GES Model: Combining Pearson Correlation Coefficient Analysis with Multilayer Perceptron

Chunyu Sui∗
sui.chunyu@hotmail.com
School of Computer Science and Technology, Shandong University
Jinan, China

Sirui Huang∗
huang.sirui@gmail.com
School of Control Science and Engineering, Shandong University
Jinan, China

Xinrui Li∗
lixinrui@outlook.com
School of Computer Science and Technology, Shandong University
Jinan, China

Yinghang Song∗
song.yinghang12138@outlook.com
School of Computer Science and Technology, Shandong University
Jinan, China

Yunpeng Zan‡
zanyunpeng@gmail.com
School of Computer Science and Technology, Shandong University
Jinan, China

ABSTRACT
With the development of technological progress, mining on asteroids is becoming a reality[1][25]. This paper focuses on how to distribute asteroid mineral resources in a reasonable way to ensure global equity.

To distribute asteroid resources fairly, 7 primary indicators and 20 secondary indicators are introduced to build a mathematical model to evaluate global equity and the weights are given by Analytic Hierarchy Process (AHP). Then Global Equity Score (GES) Model based on 12 primary indicators and 40 secondary indicators is built and TOPSIS method is applied to rank all countries. A t-distribution probability density function is applied to simulate the rate of asteroid mining. The Backward Algorithm is applied to quantitatively measure the impact of changing indicators on global equity. Then Pearson correlation coefficient analysis is conducted for each indicator, and t-test is performed lastly. The results demonstrate that asteroid mining promotes global equity that poor countries can be allocated slightly more mineral resources, and a schedule of the implementation of each measure is given.

To gain more insight, sensitivity analysis is conducted and the results demonstrate that scores vary less than 7%. It can be concluded that our GES model have great potential as its robustness, accuracy and strengths.

CCS CONCEPTS
• Computer systems organization → Embedded systems; Redundancy; Robotics; • Networks → Network reliability.

∗Corresponding authors

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ICBICC 2022, December 2–4, 2022, Chengdu, China
© 2022 Copyright held by the owner/author(s). Publication rights licensed to ACM.
ACM ISBN 978-1-4503-9954-8/22/12... $15.00
https://doi.org/10.1145/3588340.3588368

1 INTRODUCTION
1.1 Problem Background and Restatement
With the great progress of science and technology, the asteroid mining is gradually becoming a reality[9]. In recent years, more and more countries have agreed to make outer space benefit whole humanity[5], so how to ensure the equitable distribution of benefits after mining asteroids has become an issue to be discussed by all allied powers.

Before the asteroid mining project is officially conducted, there are many unsettled issues that deserve to be discussed and resolved, including the feasibility of mining on asteroids and the equitable distribution of benefits[10]. Therefore, it is a critical issue to determine an equitable benefit distribution strategy for the project ensuring the project is carried out while promoting world peace and reducing inequality.

Considering the background, we should address 4 questions in the paper:

Task 1: First, a global equity definition should be developed. Then, find appropriate indicators and build a model to measure global equity. Next, apply the model to a historical or regional analysis to verify its validity.

Task 2: Describe the possible future state and vision of the asteroid mining industry. Then analyze the impact on global equity by using the global equity measurement model developed in Task 1.

Task 3: Improve models to analyze and explore how asteroid mining will affect global equity.

Task 4: Assuming that UN intends to update its Outer Space Treaty to develop asteroid mining and ensure that asteroid mining
benefits all of humanity. Combine your model and results to propose reasonable policies to ensure that asteroid mining will benefit all of humanity.

1.2 Our Work
First of all, we give the definition of global equity and introduce 5 primary indicators and 26 secondary indicators to measure the established mathematical model. Next, we use Analytic Hierarchy Process to assign weights to every indicator and perform the consistency test on the weight matrix, and finally the test passed. We calculate the global development balance scores and perform calculations for the last 10 years of data.

Secondly, we combine the data to provide a vision of asteroid mining’s future. Next, we improve our model to take into account of the contribution of science and technology to ensure that "those who contribute more get more". We use the t-distribution probability density function to simulate the profitability of asteroid mining. Finally, we use TOPSIS to rank the contribution of each country and use the contribution of each country to allocate resources.

