

Asteroid Mining Impact Prediction Model

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Abstract. According to the Outer Space Treaty of the United Nations, "Space exploration shall be the common domain of all mankind," and all mankind should share outer space resources. With the continuous advancement of science and technology, the gap in comprehensive strength between countries is increasing, and there is a gap in the acquisition of outer space resources between countries. In order to measure the fair distribution of this resource, we quantify the fairness and formulate relevant policies by collecting data to build a model.

Keywords: Entropy weight method, TOPSIS, Cluster analysis, Input-output analysis.

1. Introduction

With the rapid development of science and technology, more and more countries have entered the space field. The UN Outer Space Treaty provides the legal basis for promoting multinational access to space and reducing inequality. However, in the process of human beings seeking to obtain space resources, how to ensure fairness, the impact of an unknown industry such as asteroid mining on fairness, and how to formulate policies to encourage the development of the asteroid mining industry and promote fairness are all issues that need to be studied.

Based on the concept that "all mankind is trying to explore space, space resources should be used by all mankind." We believe that if we want to define global equity in the space field, we should establish a stable system to measure global equity, population, capital, available resources, and Pollution control capacity is an important consideration. Therefore, determining the importance of these factors, that is, determining their weight, is our top priority. Beyond that, we also need to consider how the many unanswered questions in the unknown industry of asteroid mining will affect global equity in future developments.

2. Global Fairness Measure of TOPSIS Model

2.1. Selection of indicators for measuring factors of global equity

Outer space is an unknown exploration for all human beings. All human beings should share outer space resources. We define the equality of everyone in the acquisition and distribution of outer space resources as global fairness. Considering the different levels of development and comprehensive strength of countries around the world, there is a gap in the acquisition and allocation of outer space resources.

After searching and analyzing various data and data to measure global fairness, we divide the comprehensive strength of a country into five aspects: economic strength, scientific research strength, resource quantity, social security level, and impact on the environment. To reflect the degree of comprehensive strength, we use nine indicators, including population, per capita GDP, per capita area, national scientific research investment, total renewable water resources, per capita greenhouse gas emissions, male-to-female ratio, poverty rate medical level, as the comprehensive national indicator. Indicators of strength determine the allocation of the country's resources in outer space.

2.2. Resource Allocation Evaluation Model

We selected 24 countries such as the United States, Canada, Japan, China, and South Korea as our research objects through the above analysis and literature search and collected the above-mentioned indicators data. We currently have 24 countries as evaluation objects. 9 evaluation indicators, the TOPSIS matrix is constructed as follows:

$$Z = \begin{bmatrix} z_{1,1} & z_{1,2} & \cdots & z_{1,9} \\ z_{2,1} & z_{2,2} & \cdots & z_{2,9} \\ \vdots & \vdots & \vdots & \vdots \\ z_{23,1} & z_{23,2} & \cdots & z_{23,9} \\ z_{24,1} & z_{24,2} & \cdots & z_{24,9} \end{bmatrix}$$

2.2.1 Discussion on the pros and cons of indicators

Considering that different indicators have different impacts on global equity, among the evaluation indicators selected in this paper, the largest indicator is the population: the more population a country has, the more resources the country deserves; GDP per capita, GDP per capita The larger the value, the better the country's economic level and the stronger its strength; the higher the poverty rate, the lower the country's economic strength, and the country's access to relatively fewer resources. According to the characteristics of different indicators, we trend the original data indicators and convert the disadvantaged indicators into extremely large indicators.

After forwarding each indicator, the forwarding matrix can be obtained. In order to remove the influence of the dimension, it is standardized. The matrix is recorded as z , and each element in z is:

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

2.2.2 Determination of indicator weights

After normalization, we get the matrix $\tilde{Z}$. We calculate the probability matrix P , where the elements of P are:

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

For the j th index, the calculation formula of its information entropy is:

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

By normalizing the information utility value, we can get the entropy weight corresponding to each indicator:

$$W_j = d_j / \sum_{j=1}^m d_j \quad (j = 1, 2, \dots, m)$$

2.2.3 Calculate the final score and normalize

We use the TOPSIS comprehensive evaluation method to calculate the allocation of outer space resources for 24 countries.

