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Impact of Asteroid Mining on Global Equity Based on Two-Level Fuzzy Comprehensive Evaluation Model

Zeshan Shou[1,a]

[1]School of Business, Shantou University, Guangdong, Shantou, China
[a]20zsshou@stu.edu.cn

Abstract: *With the development of outer space exploration and development technology, people began to consider the possibility of asteroid mining. However, due to the imbalance of power among countries in the world, this will have a huge impact on global equity. To study the impact of asteroid mining on global equity, first, I built a two-level fuzzy comprehensive evaluation model, selected 14 indicators, and determined the weight of 6 first level indicators using the analytic hierarchy process. Then, I determined the weight of 8 second level indicators using the objective entropy weight method and calculated the membership of each type of country. Then we use time series analysis to predict the degree of membership of different types of countries in the next few years. So as to draw the impact of different indicators on global equity, so as to promote global equity and make asteroid mining truly benefit all mankind.*

Keywords: *Asteroid Mining, Global Equity, AHP, EWM, Time Series Analysis*

1. Introduction

With the development of world economy, science and technology and the increase of population, the demand for resources is increasing. The earth's resources are limited and will be exhausted due to increased mining intensity and demand. However, the resources beyond the earth are very abundant, and the exploitation of resources outside the earth plays a vital role in the sustainable development of human beings. As far as the solar system is concerned, the moon, Mars, asteroids and other celestial bodies are rich in mineral resources and rare metals[1].

On the basis of existing space science and technology, aerospace technology and mining technology, it is feasible to realize experimental mining of space resources on near-Earth objects within 10 ~ 20 years[2]. The 1967 UN Outer Space Treaty stipulates that the exploration and use of outer space shall be for the benefit of all nations and the business of all mankind. There is no doubt that asteroid mining will affect global equity, but now we do not have a complete system to measure global equity. Therefore, the development of an indicator evaluation model to evaluate the global equity situation is essential for equitable global development[3].

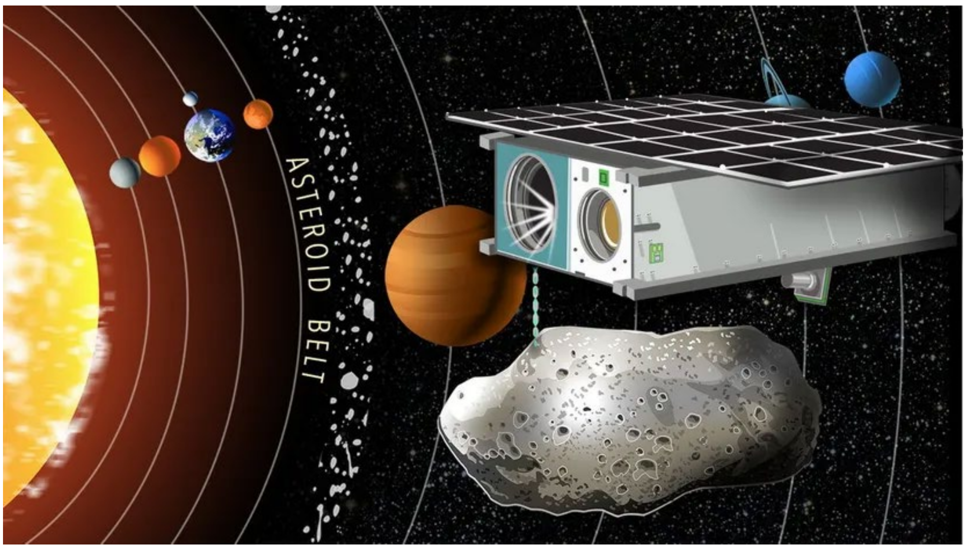

Figure 1: Asteroid Mining[4]

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2. Establishment of Two-level Fuzzy Comprehensive Evaluation Model

According to the classification of countries by the United Nations, I divide all countries into developed countries C1, developing countries C2 and least developed countries C3. In order to measure global equity, we will consider six aspects: science and technology U1, economy U2, education U3, population U4, environment U5, and transportation U6. On this basis, we have determined eight secondary factors, namely, scientific and technological research and development cycle, rocket raw material manufacturing difficulty, investment, income, unstable costs, risks, professional talent training cycle, and fuel storage.

First, the analytic hierarchy process is used to determine the weight of six first level indicators, and then the entropy weight method is used to determine the weight of the second level indicators, so as to build a second level fuzzy comprehensive evaluation model to obtain the membership of different types of countries, so as to measure global equity.

2.1. Calculate the Weight of Primary Indicators

First, I construct a judgment matrix for six primary indicators, and then we construct a judgment matrix for each type of country based on different indicators.