After that, we calculate the impact of changing indicators on global equity by using the back propagation algorithm. Next, we calculate the correlation between each indicator and the global development balance score using Pearson correlation coefficient analysis and pass the t-test.

2 ASSUMPTION AND SYMBOL EXPLANATION
2.1 Assumption
Assuming that global equity is influenced by the six indicators including EI, IDG, CEA, MA, HR, ER and SA, and that unexpected factors such as natural disasters do not have obvious impacts on global equity as they may happen anywhere and anytime on the earth.

Assuming that our mineral extraction rate rises first and then falls, this means we can fit the mineral extraction rate with a t-distribution probability density function curve.

Assuming stable international conditions and a stable development of the space industry. Meanwhile, mankind can achieve asteroid mining in 15 years or so.

Assuming that each secondary indicator has a linear effect on the primary indicator, this means that we can easily find the partial derivative of the impact function and analyze the impact of each secondary indicator on global equity accordingly.

3 GLOBAL EQUITY SCORE MODEL
3.1 Definition of Equity
To address this issue, first we should define what is equity, “equity means equal rights for all people on earth”. More specifically, rights include: fair distribution of resources, fair income, fair opportunities, fair carbon emissions, etc.

To measure global equity, we adopt the method of calculating the variance after computing the development equity factor for each country. Then, we combine Zhang’s descriptions to establish the following model to measure global equality.

3.2 Global Equity Evaluation System
3.2.1 Establishment of Evaluation Indicators. We use 7 primary indicators and 15 secondary indicators to measure Country Development Score. Country Development Score for each country is the ratio of the country’s development score to the average of the development scores of other countries. The primary indicators that affect Country Development Score are shown in figure 2.
Then we obtain the eigenvalues of the matrix and show it in table 1 and table 2.

Table 1: The Eigenvalues of the Weight Coefficient Matrix - 1

| Indicators | EI  | IDG | CEA |
|------------|-----|-----|-----|
| Eighenvalues | 7.7200 | 1.8900 | 1.8900 |

Table 2: The Eigenvalues of the Weight Coefficient Matrix - 2

| Indicators | MA  | HR  | ER  | SA  |
|------------|-----|-----|-----|-----|
| Eighenvalues | 0.2948 | 0.2948 | 0.0000 | 0.0000 |

**Consistency Check**
After getting the eigenvalues of the weight coefficient matrix, we perform a consistency check, the equations are as follow

\[
CI = \frac{\lambda_{\text{max}} - n}{n - 1} = \frac{7.72 - 7}{7 - 1} = 0.12. \tag{1}
\]

Also, RI denotes stochastic consistency index, and its standard values are shown in table 3 and table 4.

Table 3: Values of RI - 2

| n | 1   | 2   | 3   | 4   | 5   |
|---|-----|-----|-----|-----|-----|
| RI | 0.00 | 0.00 | 0.58 | 0.90 | 1.12 |

Table 4: Values of RI - 1

| n | 6   | 7   | 8   | 9   | 10  |
|---|-----|-----|-----|-----|-----|
| RI | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |

Substituting the data obtained before, we get

\[
CR = \frac{CI}{RI} = \frac{0.12}{1.32} = 0.0909 < 0.1. \tag{2}
\]

So it pass the consistency check. Then, we use Arithmetic Mean Method, Geometric Mean Method and Eigenvalue Method to calculate the weight of the primary indicators, finally we get the results shown in table 5.

Table 5: Weight of the First-level Indicators

| Indicators | Arithmetic Mean Method | Geometric Mean Method | Eigenvalue Method |
|------------|------------------------|-----------------------|------------------|
| EI         | 0.1831                 | 0.1965                | 0.1810           |
| IDG        | 0.3831                 | 0.3965                | 0.3810           |
| CEA        | 0.0989                 | 0.0996                | 0.0921           |
| MA         | 0.0435                 | 0.0436                | 0.0438           |
| HR         | 0.0926                 | 0.0620                | 0.1027           |
| ER         | 0.0833                 | 0.0852                | 0.0808           |
| SA         | 0.1157                 | 0.1166                | 0.1187           |

Next, after calculating the average of the statistics in table 5, we get figure 4.