From the above calculations, we can get a normalized Z matrix, and now we determine the best and worst solutions for each indicator:

Define the distance between the i -th ($i=1, 2, \dots, n$) evaluation object and the maximum value:

$$D_i^+ = \sqrt{\sum_{j=1}^m (Z_j^+ - z_{ij})^2}$$

Define the distance between the i-th (i=1, 2, ..., n) evaluation object and the minimum value:

$$D_i^- = \sqrt{\sum_{j=1}^m (Z_j^- - z_{ij})^2}$$

Calculate the unnormalized score of the evaluation object:

$$S_i = \frac{D_i^-}{D_i^+ + D_i^-}$$

Normalize the score:

$$S_i = \frac{S_i}{\sum_{i=1}^n S_i}$$

The weights of the indicators to be extracted are shown in the following figure:

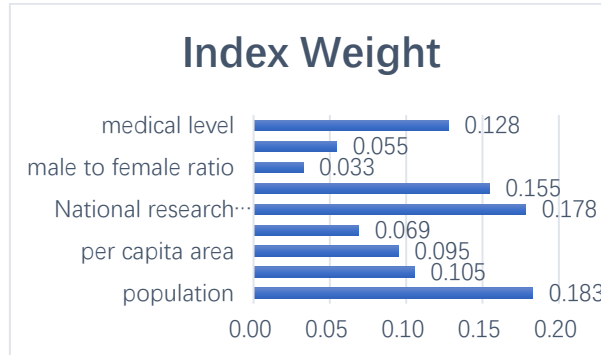


Figure 1. Indicator weight map

We interpret the score level as the number of outer space resources of each country, and we can obtain the resource allocation diagram as shown in the following Figure 2.

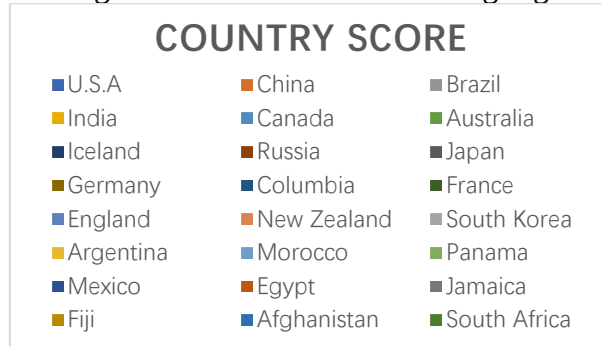


Figure 2. The size of the score reflects the number of resources

We regard the score as what a country deserves at the level of resources in outer space. The higher the score, the more resources the country has in outer space.

2.3. The Theil Index measures global fairness

The larger the Theil index, the more significant the gap between data, the more unfair the distribution of resources, so we use the Theil index to measure global fairness.

The expression for the Theil index is:

$$T = \frac{1}{n} \sum_{i=1}^n \frac{y_i}{\bar{y}} \log \left(\frac{y_i}{\bar{y}} \right)$$

Among them, T is the Theil index that measures the degree of resource gap, y_i is the resource allocation of the ith country, and $\bar{y}$ is the average allocation size of outer space resources of all countries.

Define the Theil index $0 < |T| < 0.1$ as fair, $0.1 < |T| < 0.15$ as fair, $0.15 < |T| < 0.2$ as fairly unfair, $T > 0.2$ as unfair, and above 0.4 as very unfair.

The Theil index of each country is:

Table 1. Theil index for each country

country	Theil index	country	Theil index	country	Theil index
U.S.A	1.1511	Japan	0.1721	Morocco	-0.1587
China	1.1107	Germany	-0.04	Panama	-0.1589
Brazil	0.5299	Columbia	-0.1083	Mexico	-0.1597
India	0.519	France	-0.1096	Egypt	-0.1598
Canada	0.3306	England	-0.1123	Jamaica	-0.1598
Australia	0.312	New Zealand	-0.1144	Fiji	-0.1672
Iceland	0.285	South Korea	-0.1164	Afghanistan	-0.1765
Russia	0.2108	Argentina	-0.1489	South Africa	-0.18666

3. Analysis of the impact of asteroid mining on global equity

3.1. Input-output model

Considering the huge cost of asteroid mining, aerospace powers use their scientific research capabilities and funds to develop robots to collect mineral resources on asteroids. Different countries have different sources of funds. We divide the final output into mining mineral resources (belonging to social collective consumer goods), the impact of asteroid mining on the volatility of stock prices of all parties (belonging to newly added non-productive fixed assets), and various transactions generated in asteroid mining financial assets and various receivables (belonging to newly added other reserve products).

