

Asteroid Mining research based on the Global Equity Evaluation Model

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Abstract. With the aggravation of the imbalance in world development, people pay more and more attention to global equity. In general, global equity means that the fruits of development are shared by all mankind, and the development gap between countries is reasonable, so that people of all countries can enjoy stability and happiness. Based on the principle of global equity, this paper further studies the problem of asteroid mining. First, we established a global equity evaluation model (two-level) model, which calculates development indicators from economic, scientific and technological, cultural, social and other aspects, and uses analytic hierarchical process (AHP) and entropy weight method (EWM) to determine the dimensions and weight of indicators. We then describe our vision for asteroid mining. Based on the premise that asteroid mining is managed by a unified department, an asteroid mining allocation model (three-level) is established, using the ARIMA model to predict the data, using AHP and EWM to define the weights to reflect the impact of mining on global equity. In the end, we discuss the strengths and weaknesses of our models, leaving room for further studies.

Keywords: AHP; EWM; Global equity; ARIMA; Asteroid mining.

1. Introduction

The outer space is a mysterious and unknown world, attracting human beings to explore all the time. And people have been trying to explore outer space by various approaches, since Gagarin first went into space. As more and more countries achieve space exploration, human beings need to establish a unified order to regulate the exploration and use of outer space.

Based on the more knowledge of outer space, people are no longer satisfied with space travel, but making use of space resources. With the development of science and technology, we assume that asteroid mining is feasible in the future and humans can bring usable minerals back to Earth, which is financially worth the investment [1]. Since asteroid mineral is regarded as common heritage of mankind, its application and allocation are aimed to promote the progress of all mankind. However, due to inherent gap between developed and developing countries, asteroid mining may cause different influence. In order to guarantee the global equity, we intends to set up a complete system and regulate asteroid mining [2, 3].

2. Global Equity Evaluation Model

2.1. Indicator

In our model, there are 4 dimensions consisting of 10 indicators. Economy (Eco), Science and technology (ST), Culture (Cul) and Society (Soc). Economy (Eco) include GDP, Gini index (GI), Adjusted net national income per capita (ANNI). Science and technology (ST) include Researchers in R&D, High-technology exports, Research and development expenditure (% of GDP). Culture (Cul) include Government expenditure on education (GEE), School enrollment of tertiary (SET). Society (Soc) include Employment to population ratio (EPR), Life expectancy at birth (LE) [2].

2.2. Weight of Indicators

The determination of the weight of indicators at each level is a bottom-up process, that is, the weight of indicators at the second level is calculated first, and then the weight of dimensions at the first level is calculated. To avoid the excessive subjectivity influenced by the determination method of weight factor, Entropy Weight Method (EWM) and the Analytic Hierarchy Process(AHP) are used to determine the weight, successively [3].

2.2.1 Entropy Weight Method (EWM)

a. Forward Transformation and Standardization

The education investment has three indicators, including government expenditure on education, total education expenditure, research and development investment (R&D investment). So we extract the data of 9 countries in 2015 to form a 10×3 matrix. First of all, the original matrix needs to be forward-transformed to form the forward-transformed matrix:

$$X = \begin{pmatrix} x_{11} & x_{12} & \cdots & x_{1,10} \\ x_{21} & x_{22} & \cdots & x_{2,10} \\ x_{31} & x_{32} & \cdots & x_{3,10} \end{pmatrix} \quad (1)$$

To guarantee every element is non-negative when calculating the probability, the data needs to be standardized, using the following formula:

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

If there is a negative number in the matrix Z, it needs to be further normalized by the following formula:

$$\tilde{z}_{ij} = \frac{x_{ij} - \min\{x_{1j}, x_{2j}, \dots, x_{nj}\}}{\max\{x_{1j}, x_{2j}, \dots, x_{nj}\} - \min\{x_{1j}, x_{2j}, \dots, x_{nj}\}} \quad (3)$$

b. Calculation of the Entropy Weight

First, we calculate the proportion of the i th country of the j th indicator, as the probability of the relative entropy:

$$\tilde{Z} = \begin{pmatrix} \tilde{z}_{11} & \tilde{z}_{12} & \cdots & \tilde{z}_{1m} \\ \tilde{z}_{21} & \tilde{z}_{22} & \cdots & \tilde{z}_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{z}_{n1} & \tilde{z}_{n2} & \cdots & \tilde{z}_{nm} \end{pmatrix} \quad (4)$$

