# Strive for equitable use of space minerals resources

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**Abstract.** The global world has been paying great attention to the issue of space resources. To measure global equity, according to the dominant criteria, this paper selects resources, economic, opportunity, and policy indicators by using the entropy weight method to calculate the information entropy and weight of each indicator, to measure the degree of equity. In the future exploitation of space resources, in terms of financing and returns, this paper uses the global equity model, and to calculate the maximum mining returns, this paper uses linear programming. The results show that the maximum benefit is $20.01 million per ton.

**Keywords:** Global equity model, Entropy weight method, Linear programming, Asteroid mining.

## 1. Introduction

Asteroids are rich in minerals, which is undoubtedly beneficial for future space exploration because the use of these space resources can make unaffordable dreams come true.[1]Space exploration is growing rapidly, underwritten by technologies evolving rapidly. The development of asteroid mines is mainly concerned with transportation issues to maximize the benefits and reduce costs.[2-4]To determine the optimal profit of tin ore in inland and offshore mining, Aryo used linear programming, as a result of which this paper chooses linear programming to calculate the maximum mining returns.[5]

## 2. Impact of Asteroid Mining on the Future of Global Equity

### 2.1. Measuring Global Equity

We define global equity in three broad dimensions: resource and economic equity, opportunity equity, and policy equity. Therefore, we develop a Global equity model to measure global equity through data conditions such as the GINI index, ore, and metal resources export, space launch number, and national policy inclusiveness. All data are sourced from the World Bank and Infogalactic.

Since the subjectivity of hierarchical analysis is too strong, the determination of the judgment matrix depends on experts, and their subjective judgment has a great influence on the results. The entropy weight method is introduced to solve the Global equity model and calculate the weights more objectively. Based on a set of data, the smaller the variance, the greater the similarity of that data, and the higher the global equity index. In extreme cases, a certain indicator, each object has the same score, and the similarity of the data reached the maximum, the global can reach a fair state of equality for all.

The conversion of all metrics into very large metrics, i.e., the larger the data, the better, is called the forwarding of metrics[6]. The following is the forwarding formula for converting very small sex data into very large data:

$$x_j = \max\{x_1, x_2, \cdots, x_i\} - x_i . \tag{1}$$

If all elements are positive, the reciprocal can be taken directly

$$x_k = \frac{1}{x_i} . \tag{2}$$

If the data is an intermediate indicator, i.e., the closer to a certain value, the better. $\{x_i\}$ is a set of intermediate-type indicator series, and the best value is $\{x_{best}\}$. $\{x_{new}\}$ is a very large indicator after forwarding, and the forwarding formula is as follows:[7]

$$M = \max\{|x_i - x_{best}|\}, \tag{3}$$

$$x_{new} = 1 - \frac{|x_i - x_{best}|}{M}. \tag{4}$$

Then, to balance the error caused by the difference between the indicators or the scale[8], we normalize the data of x evaluation objects and x evaluation indicators that have been normalized

$$\begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix}. \tag{5}$$

Then, the matrix normalized to it is noted as Z. For each element in Z:

$$z_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^{\ 2}}}. \tag{6}$$

Calculate the probability matrix p:

$$p_{ij} = \frac{z_{ij}}{\sum_{i=1}^{n} z_{ij}}. \tag{7}$$

Calculate the information entropy e of each indicator, i.e. the uncertainty

$$e_j = -\frac{1}{\ln n} \sum_{i=1}^{n} p_{ij} \ln(p_{ij}),\ j = 1, 2, \cdots, m. \tag{8}$$

Among them,

$$\frac{1}{\ln n} > 0, e_j \geq 0. \tag{9}$$

Then we calculate the weights. 1-e is the information utility value, and then normalized to the weights

$$d_j = 1 - e,\ j = 1, 2, \cdots, m, \tag{10}$$

$$\omega_j = \frac{d_j}{\sum_{j=1}^{m} d_j},\ j = 1, 2, \cdots, m. \tag{11}$$

Table 1 shows the weights and variances calculated based on the GINI index, number of space launches, etc. for each country from 2010 to 2020. We can see that the variance of resource and economic equity, opportunity equity, and policy equity are, respectively, 0.01883, 0.0066, and 0.05459. In contrast, in opportunities such as space launches, the world maintained an equitable state, but in resources and economy, and policy, the world cannot reach relative equity.