Take the value brought by mineral resources as an example:

According to the Leontief model, it is assumed that the minerals in all countries globally are divided into two categories. The first category is the mineral resources on the earth. These minerals are only consumed within the country, so their products only need to achieve a balance between supply and demand nationwide; the second category is the mineral resources on the earth. They are mineral resources in outer space, and these minerals need to be circulated on a global scale. The direct consumption coefficients are assumed to be the same across countries. In the actual calculation process, the proportion of minerals on the earth in each country is set as:

$$r_{ij}^{(k)} = \frac{X_{ij}^{(k)}}{X_j} (i = h + 1, h + 2, \dots, n; j = h + 1, h + 2, \dots, n; k = 1, 2, \dots, S)$$

Where $r_{ij}^{(k)}$ represents the direct consumption coefficient of country k for the output of mineral resources, $X_{ij}^{(k)}$ represents the input value of the i th mineral in country k , the output value of the j th national mineral. The world is divided into S regions. Based on the known national earth mineral production, the national outer space mineral production is obtained using the national input-output list. The outer space mineral production of each country can be obtained according to the allocation coefficient in the above formula. The demand for minerals in outer space by countries can be obtained according to the following formula:

$$\begin{pmatrix} R_{HH} & R_{HN} \\ R_{NH} & R_{NN} \end{pmatrix} \begin{pmatrix} X_H^{(k)} \\ X_N^{(k)} \end{pmatrix} + \begin{pmatrix} Y_H^{(k)} \\ Y_N^{(k)} \end{pmatrix} = \begin{pmatrix} X_H^{(k)} \\ X_N^{(k)} \end{pmatrix} (k = 1, 2, \dots, S; i = 1, 2, \dots, n)$$

$X_H^{(k)}$ and $Y_H^{(k)}$ represent the column vector of consumed earth minerals and the column vector of consumed outer space minerals of k country, $X_N^{(k)}$ and $Y_N^{(k)}$ represent the earth mineral column vector (actual demand) and the outer space mineral column vector (actual demand) of k country, denoted as X_m . R_{HH} represents the direct consumption coefficient matrix in the production process of earth minerals, and R_{HN} represents the outer space mineral column vector (actual demand). The matrix of direct consumption coefficients in the production process of minerals in outer space R_{NH} represents the matrix of direct consumption coefficients of minerals in outer space in the production process of minerals in outer space and R_{NN} is the matrix of direct consumption coefficients of

various earth minerals in the production process of minerals in outer space. Denote it as A_m . We can get:

$$A_m X_m^{(k)} + Y_m^{(k)} = X_m^{(k)}$$

In general, according to the assumptions of this model, in order to calculate the output of earth minerals in countries around the world, it is necessary to collect, modify, and determine the relevant coefficients in advance, and then obtain the relationship between the various inputs and outputs of minerals in outer space by countries around the world.

Based on the above discussion of mineral resources, one of the outputs, we finally establish an overall continuous input-output model:

$$\sum_{j=1}^n r_i^{(k)} X_j + Y_i = X_i, i = 1, 2, \dots, n$$

Among them, the final output X_i is the global mineral resources for mining, the impact of asteroid mining on the fluctuation of the stock prices of all parties, and the sum of the three parts of various transactional financial assets and various receivables generated in asteroid mining.

$$X_i = \sum_{i=1}^k X_m$$

The final input-output table is as follows. In order to verify the model, we assume that the data simulate the input-output model. A set of data is given, and the output is estimated according to the existing data. The results are calculated. The data and results are as follows:

Table 2. Data Estimated Production Calculation Table

input \ output		Intermediate output					demand	total output
		R&D	manufacture	exploration	fuel	emission		
input	R&D	12	18	20	24	10	56	140
	manufacture	16	24	14	8	11	117	190
	exploration	24	23	15	9	13	126	210
	fuel	29	25	4	7	10	75	150
	emission	15	32	25	11	9	118	210
	total input	140	190	210	150	210		

The results calculated according to this model under the above inputs are shown in the following Table 3.

Table 3. Demand output calculation table

Quality demanded	Total output
70.000	166.857
120.000	203.408
150.000	246.551
90.000	175.893
140.000	244.881

By analyzing the collected data on capital investment in aerospace equipment R&D, manufacturing, asteroid exploration, and launch fuel, as well as the sources and consumption of mineral resources in various countries, it is not difficult to find that aerospace powers and aerospace powers are strong due to their strength and development. For these countries, the output brought by asteroid mining is far greater than the input; for ordinary countries, although outer space resources can be used, the benefits of asteroid mining are minimal due to their limited strength.

3.2. Solving for Global Equity Impact

In order to measure the impact of the above indicators on global equity, we have added four new evaluation indicators to the evaluation indicators in the first question: the investment in aerospace funding, the number of satellites launched in 2021, the proportion of world-class universities, and the consumption of iron resources per capita in 2020.