Finally, we get the formula to measure the national development score(Eq.)

\[
E_{Qk} = 0.187 \times EI + 0.387 \times IDG + 0.097 \times CEA \\
+ 0.0436 \times MA + 0.086 \times HR + 0.0831 \times ER \\
+ 0.117 \times SA. \tag{3}
\]

**Model Validation**
Take Income Distribution Gap(IDG) as an example, according to the factors affecting IDG obtained from the previous analysis, the income inequality score of each country is finally shown in figure 5.
For a certain country, first we de-self the country by comparing its development score ($E_{Q_k}$) with the average of other countries’ development scores ($E_{Q_m}$) ($k \neq m$). Then we subtract it from the mean of all selected countries ($E_{Q_k}$) and take the mean value. That is, using the following formula:

$$GE = \frac{1}{10n} \sum \left( \frac{E_{Q_k}}{n} - \overline{E_{Q_k}} \right)^2.$$  \hspace{1cm} (4)

On balance, we derive the degree of inequity over the last 10 years which was shown in figure 6.

### 3.3 Our Conclusion

By calculating the Global Development Imbalance Index (GDI), it can be concluded that global imbalances are tending to accelerate over the past decade due to factors such as uneven economic development.

### 4 IMPACTS OF ASTEROID MINING ON GLOBAL EQUITY

To explore the impact asteroid mining can have, we first analyze the value asteroids can bring. Take minerals from asteroids as an example, relevant evidence suggests that the asteroid is indeed rich in minerals.

With the depletion of Earth’s resources, people are destined to place goals in outer space, and the first bear to brunt is asteroids. In this task, we have made an outlook on the future of asteroid mining and analyze it.

#### 4.1 Promoting Global Economic Development

Through our research, we found that some of the asteroids have the following commercial valuations shown in table 6.

| Asteroid   | Est. Value (US$ billion) | Est. Profit (US$ billion) | $\Delta V$ (km/s) |
|------------|--------------------------|---------------------------|-------------------|
| Didymos    | 62                       | 16                        | 5.162             |
| Anteros    | 5570                     | 1250                      | 5.44              |
| 2001 CC21  | 147                      | 30                        | 5.636             |
| 1992 TC    | 84                       | 17                        | 5.648             |

The growth of global economic has slowed down due to factors such as the COVID-19 outbreak and the declining birth rate of the population[11][23]. It is speculated that a relatively small metallic asteroid with a diameter of 1.6 km (1 mile) contains more than $20$ trillion worth of industrial and precious metals[15]. Other studies have shown that rockets can achieve “zero loss” of energy in transit by using solar energy. Other costs are negligible relative to the net profit. The complete utilization of just one 1.6 km asteroid could generate over $20$ trillion in net profits. We speculate that after a breakthrough in space technology, the global economy will grow at a rate of at least 9% per year, and the economy will grow by more than $10.17$ trillion per year[3].

#### 4.2 Space Becomes a Major Battleground for Human Development

The economic appeal of asteroid mining is clear: precious metals such as gold and platinum sell for around US $50,000 per kilogram[27]. Due to the huge potential value of planetary mining[4], space is becoming a major battleground for various countries[21]. A breakdown of the first successful missions by country is as follows. At the same time, some strong aviation companies (e.g., SPACEX) will also participate[13], and the booming aviation business will drive the progress of technology and the growth of the job market[19].

#### 4.3 Improving the Environment

Asteroid mining has equally profound effects on the Earth’s environment[7]. Take the mining of the rare earth resource platinum, for example. Space mining would have a lower environmental impact[24], if the spacecraft is able to return between 0.3% and 7%
We measure the importance of a country in asteroid mining by its wealth gap and ensure global equity, we allocate resources slightly differ.