From the normalized matrix obtained above, we compute the probability matrix P, where each element is computed as follows:

$$p_{ij} = \frac{\tilde{z}_{ij}}{\sum_{i=1}^n \tilde{z}_{ij}} \quad (5)$$

Then, according to the probability matrix P, the information entropy of each indicator is calculated by follows:

$$e_j = -\frac{1}{\ln n} \sum_{i=1}^n p_{ij} \ln(p_{ij}) \quad (6)$$

Finally, we calculate the information utility value and obtain the entropy weight of each index by normalization. Information utility value is used to measure the amount of information, and the larger the information utility value is, the more information it contains. The definition of information utility value is:

$$d_j = 1 - e_j \quad (7)$$

We obtain the entropy weight of each index by normalization as well as the weight:

$$W_j = \frac{d_j}{\sum_{j=1}^m d_j} \quad (8)$$

The final weight of 3 indicators in the economy dimension is:

$$(0.3597 \quad 0.1114 \quad 0.5289)$$

2.2.2 Analytic Hierarchy Process (AHP)

We construct two levels of evaluation indicators, and in the first level including four dimensions we use analytic hierarchy process to determine the weight [4].

Firstly, we compare the dimensions of the same layer pairwise and construct the judgment matrix A according to their relative importance.

$$A = \begin{pmatrix} 1 & 3 & 5 & 2 \\ 1/3 & 1 & 2 & 1/3 \\ 1/5 & 1/2 & 1 & 1/4 \\ 1/2 & 3 & 4 & 1 \end{pmatrix} \quad (9)$$

Table 1. The judgment matrix of four dimensions

	ECO	ST	Cul	Soc
ECO	1	3	5	2
ST	1/3	1	2	1/3
Cul	1/5	1/2	1	1/4
Soc	1/2	3	4	1

The economic foundation determines the superstructure. So to a large extent, the education investment can directly determine the development of higher education which deserves the highest weight. And the Education is ultimately for human development and we should pay more attention to what higher education can bring to human. From this point, the scientific research outcome are the output of higher education which can translate into economic income, so we give a higher weight to it.

Calculation formula of consistency index:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (10)$$

Then find the corresponding average random consistency index $RI = 0.89$, and calculate the formula according to the consistency proportion:

$$CR = \frac{CI}{RI} \quad (11)$$

We calculate it then get $CR = 0.0212 < 0.1$, It is proved that the consistency test is passed.

We first need to test the consistency of the discriminant matrix. The maximum eigenvalue λ_{max} can be easily obtained by solving the eigenvalue of discrimination matrix A, and the weight vector ω_j is

$$(0.46837 \ 0.13797 \ 0.07937 \ 0.3143)^T$$

In the end we get the weight of different indicators:

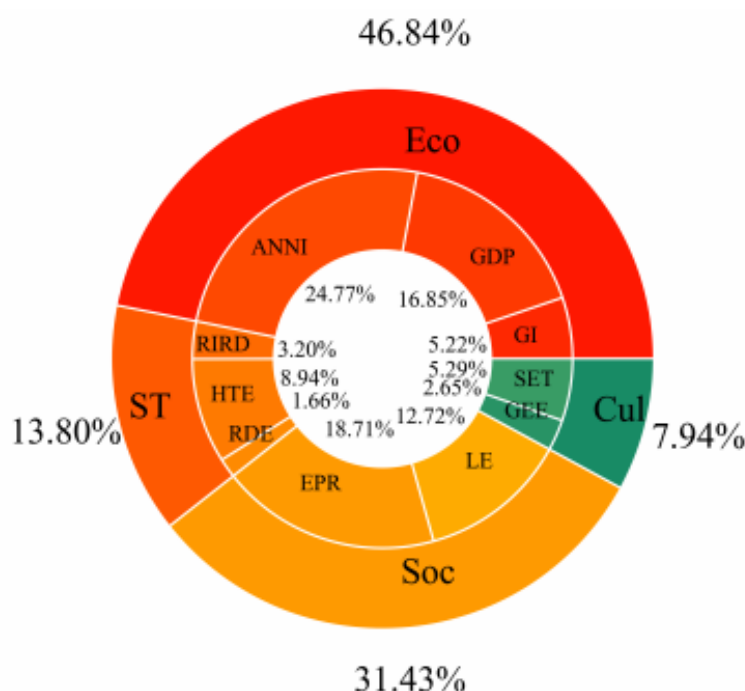


Fig. 1 The weight of different indicators

3. Asteroid Mining Allocation Model

Firstly, on the basis of Global Equity Evaluation Model, we reconstruct a three-layer comprehensive evaluation model with four dimensions and ten indicators. Considering human can't mine asteroid now and it will happen in the future, we apply ARIMA model to predict the data of training set countries in 2025. Then, analytic hierarchy process (AHP) is employed to determine the weight of four dimensions and entropy weight method (EWM) is used to calculate the weight of indicators and index.

3.1. Indicators

The 4 dimensions and 10 indicators are Technology Strength (TS), Contribution (Con), Balance (Bal), Human and Nature Factor (HNF). Technology Strength (TS) include Aerospace Strength (AS), Mine and Energy Extraction (MEE), Science and Technology (ST). Contribution (Con) include Aerospace Investment (AI), Contribution to Human Society (CHS). Balance (Bal) include Aid Dependence (AD), National Income (NI). Human and Nature Factor (HNF) include Population (POP), Surface Area (SA).

3.2. Indicators Prediction by ARIMA Model

We do not believe that asteroid mining is possible in the current capacity of nations, and predict that it will be possible in 2025. Therefore, we adopt ARIMA model to predict each indicator. Due to too much data, we only forecast the population of the UK here and the other data are treated in the same way [5].

3.2.1 Time series data observation

We use $Pop_{GBR,t}$ to represent the population of the UK where GBR means the UK and t represents the year. Then time series graph is plotted to show the UK's population growth from 1960 to 2020. Shown in the following picture, the population of the UK in the past 61 years has a positive correlation with time, meaning the population increasing over time. Moreover, the population curve is smooth, and the natural population growth rate is gentle, indicating that time series data has high stability, so time series prediction model can be established.

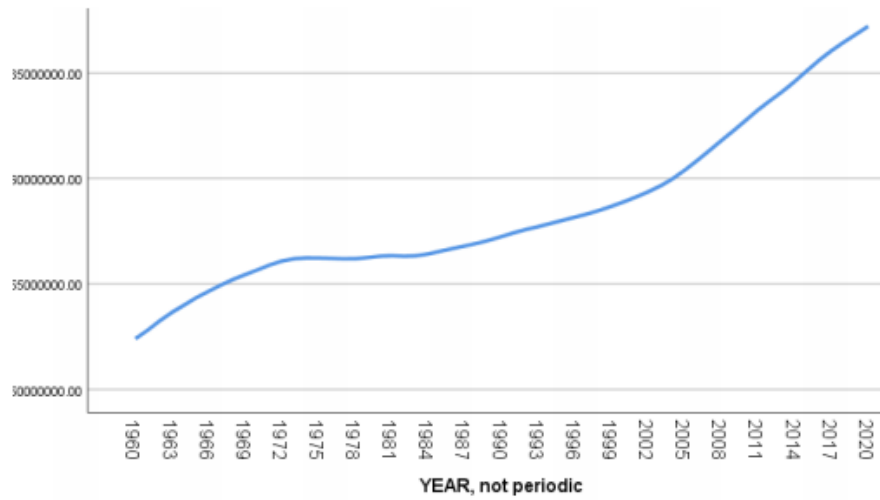


Fig. 2 The observation of GBR's population

3.2.2 ARIMA(0,2,1) Model

According to Expert Modeler in SPSS, we constructed ARIMA(0,2,1) time series prediction model to predict the population of the UK. First, we need a white-noise test for residuals which is the actual population of the UK and the estimated population of the model. We make an assumption as follow:

H_0 : Assume that the residual is white noise

Q significance test index is 0.985, more than 0.05, so we can accept the null hypothesis, that is, residual is considered white noise. Meanwhile, the residual of ACF and PACF images also show white noise, indicating that the effect of residual on model estimation could be ignored.