**Table 1.** Country weights and variances

| Country | GINI | Poverty index | Ore metal export | Number of space launches | Patent application quantity | Legal right | Inclusiveness of national policies |
|---|---|---|---|---|---|---|---|
| Brazil | 0.031 | 0.076 | 0.000 | 0.086 | 0.000 | 0.094 | 0.031 |
| China | 0.089 | 0.177 | 0.152 | 0.143 | 0.000 | 0.095 | 0.089 |
| France | 0.220 | 0.110 | 0.000 | 0.094 | 0.000 | 0.125 | 0.220 |
| UK | 0.107 | 0.107 | 0.000 | 0.065 | 0.000 | 0.187 | 0.107 |
| India | 0.082 | 0.171 | 0.151 | 0.123 | 0.702 | 0.047 | 0.082 |
| Israel | 0.220 | 0.079 | 0.190 | 0.060 | 0.000 | 0.082 | 0.220 |
| Korea | 0.051 | 0.047 | 0.075 | 0.136 | 0.000 | 0.115 | 0.051 |
| Russian | 0.107 | 0.115 | 0.115 | 0.074 | 0.298 | 0.121 | 0.107 |
| US | 0.077 | 0.088 | 0.141 | 0.099 | 0.000 | 0.072 | 0.077 |
| Japan | 0.304 | 0.016 | 0.032 | 0.176 | 0.121 | 0.000 | 0.063 |
| Variance | 0.011 | 0.005 | 0.002 | 0.005 | 0.001 | 0.053 | 0.002 |

To validate our model, Cambodia is used as an example. Historically, Cambodia is a member of the Association of Southeast Asian Nations with a predominantly agricultural economy and a weak industrial base. It has a constitutional parliamentary monarchy, a liberal democracy, and a free market economy with a separation of powers between the legislature, the executive, and the judiciary. According to news reports in 2018, Chinese cooperation with Cambodia is expected to launch the Prince I satellite in 2021. Thus, we substitute weighted data on Cambodia's poverty index, the number of patents, and the inclusiveness of national policies into the model. The largest change is the variance of the GINI coefficient of 0.009. It is clear that the variance changes of the model are < 0.002, and our Global equity model is reliable.

## 3. A Vision of the Future of Asteroid Mining

Today, everything called a resource is facing a state of resource scarcity in the 21st century. On Earth, and indeed on any planet, there are limited reserves of heavy elemental minerals. The mineral resources of any planet will eventually be depleted when recycling technology is not mature. Metals such as nickel, copper, and manganese, which are mainly used in industrial production, will also face a state of resource depletion within the next 50 years.

With the current human vision and technical difficulty, asteroid mining has entered a starting phase. Space is very rich in resources, but wanting more countries to get the resources, we have to face many problems. First of all, we need to pick out asteroids that were relatively cheap to mine and relatively profitable. Specifically, we show some 10 asteroids that are close to the minimum orbital crossing distance of the Earth in Table 2. These asteroids have a theoretical chance of reaching the Earth because of the possibility of "passing by" them. In other words, these asteroid resources are the first targets to be exploited in the first wave of space migration.