Table 7: Comparison of Space and Earth-based platinum mining greenhouse gas emissions - 1

| \( b_{\text{mining}} \) | \( \frac{\text{CO}_2 \text{ eq}}{\text{kg Pt}} \) | \( \text{Ratio Reference} \) |
|---|---|---|
| 10 | 69 | 580 |
| 20 | 65 | 620 |
| 30 | 63 | 635 |
| 40 | 62 | 643 |

Table 8: Comparison of Space and Earth-based platinum mining greenhouse gas emissions - 2

| \( b_{\text{mining}} \) | \( \text{Ratio Reference} \) |
|---|---|
| 10 | 29 |
| 20 | 31 |
| 30 | 32 |
| 40 | 32 |

We can see that though asteroid mining account for a lower bound in \( \text{CO}_2 \text{ eq} \), compared to Earth-based mining, one order of magnitude higher emissions would lead to one order of magnitude savings[14].

4.4 The Impact of Asteroid Mining

In order to ensure the fairness of resource allocation among different countries in the asteroid mining project, we supplement our model by adding a measure of the scientific and technological contribution of each country[16]. At the same time, in order to narrow the global wealth gap and ensure global equity, we allocate resources slightly more to the extremely poor countries.

4.4.1 Determination of the Total Contribution. Considering the different contributions of different countries in asteroid mining, the countries that contribute more to science and technology deserve to share more resources.

4.4.2 Determination of Scientific and Technological Contribution. We measure the importance of a country in asteroid mining by its scientific and technological contribution[6]. We introduce 5 primary indicators and 21 secondary indicators. We use AHP method to calculate the weight of each indicator and the contribution degree is calculated as follows.

4.4.3 Calculation Total Score by Using TOPSIS. After defining how these variables are determined, we use the TOPSIS method to continue our analysis of the problem[17].

*The basic Steps of TOPSIS*

- Normalize the Original Matrix

Suppose \( x_i \) is a set of intermediate type indicator series and the optimal value is \( x_{\text{best}} \), then equation 5, 6 are the forwarding equations.

\[
M = \max (x_i - x_{\text{best}})
\]

\[
\tilde{x}_t = 1 - \frac{|x_i - x_{\text{best}}|}{M}
\]

- Normalize the Normalization Matrix

If the normalized matrix is noted as \( Z \), then we use equation 7 to normalize the matrix \( X \).

\[
z_{ij} = x_{ij} \sqrt{\sum_{t=1}^{n} x_{ij}^2}
\]

Assume that there are \( n \) objects to be evaluated and a standardized matrix of \( n \) evaluation indicators.

\[
Z = \begin{bmatrix}
z_{11} & z_{12} & \cdots & z_{1m} \\
z_{21} & z_{22} & \cdots & z_{2m} \\
\vdots & \vdots & \ddots & \vdots \\
z_{n1} & z_{n2} & \cdots & z_{nm}
\end{bmatrix}
\]

(8)

Then we define maximum value(\( Z^* \)):

\[
Z^* = (Z^*_1, Z^*_2, \cdots, Z^*_m)
\]

\[= \left( \max \{z_{11}, zn, \cdots, z_{n1}\}, \max \{z_{12}, z_{22}, \cdots, z_{n2}\}, \right. \]n

\[\cdots, \left. \max \{z_{1m}, z_{2m}, \cdots, z_{nm}\} \right)
\]

(9)
minimum value($Z^-$):
\[
Z^- = (Z^-_1, Z^-_2, \cdots, Z^-_m) = (\min \{z_{11}, z_{21}, \cdots, z_{n1}\}, \min \{z_{12}, z_{22}, \cdots, z_{n2}\}, \cdots, \min \{z_{1m}, z_{2m}, \cdots, z_{nm}\}).
\]

Distance of the $i^{th}$ ($i = 1, 2, \cdots, n$) evaluation object from the maximum value($D^+_i$):
\[
D^+_i = \sqrt{\sum_{j=1}^{m} (Z^+_j - z_{ij})^2}.
\]

Distance of the $i^{th}$ ($i = 1, 2, \cdots, n$) evaluation object from the minimum value($D^-_i$):
\[
D^-_i = \sqrt{\sum_{j=1}^{m} (Z^-_j - z_{ij})^2}.
\]

Then, we can calculate the un-normalized score of the $i^{th}$ evaluation object:
\[
S_i = D^-_i / (D^+_i + D^-_i). \quad (13)
\]

Next, we normalize the score using equation 14:
\[
\hat{S}_i = S_i / \sum_{i=1}^{n} S_i. \quad (14)
\]

Finally, we calculated the scores of the top 7 countries which was shown in table 9 and table 10.