According to the formula:

$$\omega_i=\frac{1}{n}\sum_{j=1}^{n}\frac{aij}{\sum_{k=1}^{n}akj} \quad (i=1,2,3\ldots n), \tag{1}$$

Calculate the weight vector. And the maximum characteristic value, consistency index and consistency ratio are calculated, and the final weight of the primary index is shown in table 1.

Table 1: Final weight result

	w	C1	C2	C3
U1	0.3510	0.6824	0.2003	0.1172
U2	0.3037	0.6358	0.2590	0.1052
U3	0.1726	0.5580	0.3198	0.1222
U4	0.0825	0.0858	0.2716	0.6426
U5	0.0463	0.2003	0.1172	0.6824
U6	0.0439	0.6955	0.2393	0.0652

2.2. Determine Factor Set, Comment Set and Weight

2.2.1. Determining the Set of Factor and Comment

First level factor set U= {technology U_1, population U_2, education U_3, economy U_4, transportation U_5, environment U_6}

Second level factor set U_1= {technology R&D cycle $U_1^{(1)}$, rocket raw material manufacturing difficulty $U_1^{(2)}$}

U_2= {specialist training period $U_2^{(1)}$}

U_4= {input capital $U_4^{(1)}$, revenue $U_4^{(2)}$, risk $U_4^{(3)}$, instability cost $U_4^{(4)}$}

U_6= {fuel storage $U_6^{(1)}$}

where the first level factor set U_3, U_5 does not contain the second level factor set.

Then determining the set of comment V= {developed countries V_1, developing countries V_2, undeveloped countries V_3 }

2.2.2. Determination of Weights

The weight calculation process of entropy weight method is as follows:

1) Calculate the weight of the four factors of U4

Step 1: Matrix standardization

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According to the comment set, we have three evaluation objects: V1, V2 and V3; In the economic category, there are four factors: $U_4^{(1)}$, $U_4^{(2)}$, $U_4^{(3)}$ and $U_4^{(4)}$. The standardized matrix composed of the three evaluation objects and four factors is as follows:

Derive the normalization matrix

$$Z=\begin{bmatrix}0.9058 & 0.7600 & 0.8445 & 0.6985\\ 0.4180 & 0.6384 & 0.5348 & 0.6985\\ 0.0697 & 0.1216 & 0.0281 & 0.1552\end{bmatrix}$$

Step 2: Calculate the weight of the ith sample under the jth indicator and consider it as the probability used in the relative entropy calculation. Now we will calculate the probability matrix P, where each element Pij in P is calculated as follows:

$$P_{ij}=\frac{zij}{\sum_{i=1}^{n} zij} \quad (2)$$

So the obtained probability matrix

$$P=\begin{bmatrix}0.65 & 0.50 & 0.60 & 0.45\\ 0.30 & 0.42 & 0.38 & 0.45\\ 0.05 & 0.08 & 0.02 & 0.10\end{bmatrix}$$

Step 3: Calculate the information entropy and information utility value of each index

For the jth indicator, its information entropy of

$$e_j=-\frac{1}{ln\, n}\sum_{i=1}^{n} p_{ij}\ln(p_{ij}) \quad (j=1, 2, \ldots, m) \quad (3)$$

The information entropy is calculated as e=(0.7200, 0.8310, 0.6849, 0.8637)

Since the larger ej, the greater the information entropy of the jth indicator, indicates that the jth indicator has less information. In order to facilitate uniform calculation, we use the function of information utility value,

$$d_j=1-e_j \quad (4)$$

Thus, the larger the information utility value, the more information corresponds to it.

The calculated information utility value d=(0.2800, 0.1690, 0.3151, 0.1363)

Step 4: Calculate the entropy weight of each indicator

Normalizing the information utility values, we obtain the entropy weight for each indicator.

$$W_j=\frac{d_j}{\sum_{j=1}^{m} d_j} \quad (j=1, 2, \ldots, m) \quad (5)$$

So the final weight $W_4 =$ (0.2810, 0.4126, 0.2014, 0.1050)

2) Find the weights of the factors under the other factor

According to the above method, we can also find the weight of the two indicators $U_1^{(1)}$ and $U_1^{(2)}$ under the first – level factor U_1. So weights W_1=(0.6037, 0.3863)

At the same time, there is only one secondary indicator for the primary factor U_2 and U_6, so their weight is 1. The final weight result is shown in figure 2.

