at the 95% confidence level.

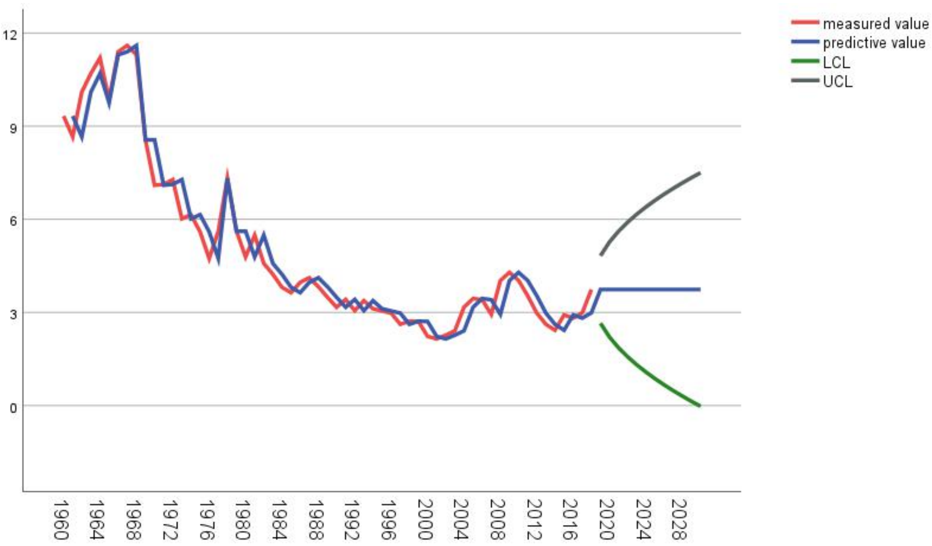

Figure 14: the time series prediction of ore and metals imports at 95% confidence level

In ore and metals imports, Stationary R-squared is 0.513 and Normalized BIC is -1.015, so we can conclude that the model fits well.

It can be seen from the figure 14 that the time sequence diagram of real data and fitted data almost overlaps, which indicates that the model has a good fitting effect on the original data. In addition, the predicted data have a smooth trend, which suggests that as time goes by, the import of ores and metals will become stable.

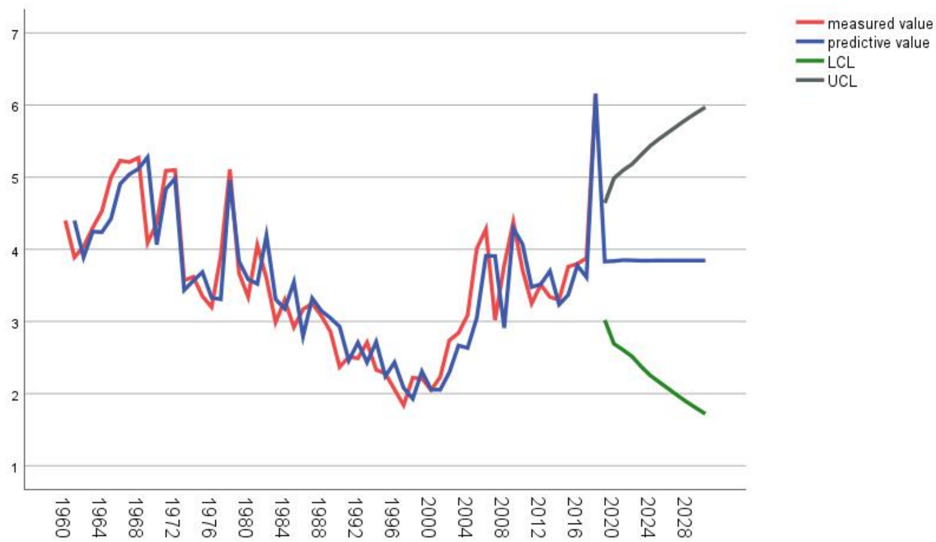

Figure 15: the time series prediction of ore and metals exports at 95% confidence level

In ore and metals imports, Stationary R-squared is 0.584 and Normalized BIC is -1.524, so we can conclude that the model fits well.

It can be seen from the figure 15 that the time sequence diagram of real data and fitted data almost overlaps, which indicates that the model has a good fitting effect on the original data. In addition, the predicted data have a smooth trend, which suggests that the export of ores and metals will become stable.

As time goes by, the import and export of mineral resources have reached a balance.It indicates new economic growth points need to be found. In addition, the saturation of some mineral resources has increased the demand for rarer minerals, which has also increased the difficulty of mining them. Some developing countries with low level of scientific research and technology would not only benefit from the current exploitation of mineral resources, but they will not benefit from the exploitation of other rarer resources in the future.

7 Task 4: Recommendations for Policy

7.1 Promotion of the Outer Space Treaty

With rapid development of asteroid mining, previous Outer Space Treaty has no longer applicable to current background. In order to promote global equity, we need to modify the treaty based on current reality.

In article I, “The exploration and use of outer space, including the moon and other celestial bodies, shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind.” It is true that we should take the interests of all countries into consideration when exploring outer space. However, global equity does not mean that we do not need to consider each country's economic or scientific development. Global equity means that each country participating in international cooperation bears its due responsibilities and gets its due benefits. It is unfair if the benefits to a country are less than its responsibilities. So, we need to introduce a global equity model to calculate each country's share of the benefits.