Table 9: Top 7 Overall Scoring Countries - 1

| Countries | USA | China | Japan |
|-----------|-----|-------|-------|
| Score     | 298.9914 | 132.6379 | 64.8017 |

Table 10: Top 7 Overall Scoring Countries - 2

| Countries | UK | France | Germany | Canada |
|-----------|----|--------|---------|--------|
| Score     | 60.4439 | 41.5603 | 34.6638 | 32.9397 |

4.4.4 Determination of Annual Profit. Considering that the technology is not fully mature in the early stage, the mining rate should rise first and then fall. We use the t-distribution probability density function as our mining curve[20]. The function is defined as follows.
\[
p(t) = \frac{\Gamma\left(\frac{n+1}{2}\right)}{\sqrt{n\pi}\Gamma\left(\frac{n}{2}\right)} \left(1 + \frac{t^2}{n}\right)^{-\frac{n+1}{2}}, \quad 0 < t < +\infty
\]

With this definition of the mining curve, we then calculate the income.
\[
income = \int_{t_1}^{t_2} p'(t) \cdot V dt
\]

where $V$ denotes total mineral value and we take $V = 70$ trillion. Then,
\[
Profit = income - cost
\]

4.4.5 Determination of Poor Countries. In order to narrow the global wealth gap and ensure global equity, we provide assistance to countries with extreme poverty by giving them slightly more resources. We use GDP as a measure of extreme poverty, and countries in the bottom 20 of the world GDP ranking are considered extremely poor. World GDP per Capita is shown below.

Table 9: Top 7 Overall Scoring Countries - 1

| Countries | USA | China | Japan |
|-----------|-----|-------|-------|
| Score     | 298.9914 | 132.6379 | 64.8017 |

Table 10: Top 7 Overall Scoring Countries - 2

| Countries | UK | France | Germany | Canada |
|-----------|----|--------|---------|--------|
| Score     | 60.4439 | 41.5603 | 34.6638 | 32.9397 |

Let $\gamma$ be the poverty index of the $k^{th}$ country and we specify the value of $\gamma$ could be calculated by equation 18 .
\[
\gamma = \begin{cases} 1.2, & \text{if the country is one of the 20 countries with the lowest GDP}, \\ 1.0, & \text{otherwise}. \end{cases}
\]

Then, the formula for total profit is:
\[
proc = \gamma \left[ \frac{(income - cost) \cdot Eq_k}{\sum Eq_k} \right] \quad (19)
\]

where $proc$ represents the total profit of Country C. After calculating the total profits for each country in turn using equation 11 , we represent the top 7 countries with the highest total profits in figure 10 and figure 11.

Figure 9: World GDP per Capita

![World GDP per Capita](image)

Figure 10: Top 9 Countries with the Highest Degree of Inequity
Finally, we calculated the Global Inequity Index for 2030-2039 and the results are shown in Figure 11.

5 IMPACTS OF CHANGING CONDITIONS ON GLOBAL EQUITY

To quantitatively measure the impact of each indicator on Country Development Score, we use a back propagation algorithm to calculate it and validate it by Pearson correlation coefficient analysis.

5.1 Backward Propagation Algorithm

5.1.1 Brief Introduction to the Back Propagation Algorithm. The backpropagation algorithm is a supervised learning method used in conjunction with optimization algorithms such as gradient descent[12]. It is a generalization of the Delta rule for multilayer feedforward networks, which allows the gradient to be computed using a chain rule for each layer iteration.