**Table 2.** The asteroid most likely to reach[9]

| Name | Minimum track crossing distance (AU) | Total value (billions of dollars) | Expected profit (billions of dollars) | Planetary resources |
|---|---|---|---|---|
| Nereus | 0.0032 | 47.1000 | 13.9000 | Nickel, iron, cobalt |
| Bennu | 0.0032 | 6700.0000 | 1850.0000 | Iron, hydrogen, ammonia, nitrogen |
| Didymos | 0.0398 | 622.5000 | 164.1000 | Nickel, iron, cobalt |
| 2011 UW 158 | 0.0029 | 66.9000 | 17.4000 | Platinum, nickel, iron, cobalt |
| 2002 AL31 | 0.0128 | 105.8000 | 24.1000 | Nickel, iron, cobalt |
| Anteros | 0.0622 | 55.7000 | 12.5000 | Magnesium silicate, aluminum, ferric silicate |
| 2001 CC21 | 0.0831 | 1470.0000 | 298.0000 | Magnesium silicate, aluminum, ferric silicate |
| 1992 TC | 0.1672 | 840.0000 | 168.0000 | Nickel, iron, cobalt |
| 2002 DO3 | 0.0032 | 3344.0000 | 590.0000 | Nickel, iron, cobalt |
| 2002 EC | 0.0445 | 483.4000 | 82.1000 | Nickel, iron, cobalt |

Next, we need to know who is mining. As of April 2020, 2,665 satellites are working in orbit around the world. There are not many cases of humans going directly into space for mining because humans cannot adapt to the vacuum in space. Therefore we need machines, also known as satellites, as well as launch vehicles to go into asteroids for mining instead of us. Based on the Global equity model in the first question, we know that resources and economies cannot maintain relative equity on a global scale.

As seen in Figure 1, the process of space mining can be divided into four areas: resource exploration, design of mining robots, resource adoption, and in situ utilization. Currently, the most reliable method is landing sampling, followed by probe flyby or orbit. New Horizons, which explores Pluto, uses flybys to find out the content of nitrogen and methane ice at its north pole.

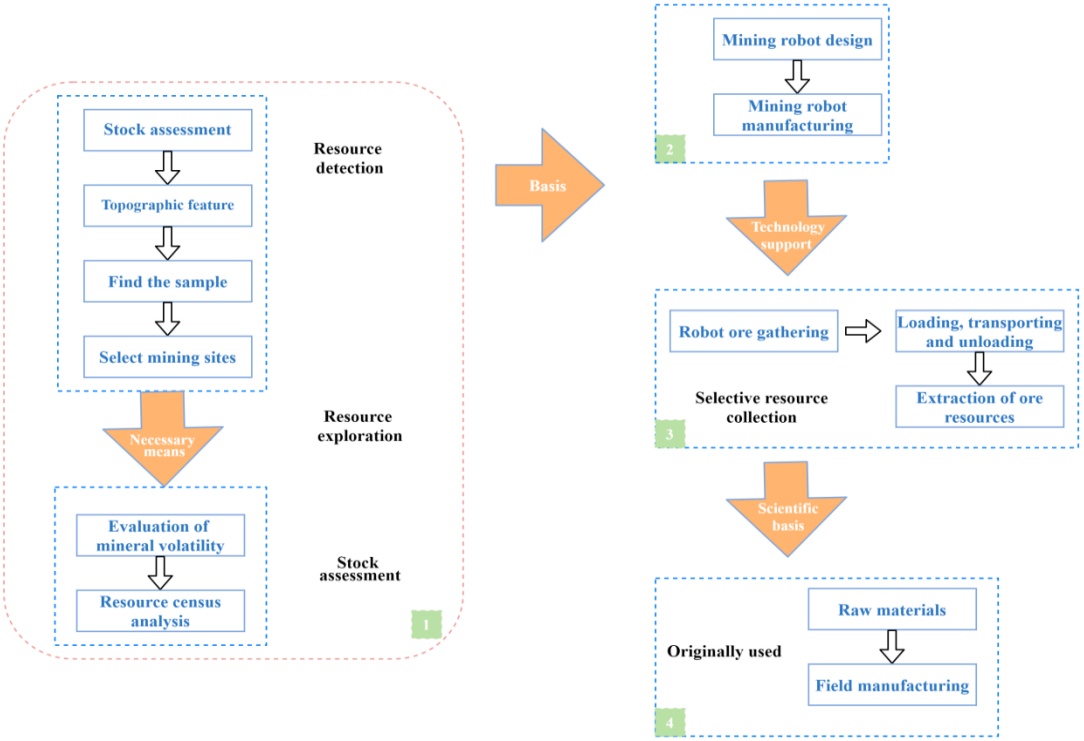



**Figure 1.** Space mining research route [10]

Then, the mining process needs to be supported by a fund, and we need to get a lot of money. "According to the current level of technology, even 99% gold content from the moon back was not cost-effective." Zheng Yongchun said. The U.S. Apollo shipped 380 kilograms of samples back from