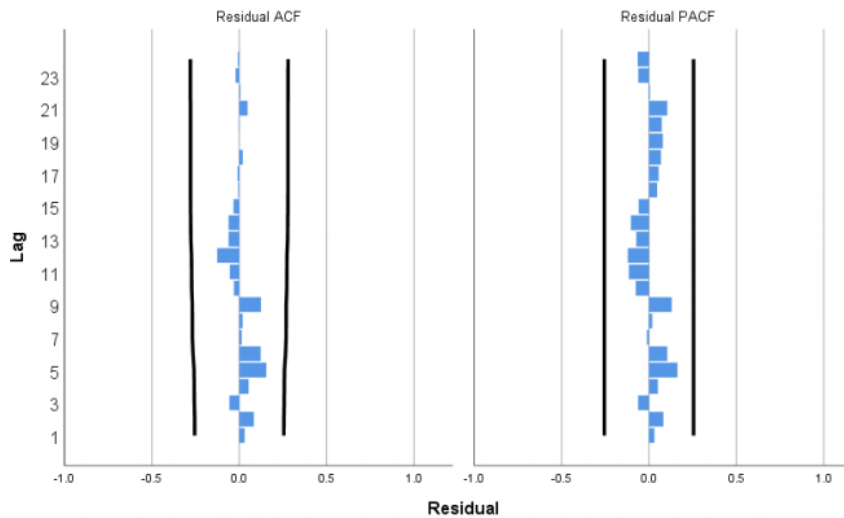


Fig. 3 Residual ACF & Residual PACF

Then, we establish the ARIMA(0, d, p) model

$$\Delta^d Pop_{GBR,t} = \left(1 + \sum_{i=1}^p \beta_i L^i \right) \varepsilon_t \quad (12)$$

Where Δ^d represents the difference operator of order, $\varepsilon_t \sim N(0, \sigma_\varepsilon^2)$ means the residual between the true value and the fitted value of population in year t. In accordance with SPSS modeling results, $d = 2$, $p = 1$, then

$$\Delta^2 Pop_{GBR,t} = (1 + \beta L) \varepsilon_t \quad (13)$$

$$(1 - L)^2 Pop_{GBR,t} = (1 + \beta L) \varepsilon_t \quad (14)$$

L represents lag operator. The prediction model of UK population is as follows:

$$Pop_{GBR,t} = Pop_{GBR,t-1} - 2Pop_{GBR,t-2} + \varepsilon_t - 0.855\varepsilon_{t-1} \quad (15)$$

Calculating the validation parameters of the model, R^2 is 1 and stationary R^2 is 0.436, indicating that the model has good estimation effect and can be referred to.

Based on the above analysis, we can reasonably predict the population change in the UK in the next five years. By 2025, the UK population is forecast to be 69.13 million. The projected population is shown below:

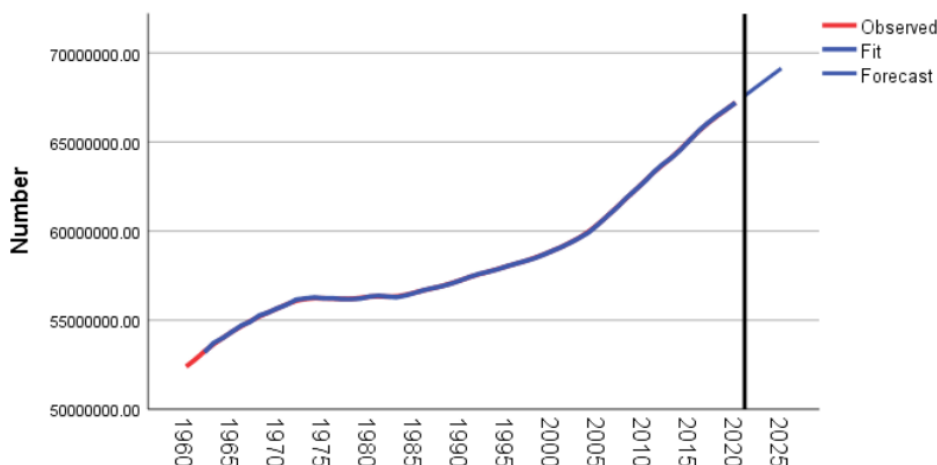


Fig. 4 The prediction of GBR's population in 2025

3.2.3 The weights calculated by data in 2022

We still adopt the bottom-up idea of computing weights. First, the weights of the third layer were calculated by using EWM based on the data of various indices of weight calculation countries in 2025. Then, the weights of the second layer and the first layer were calculated separately by using AHP.

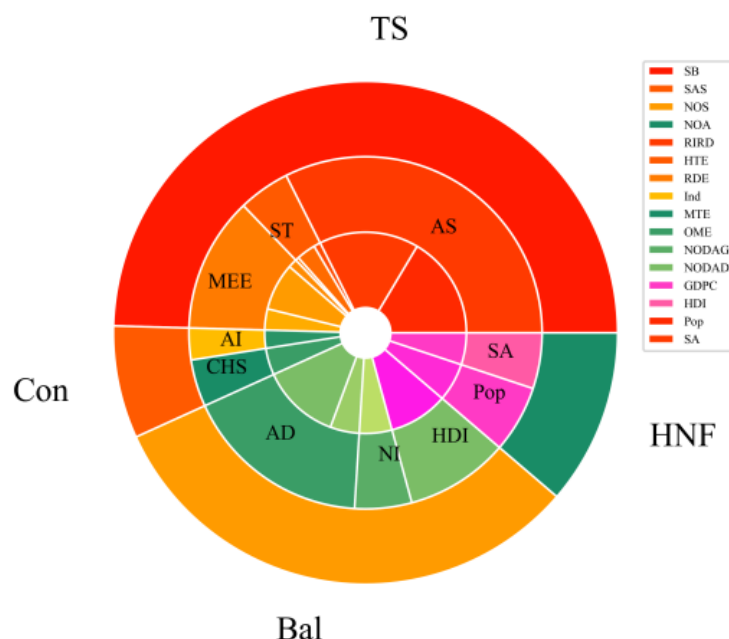


Fig. 5 The weights of different indicators in Asteroid Mining Allocation Model

3.2.4 The way asteroid mining affect global equity

After we have predicted the data of 2025, we substitute the new evaluation model to calculate the benefit distribution of various European countries. we get

$$\omega = (0.0792 \ 0.2088 \ 0.141 \ 0.3463 \ 0.2247)^T \quad (16)$$

Then we found that UK's TS is highest in 5 countries, then we choose UK to undertake the mining task, and then substitute the data into the previous first model to calculate the score of the four indicators.

We assume that the income brought by mining is short-term and greater than 0, so it will only have an impact on the economic indicators in a short time. Assuming that the overall increase is 1%, we return to the economic system score of five countries. Add the economic score of each country to the profit of the corresponding weight to get a new score, which is normalized as follows

$$Z_2 = \begin{pmatrix} 0.0873 & 0.0810 & 0.1258 & 0.0517 \\ 0.1336 & 0.0924 & 0.1003 & 0.1274 \\ 0.0852 & 0.0997 & 0.1487 & 0.0651 \\ 0.1237 & 0.0831 & 0.1079 & 0.1092 \\ 0.0968 & 0.0476 & 0.0827 & 0.0262 \end{pmatrix} \quad (17)$$

$$\omega = (0.01764 \ 0.02653 \ 0.2108 \ 0.2224 \ 0.1250)^T \quad (18)$$

Multiply the benefit distribution matrix and Economy allocation matrix,

$$E = (0.1 \ 0 \ 0 \ 0) \quad (19)$$

$$\Delta Z = \omega E = \begin{pmatrix} 0.1764 & 0 & 0 & 0 \\ 0.2653 & 0 & 0 & 0 \\ 0.2108 & 0 & 0 & 0 \\ 0.2224 & 0 & 0 & 0 \\ 0.1250 & 0 & 0 & 0 \end{pmatrix} \quad (20)$$