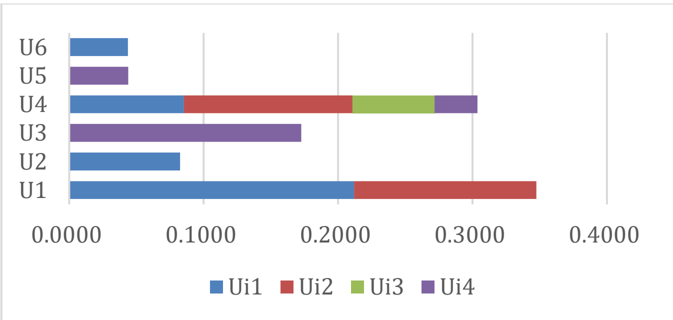

Figure 2: Graphs of weights for primary and secondary indicators

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2.3. Determine the Fuzzy Comprehensive Judgment Matrix

Here, I use the fuzzy comprehensive statistics method to obtain the membership degree of each index.

$$R_1=\begin{bmatrix} 0.5 & 0.4 & 0.1 \\ 0.35 & 0.45 & 0.2 \end{bmatrix}$$

Also since the weights W_1 = (0.6037, 0.3863) for the science and technology R&D cycle $U_1^{(1)}$ and rocket raw material manufacturing difficulty $U_1^{(2)}$.

The calculation gives $B_1=W_1\times R_1$

$$=[0.6037 \quad 0.3863]\times\begin{bmatrix} 0.5 & 0.4 & 0.1 \\ 0.35 & 0.45 & 0.2 \end{bmatrix}$$

$$=[0.4371 \quad 0.4153 \quad 0.1376]$$

In a similar way, we can calculate B_2=[0.0396 0.0330 0.0099]

$$B_4=[0.5570 \quad 0.3814 \quad 0.0616]$$

$$B_6=[0.0093 \quad 0.0139 \quad 0.0232]$$

Since U_3 and U_5 have no secondary indicators, they correspond to both B_3 and B_5 as [0 0 0].

Then, we can construct a comprehensive evaluation matrix R

$$R=\begin{bmatrix} 0.4371 & 0.4153 & 0.1376 \\ 0.0396 & 0.0330 & 0.0099 \\ 0 & 0 & 0 \\ 0.5570 & 0.3814 & 0.0616 \\ 0 & 0 & 0 \\ 0.0093 & 0.0139 & 0.0232 \end{bmatrix}$$

Also because the weights of the first-level factors:

W= [0.3510 0.0825 0.1726 0.3037 0.0439 0.0453]

So the final affiliation result B= W×R=[0.3263 0.2650 0.0689]

2.4. Find and Analyze the Degree of Membership in 2014-2019

According to the above method to calculate the membership in 2020, I can also calculate the membership of developed countries, developing countries and underdeveloped countries to asteroid mining in 2014-2019, as shown in the following figure 3:

The blue line represents the trend of affiliation of developed countries, the orange line represents the trend of affiliation of developing countries, the green line represents the trend of affiliation of underdeveloped countries, and the gray line represents the average level of affiliation of the three subjects.

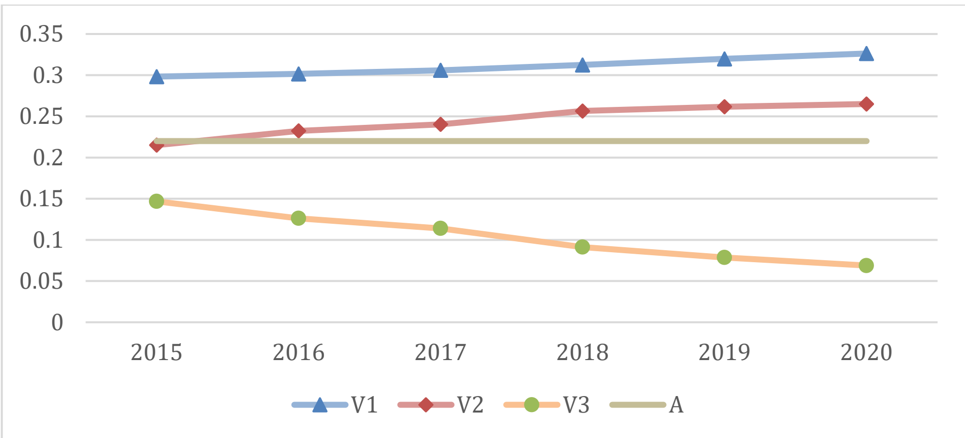

Figure 3: Membership change chart

The results shown in the figure show that the affiliation of developed countries has been at the highest

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level and the affiliation of underdeveloped countries has been at the lowest level. This indicates that in this field of asteroid mining, there is a close connection with the overall strength of the country.

At the same time, the affiliation of developing countries has been rising rapidly, and from below average to well above average. The affiliation of developed countries is also on the rise, but the growth rate is slowing down. The affiliation of underdeveloped countries is decreasing rapidly, indicating that underdeveloped countries are still very much behind in the field of asteroid mining. This trend is likely to be related to the significant multipolarization trend in recent years and the further widening of the global wealth gap.