After determining the above four evaluation indicators, we adopted the model established in question 1, calculated the normalized scores of different countries based on the entropy weight method and the Topsis model, and then calculated the Theil index. And Unfairness. The calculation results are shown in the following Table 4.

Table 4. Country Score and Theil Index before and after adding the indicator

Nation	Former Score	Former Theil	Present Score	Present Theil
U.S.A	0.1118	1.1511	0.1820	2.7957
China	0.1099	1.1107	0.1315	1.5752
Brazil	0.0792	0.5299	0.0625	0.2637
India	0.0785	0.5190	0.0233	-0.1411
Canada	0.0669	0.3306	0.0553	0.1635
Australia	0.0657	0.3120	0.0545	0.1528
Iceland	0.0639	0.2850	0.0520	0.1201
Japan	0.0427	0.2108	0.0476	0.2459
Russia	0.0560	0.1721	0.0846	0.6236
Germany	0.0376	-0.0400	0.0712	0.3970
Columbia	0.0292	-0.1083	0.0233	-0.1413
France	0.0290	-0.1096	0.0328	-0.0817
England	0.0286	-0.1123	0.0309	-0.0966
NewZealand	0.0283	-0.1144	0.0219	-0.1467
South Korea	0.0279	-0.1164	0.0522	0.1221
Argentina	0.0213	-0.1489	0.0163	-0.1594
Panama	0.0171	-0.1587	0.0143	-0.1594
Morocco	0.0170	-0.1589	0.0144	-0.1595
Egypt	0.0156	-0.1597	0.0131	-0.1579
Jamaica	0.0155	-0.1598	0.0121	-0.1560
Fiji	0.0153	-0.1598	0.0104	-0.1506
Morocco	0.0182	-0.1672	0.0141	-0.1592
South Africa	0.0123	-0.1765	0.0098	-0.1780
Afghanistan	0.0124	-0.1867	0.0100	-0.1898

Fair Country: Germany

Fairer countries: Colombia, France, UK, New Zealand, South Korea, Argentina

Countries less fair: Panama, Mexico, Egypt, Jamaica, Fiji, Morocco, South Africa, Afghanistan, Russia

Unfair countries: Canada, Australia, Iceland, Japan

Very unfair countries: USA, China, Brazil, India

4. Conclusion

Through data visualization and the comparison of the national fairness classification before and after, we can intuitively see that after adding various impact indicators of asteroid mining, countries with strong aerospace capabilities have exacerbated global inequity and reduced global fairness.

From the data, we can see that the United States, Russia and China have invested heavily in aerospace, 210, 41.7, and 11 billion yuan respectively. The number of satellites launched is 1113, 198, and 96, which reflects their strong Aerospace strength; in terms of talent education, world-class

universities in the United States, China, Japan, and Germany account for a relatively large proportion, accounting for 17.7%, 10.9%, 6.1%, and 4.6%, respectively, improving their global competitiveness; in terms of market prospects, China, South Korea, Canada, and Germany have higher iron ore consumption per capita at 691.3, 954.9, 323.1, 370.9, reflecting the better market prospects for asteroid mining in the future.

In terms of talent education factors and market prospects, Germany, with its high proportion of world-class universities and high per capita consumption of iron ore production, attaches great importance to the cultivation of talents and has good market expectations, so its Theil index has changed from -0.04. is 0.397, and its evaluation also changes from fair to unfair.

Other countries, Iceland, Canada and Australia, are less prominent than most other countries in terms of the newly added four asteroid mining evaluation indicators, with a lower level and expectation, and are also affected by factors such as the United States and China. Russia and other strong aerospace countries, the Theil index has dropped to varying degrees, from the previous 0.2850, 0.3306, 0.3120 to 0.1201, 0.1635, 0.1528, respectively, approaching a fair direction.

5. Evaluation of the model

We analyze the deserving of the distribution of outer space resources in each country from the comprehensive strength of the country, and extract indicators from five aspects: economic strength, scientific research strength, resource quantity, social security level and impact on the environment to measure global fairness. New metrics have been added to the analysis of how asteroid mining affects global equity. In the model, from the initial entropy weight method to calculate the indicator weight to the multiple regression analysis of the impact of asteroid mining on global equity, the data intuitively shows the degree of impact of each indicator on global equity. Faced with the impact of the unknown industry of asteroid mining on global equity, we classify countries according to the initial model and imagine and analyze the different development prospects of countries in this industry according to the strength of national aerospace strength and input-output analysis. Based on extracted metrics and analysis of the impact of asteroid mining on global equity, we developed policies to promote global equality and assessed policy effectiveness.

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