After allocated benefits by mining sector, new score matrix is

$$Z_3 = Z_2 + \Delta Z = \omega E = \begin{pmatrix} 0.0881 & 0.0732 & 0.1311 & 0.0467 \\ 0.1357 & 0.1094 & 0.1090 & 0.1345 \\ 0.0866 & 0.0959 & 0.1579 & 0.0606 \\ 0.1271 & 0.0853 & 0.0936 & 0.1113 \\ 0.0991 & 0.0423 & 0.0843 & 0.0211 \end{pmatrix} \quad (21)$$

After normalizing, we get the final score matrix:

$$X_2 = (0.1689 \ 0.2610 \ 0.2168 \ 0.2236 \ 0.1298)^T, STDEV = 0.05112937 \quad (22)$$

$$X_3 = (0.1747 \ 0.2593 \ 0.2129 \ 0.2238 \ 0.1292)^T, STDEV = 0.049730644 \quad (23)$$

By Table 2, we can see that we use the predicted 2025 data to get the scores of five European countries in model 1, and take their STDEV as the evaluation fairness standard before mining, plus the profit matrix obtained due to mining, and get two sets of scores after normalization. We can see from the table that the overall STDEV after mining profits is smaller than before, so we conclude that it is more fair after mining [6].

Table 2. The contrast of scores in Europe

	Before Mining	After Mining
BEL	0.1689	0.1747
CHE	0.2610	0.2593
FIN	0.2168	0.2129
GBR	0.2236	0.2238
ITA	0.1298	0.1292
STDEV	0.05112937	0.049730644

4. Strengths and weakness

4.1. Strengths

a. The data we used come from authoritative and reliable websites and reports. They are collected by Organization for Economic Co-operation and Development (OECD), the World Bank, the United Nations and the United States Air Force.

b. We refer to many rules for the distribution and application of the common heritage of mankind, such as international seabed regional resources, Antarctica, outer space. Our models take various indicators into account to be more comprehensive from different dimensions.

c. We combine analytic hierarchy process (AHP) with Entropy weight method (EWM) to determine the weight of all index. By using the objective weighting approach, the indexes can accurately reflect the actual situation, overcoming the influence of subjective factors to some degree.

4.2. Weakness

a. Our data is not enough in some parts. For instance, we only collect more than 10 representative countries and many countries' data are missing. So, to some degree, the validation of our model is partial.

b. We only explain part of the shown variables in our paper.

References

- [1] Butkevičienė Eglė, Rabitz Florian. Sharing the Benefits of Asteroid Mining[J]. Global Policy, 2022, 13(2).
- [2] Zurui Wan, Yuanlong Zhong, Yingshan Zhan. Analysis of the Impact of Asteroid Mining on Equality[J]. Academic Journal of Environment & Earth Science, 2022, 4.0(3.0).
- [3] Tianyang Fan, Weixu Pang, Yating Tan. A Measuring Stick for the World: Achieving Global Equity in Asteroid Mining[J]. Academic Journal of Environment & Earth Science, 2022, 4.0(4.0).
- [4] Xiangjie Qu, Xinxin Zhang, Xue Tian. A global equity model based on hierarchy of needs analysis and asteroid mining rights allocation[J]. Equipment Manufacturing Technology, 2022(01):82-85.
- [5] Yueting Sun, Yan Liang, Xiangxi Xu. Resource evaluation and prediction model based on asteroid mining[J]. Environment, Resource and Ecology Journal, 2022, 6(4).
- [6] Chao Zheng Xu, Guosheng Huang, Qingqiang Meng. Study on Global Equity and Asteroid Mining[J]. Academic Journal of Engineering and Technology Science, 2022, 5.0(4.0).