The further widening of the gap between affiliation levels indicates a global trend toward increasing inequity. This implies that we should pay more attention to strengthening global cooperation when it comes to asteroids in the future, so that developed countries can drive the development of underdeveloped countries and seek common development, so that asteroid mining can truly benefit all of humanity.

3. Time Series Analysis and Prediction of Membership in the Next Few Years

As can be seen from the graph2, the affiliation changes in a linear trend, and does not contain a seasonal component, so we can choose the Holt linear trend model for forecasting.

The Holt linear trend model contains a prediction equation and two smoothing equations, the equations are as follows:

$$\begin{cases} l_{t=\alpha X_t+(1-\alpha)(l_{t-1}+b_{t-1})} \\ b_t = \beta(l_t - l_{t-1}) + (1-\beta)b_{t-1} \\ X'_{t+h} = l_t + hb_t \,, h = 1,2 \ldots \end{cases} \tag{6}$$

We calculated the values of each parameter as:

$$\hat{\alpha} = [1.000 \quad 0.390 \quad 0.301]$$

$$\hat{\beta} = [2.823 \times 10^{-5} \quad 4.742\times10^{-7} \quad 1.272\times10^{-6}]$$

We used Hotte linear trend simulation to predict the membership of developed countries, developing countries and underdeveloped countries from 2021-2023, and the predicted results are shown in figure 4:

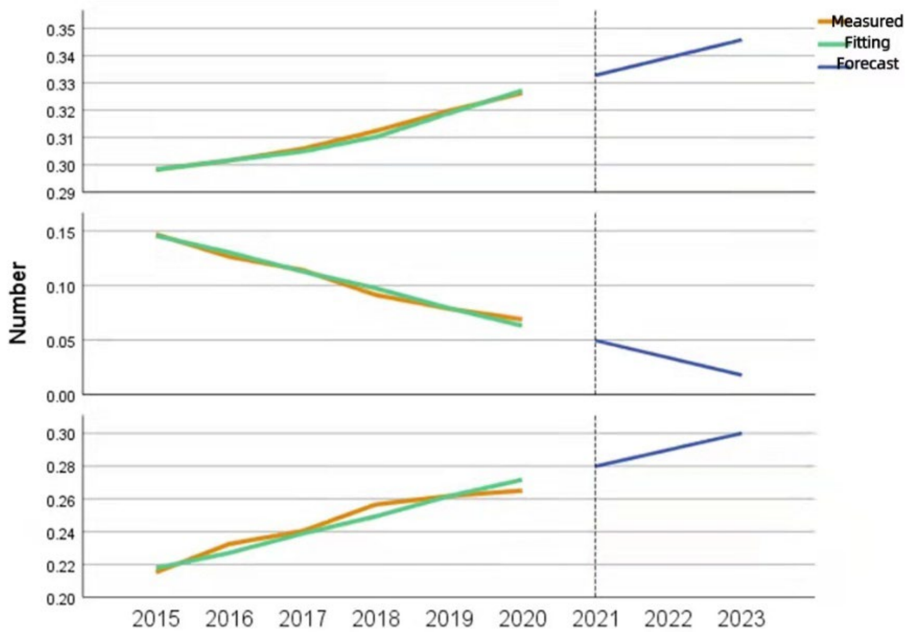

Figure 4: Time series prediction results

The first figure represents the affiliation curves of developed countries, the second figure represents the affiliation curves of underdeveloped countries, and the third figure represents the affiliation curves of developing countries.

The fitted curves in the figure are basically consistent with the measured curves, which indicates that

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the Holt linear trend model can handle the affiliation data well, and it can also show that our prediction results are more reliable.

From the results shown in the figure, we can see that the affiliation of developed and developing countries will continue to show an increasing trend in the coming years, and the affiliation of underdeveloped countries is rapidly decreasing, which indicates that under the existing premise about the asteroid mining system, the benefits are more inclined to developed and developing countries. If corresponding measures are not taken to help underdeveloped countries in the future, the global gap will further widen, which will also further affect global equity.

4. Conclusion

By establishing a two-level fuzzy comprehensive evaluation model, it is concluded that the two indicators of economy and science and technology have the greatest impact on global equity. At present, the economic and technological strength of developed countries is in the leading position.

In the future, the economic and technological strength of developed countries will continue to increase, which will lead to an increase in the subordination of developed countries and exacerbate global inequities. In the future, relevant policies can be formulated in terms of economy and science and technology to alleviate inequities, so that asteroid mining can truly benefit all mankind.

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