In a word, the following equation holds:

\[
\begin{align*}
\hat{z}^{(l)}_1 &= w^{(l)}_{11} a^{(l-1)}_1 + w^{(l)}_{12} a^{(l-1)}_2 + \cdots + w^{(l)}_{1N(l-1)} a^{(l-1)}_{N(l-1)} + b^{(l)}_1 \\
\hat{z}^{(l)}_2 &= w^{(l)}_{21} a^{(l-1)}_1 + w^{(l)}_{22} a^{(l-1)}_2 + \cdots + w^{(l)}_{2N(l-1)} a^{(l-1)}_{N(l-1)} + b^{(l)}_2 \\
&\vdots \\
\hat{z}^{(l)}_{N(l)} &= w^{(l)}_{N(l)1} a^{(l-1)}_1 + w^{(l)}_{N(l)2} a^{(l-1)}_2 + \cdots + w^{(l)}_{N(l)N(l-1)} a^{(l-1)}_{N(l-1)} + b^{(l)}_{N(l)}
\end{align*}
\]  

(20)

written in the form of matrix multiplication:

\[
\begin{pmatrix}
\hat{z}^{(l)}_1 \\
\hat{z}^{(l)}_2 \\
\vdots \\
\hat{z}^{(l)}_{N(l)}
\end{pmatrix} =
\begin{pmatrix}
w^{(l)}_{11} & w^{(l)}_{12} & \cdots & w^{(l)}_{1N(l-1)} \\
w^{(l)}_{21} & w^{(l)}_{22} & \cdots & w^{(l)}_{2N(l-1)} \\
\vdots & \vdots & \ddots & \vdots \\
w^{(l)}_{N(l)1} & w^{(l)}_{N(l)2} & \cdots & w^{(l)}_{N(l)N(l-1)}
\end{pmatrix}
\begin{pmatrix}
a^{(l-1)}_1 \\
a^{(l-1)}_2 \\
\vdots \\
a^{(l-1)}_{N(l-1)}
\end{pmatrix} +
\begin{pmatrix}
b^{(l)}_1 \\
b^{(l)}_2 \\
\vdots \\
b^{(l)}_{N(l)}
\end{pmatrix}
\]

(21)

that is:

\[
\hat{z}^{(l)} = w^{(l)} a^{(l-1)} + b^{(l)}.
\]  

(22)

Since \(a^{(l)} = \sigma(z^{(l)})\), we can conclude that

\[
a^{(l)} = \sigma(w^{(l)} a^{(l-1)} + b^{(l)})
\]  

(23)

where \(\sigma(x)\) denotes Activation Function, usually take \(\sigma(x) = \frac{1}{1+e^{-x}}\).

5.1.2 Error Analysis. The back propagation algorithm can be divided into three main layers, namely the input layer, the hidden layer and the output layer, and the relationship between them is shown in Figure 12.

\[x_1 \xrightarrow{\Delta z_j} x_2 \xrightarrow{\Delta a_j} x_3 \xrightarrow{\Delta C(\theta)} +1 \]

\[\text{Layer 1: Input Layer} \quad \text{Layer 2: Hidden Layer} \quad \text{Layer 3: Output Layer} \]

\[x_1^{(2)} \xrightarrow{+1} x_2^{(2)} \xrightarrow{+1} x_3^{(2)} \xrightarrow{+1} +1 \]

\[\text{Figure 12: Neural Network Hierarchy} \]
The error of the output layer has been found above, so for all neurons on the output layer, this can be represented as a vector form.

\[
\sigma^{(L)} = \begin{bmatrix} \sigma_1^{(L)} \\ \sigma_2^{(L)} \\ \vdots \\ \sigma_{N_L}^{(L)} \end{bmatrix} = \begin{bmatrix} \frac{\partial C(\theta)}{\partial a_1^{(L)}} \sigma'(z_1^{(L)}) \\ \frac{\partial C(\theta)}{\partial a_2^{(L)}} \sigma'(z_2^{(L)}) \\ \vdots \\ \frac{\partial C(\theta)}{\partial a_{N_L}^{(L)}} \sigma'(z_{N_L}^{(L)}) \end{bmatrix} = \nabla_{\theta} C(\theta) \odot \sigma'(z^{(L)})
\]

where \( \odot \) is the Hadamard Product (the product of the corresponding elements of the two matrices).