The global equity model takes each country's political, economic, and scientific and technological development into consideration. On the basis of giving equal weight to these three factors, the size of each sub-factor is calculated according to the conditions of each country, so as to get the share of interest distribution matching the national conditions. These factors reflect the degree to which each country contributes to its own social equity in political, economic, and scientific and technological development. Global equity is achieved by matching each country's contribution to global equity with the benefits of meeting its responsibilities.

7.2 Idealistic Organization

We have introduced the SMOC International organization to achieve equitable distribution of mineral resources. If each country is allowed to mine and own its own ores, it will inevitably lead to vicious competition among countries and undermine equity. Developed countries use advanced technology to seize the initiative in mining asteroid mineral resources and form a monopoly in the market of mineral resources. For the purpose of promoting peace and reducing inequity, we designed the SMOC international organization to achieve the goal of global equity.

Countries and regions around the world sign agreements to become parties to SMOC and pay fees to maintain funding, operation, management and supervising activities of SMOC. All mining missions are licensed by SMOC, and only licensed companies are allowed to conduct asteroid mining. The enterprises have no right to own the mineral resources obtained from mining, and the right to own and sell the mineral resources is owned by SMOC only. SMOC is a non-profit organization. Some of the profits from the sale of mineral resources go to the mining enterprises as a commission, and the rest is distributed to each country based on a proportion calculated by the Global Equity Model after deducting necessary operating expenses. SMOC sells mineral resources to countries based on their actual needs in production. By establishing SMOC institution, we can avoid vicious competition between countries for mineral resources, promote global equity, and take the economic interests of mining companies into account.

7.3 Combination with Tasks' Results

- A Minimum Number of Mineral Resources

Reserve a minimum number of mineral resources for each country. The demands for mineral resources per capita have declined significantly over time, but this decline is more likely to happen in developed countries. The developed countries have advanced technology and abundant funds, so the actual demands for mineral resources in these countries are large. As a result, most of the mineral resources sold are likely to go to these countries. As gradual maturity of industry, the demands for such minerals are likely to reach the stage of saturation, so companies in the country would reduce activities of mining asteroids which leads to the declining supply of mineral resources on the mineral market. Thus, SMOC needs to reserve a minimum number of mineral resources for each country, and the ratio of reservation refers to global equity model to ensure necessary supply for developing countries.

- A Suitable Patent Holding Period

Set up a suitable patent holding period and disclose the technology when it expires. The level of scientific research has improved, and the number of technicians has increased over time, but these improvements is more significant in developed countries. The restriction of scientific research level makes the economic benefits of developing countries less than that of developed countries, widening the economic gap between the two types of countries.

Therefore, we propose to set up a patent with appropriate expiration time for mining and manufacturing technology. After the patent expires, the country cannot profit by selling the right to use the patent, and countries all over the world can use the technology for free.

- Research and Development Funds

Each country can apply to SMOC for research and development funds in proportion to its own global equity model to promote the technologies of deep processing of mineral resources and the mining of other rare metals. As time goes by, the import and export of mineral resources have reached a balance, and new economic growth points need to be found. In addition, the saturation of some mineral resources has increased the demand for rarer minerals, which has also increased the difficulty of mining them. To avoid waste of mineral resources and increase economic benefits, SMOC provides research funding to countries to promote deep processing technologies and other rarer mineral resource mining capabilities.

8 Sensitivity Analysis

The global equity index is related to mining capacity, per capita resource demand, number of technicians, ore and metals imports and exports (% of merchandise imports). Therefore, we conducted a sensitivity analysis for X_1, X_2, X_3, X_4 and X_5 respectively and observed the global equity index under the continuous fluctuation range of 0.10%. (Initial value: $X_1 = 0.7, X_2 =- 1.4, X_3 = 1.9, X_4 =- 0.7,\ X_5 = 0.2$)The results are shown in the table 4.

Table 4: Changes of the global equity index

Changes of X_i	Changes of the global equity index	
	+0.10%	-0.10%
X_1	0.3702	0.3699
X_2	0.3698	0.3703
X_3	0.3706	0.3696
X_4	0.3702	0.3699
X_5	0.3701	0.3700

Under the fluctuation range of 0.10%, the global equity index predicted by the model fluctuates within 0.40, with no significant change in position. The model has passed the sensitivity test.

9 Strengths and Weaknesses

9.1 Strengths

- In the construction of the Global Equity, the factors for mining capacity, per capita resource demand, number of technicians, ore and metals imports and exports (% of merchandise imports) are combined, and the global equity index can be obtained through yearly prediction. The model has better interpretability and scalability.
- The GEI prediction model based on time series is scientific and reasonable, and can pass various statistical tests. The predictions obtained have a reliable statistical.
- The sensitivity analysis of the model demonstrates the effectiveness of the model under different parameter combinations.

9.2 Weaknesses

- The analysis of mineral resources and allocation score can be more accurate if we have more complete data.
- The factors of asteroid mining considered by the Principal Component Analysis Model is

still not comprehensive enough. Due to insufficient data, we cannot make an evaluation function for more detailed factors. Examples include total investment amount, mining cost and earnings.

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