the moon, but the entire program cost $25 billion and used about 300,000 people. Even mining on the moon, where landing technology is relatively mature, is still not economically viable. Landing on an asteroid for sampling is even more difficult. Japan launched the Hayabusa probe to land on the asteroid called "Silk River", which took six years to land and returned to Earth in 2010. It brings back 1,500 particles, about one-thousandth of a millimeter in size and weighing less than a milligram.

Of course, it makes sense for companies such as planetary resources in the United States to plan asteroid mining as a project with a commercial vision because the scientific value of the ore on asteroids is immeasurable. At the same time, the space industry itself now has some ability to operate in a cosmic environment to feed itself, to compensate for many problems that cannot be solved on the ground or are too costly. In the entire space industry chain, rockets, satellites, applications, and surrounding support industries are relatively independent. But in fact, each link can lead to the development of a range of peripheral industries. From a national perspective, allowing these industries to develop independently can greatly enhance comprehensive national power. From Figure 2, we call on the country's private sector to actively invest to reach about 20% of the required capital. The national governments can jointly cooperate and conclude agreements to raise about 30% of the required funds. Taking into account the management of international cooperation organizations such as the United Nations and strong financial and material resources, the remaining 50% of the required funds can be financed by international organizations.

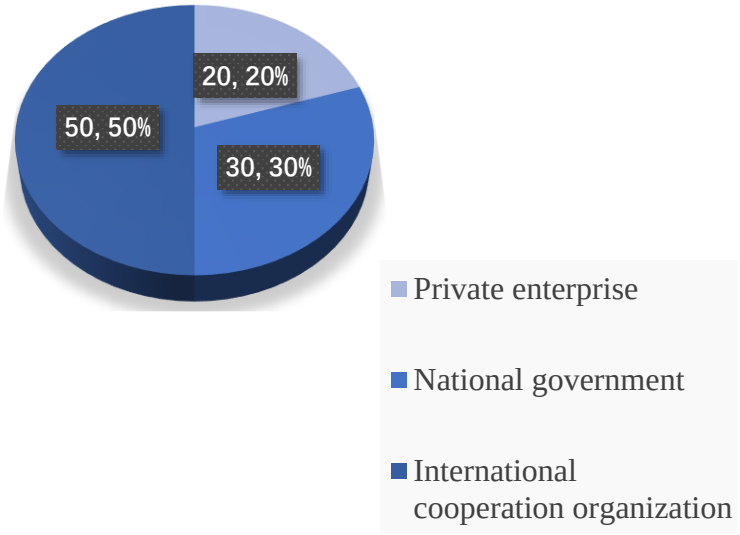



**Figure 2.** Source of funds required

Investment is tied to return, and most companies, including international cooperation organizations, want to reap satisfactory profits from asteroid mining. Thus, asteroid mining affects global equity in terms of economics, i.e., benefit capture. To investigate how asteroid mining can maximize its benefits, we use a Linear programming approach [11].

A linear programming problem is a problem of maximizing or minimizing a linear objective function subject to a set of linear constraints. The objective function of Linear programming can be maximized or minimized, and the inequality sign of the constraints can be less than or greater than the sign [12]. To avoid the inconvenience caused by this diversity of forms, the standard form of linear programming is specified in Matlab as

$$\min_x c^T x$$
$$\text{s.t.} \begin{cases} Ax \le b \\ Aeq \cdot x = beq \\ lb \le x \le ub \end{cases}. \tag{12}$$

The standard type of the general linear programming problem is

$$\max z = \sum_{j=1}^{n} c_j x_j$$
$$\text{s.t.} \begin{cases} \sum_{j=1}^{n} a_{ij} x_j = b_i, i = 1, 2, \cdots, m \\ x_j \geq 0, j = 1, 2, \cdots, n \end{cases} \tag{13}$$

The solution $x=(x_1, x_2, \ldots, x_n)$, which satisfies the above constraints, is called the feasible solution of the linear programming problem, and the feasible solution that maximizes the objective function is the optimal solution.

The following Table 3 shows the cost of asteroid mining and the profit calculated by Linear programming, with a profit of $0.3 billion. The profit will be distributed to private companies, national governments, and international cooperation organizations in the ratio of 2:3:5.

**Table 3.** Partial mining cost and profit statement

| Category | Iron | Cobalt | Nickel | Aggregate amount(billions of dollars) |
|---|---|---|---|---|
| Making rockets | 0.133 | 0.133 | 0.133 | 150.000 |
| Launch costs | 0.067 | 0.067 | 0.067 | 130.000 |
| Capital cost | 0.015 | 0.015 | 0.015 | 120.000 |
| Establishment of the base station | 5.270 | 5.270 | 5.270 | 396.000 |
| Maintain stability | 0.004 | 0.004 | 0.004 | 90.000 |
| Profit (ton/USD) | 963.600 | 4360.000 | 90145.000 | 0.200 |

In summary, we propose a vision for the future of asteroid mining that is broadly based on the selection of ten suitable asteroids as the first mining targets, the use of communication satellites to assist with exploration information, and the use of launch vehicles and mining robots for mining. Private companies, national governments, and international cooperation organizations will fund and generate revenues in a 2:3:5 ratio. Asteroid mining will primarily have a global economic impact, which we measure using the GINI coefficient from the Global equity model.

Under the future vision, we project the GINI coefficient with country weights for 2030 based on the GINI coefficient from 2010-2020 with a variance of 0.0072 and a global convergence to equity.

**Table 4.** The influence of the GINI coefficient in different countries

| Country | GINI coefficient in 2030 | Weight |
|---|---|---|
| Brazil | 52.9248 | 0.0527 |
| China | 31.2247 | 0.0599 |
| France | 29.3229 | 0.0570 |
| UK | 40.8343 | 0.0657 |
| India | 35.7000 | 0.0778 |
| Israel | 33.2585 | 0.0572 |
| Japan | 31.2008 | 0.0525 |
| Korea | 28.9326 | 0.0581 |
| Russian | 32.1534 | 0.2823 |
| US | 41.9643 | 0.2368 |
| Variance | | 0.0072 |

In Table 4, for individual regions, such as the US, Russia, and China, the GINI coefficient increases, and the gap between rich and poor widened further. But for the world, on the contrary, it is more equitable. Asteroid mining will not change the gap between rich and poor very significantly in countries without space technology, but it may widen the gap between rich and poor in countries

where the gap was not obvious. Although there are countries that have widened the gap between rich and poor as a result, they can actively adjust their national policies through political and legal means. At this time, for the global, the number of countries with widening wealth gap increases and maintains relative balance.

## 4. Conclusion

To measure global equity, we consider three indices including resource and economy, opportunity, and policy equity, and developed a Global equity model. We first normalize collected data about the GINI index, mineral and metal resource export, space launch times, and national policy inclusiveness, and then apply the Entropy weight method to calculate the information entropy and weight of each index. The variance of resource and economic equity, opportunity equity, and policy equity are, respectively, 0.01883, 0.0066, and 0.05459. These results suggest that opportunities like space launches maintain fairness, but in terms of resources, economy and policies, it is relatively hard to achieve a fair state worldwide. Finally, we validate our model with data collected from Cambodian and showed good robustness.

To realistically describe the possible future vision of asteroid mining, we use the Global equity model in terms of financing and benefits. Taking into account unknown conditions for mining, we select the first ten asteroids to be mined by using the minimum orbital crossing distance of the Earth, and designed robots to carry out mining. We find that private companies, national governments, and international partner organizations invest efforts in terms of funding and revenue with a ratio of 2:3:5. Using Linear programming, we maximize the benefit to $20.01 million/ton. Moreover, the Global equity model shows that asteroid mining has the largest impact on the GINI coefficient, with a variance of 0.0072, indicating a global trend toward equity.

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