**Error in the Hidden Layer**

Because the error of the output layer has been found above, according to the principle of error back propagation, the error of the current layer can be understood as a composite function of the error of all neurons in the previous layer (the error of the previous layer is used to represent the error of the current layer, and so on).

\[
\delta_j^{(l)} = \frac{\partial C(\theta)}{\partial z_j^{(l)}} = \sum_{k=1}^{N_{l+1}} \frac{\partial C(\theta)}{\partial a_k^{(l+1)}} \frac{\partial a_k^{(l+1)}}{\partial z_j^{(l)}} = \sum_{k=1}^{N_{l+1}} \delta_k^{(l+1)} w_{kj}^{(l+1)} \sigma'(z_j^{(l)}) = \sum_{k=1}^{N_{l+1}} \delta_k^{(l+1)} w_{kj}^{(l+1)} \sigma'(z_j^{(l)})
\]

Similarly for all neurons in the hidden layer, it can be written in vector form.

\[
\delta^{(l)} = \begin{bmatrix} \delta_1^{(l)} \\ \delta_2^{(l)} \\ \vdots \\ \delta_{N_l}^{(l)} \end{bmatrix} = \begin{bmatrix} \sum_{k=1}^{N_{l+1}} \delta_k^{(l+1)} w_{k1}^{(l+1)} \sigma'(z_1^{(l)}) \\ \sum_{k=1}^{N_{l+1}} \delta_k^{(l+1)} w_{k2}^{(l+1)} \sigma'(z_2^{(l)}) \\ \vdots \\ \sum_{k=1}^{N_{l+1}} \delta_k^{(l+1)} w_{kN_l}^{(l+1)} \sigma'(z_{N_l}^{(l)}) \end{bmatrix}
\]

Through the above steps, we get the results and show them in table 11.

**Table 11: Results of Backward Propagation Algorithm**

| Indicators | EI | IDG | CEA | MA | HR | ER | SA |
|-----------|----|-----|-----|----|-----|----|----|
| Value     | 0.042 | 0.071 | 0.029 | 0.013 | 0.015 | 0.021 | 0.019 |

### 5.2 Pearson Correlation Analysis

#### 5.2.1 Basic Principles

Pearson correlation analysis is used to explore the correlation between world equity scores and each representative indicator of each country. The Pearson correlation coefficient between the two variables is defined by the equation 28:

\[
\rho(Eq_i, GDP) = \frac{\text{cov}(Eq_i, GDP)}{\sigma_{Eq_i} \sigma_{GDP}}
\]

Then we use equation 29 to calculate the correlation coefficient \( r \).

\[
r = \frac{\frac{1}{n} \sum_{i=1}^{n} (Eq_i - \bar{Eq}) (GDP_i - \bar{GDP})}{\sqrt{\frac{1}{n} \sum_{i=1}^{n} (Eq_i - \bar{Eq})^2} \sqrt{\frac{1}{n} \sum_{i=1}^{n} (GDP_i - \bar{GDP})^2}}
\]

Next, the correlation between the two variables is determined based on the \( r \) values. The principles are shown in figure 13.
As can be seen from figure 13, the closer the absolute value of r is to 1, the stronger the correlation between the two variables. Meanwhile, the positive or negative of r determines the positive or negative of the correlation.

5.2.2 Calculation Process

Take analysis of the correlation between GDP and countries’ equity scores as an example, through the analysis of the first question we know that the mean value of $E_{qk}$ is 34.7227. Then, we use equation 30.

$$\sigma_{E_{qk}} = \sqrt{\sum (E_{qk} - \bar{E}_{qk})^2}$$

$$= \sqrt{\sum (E_{qk} - 34.7227)^2}$$

$$= 5.7147$$

(30)

to get the variance is 32.6574 and the standard deviation is 5.7147.

Similarly, since the average value of GDP is 11540.8620, we substitute it into equation 31.

$$\sigma_{GDP} = \sqrt{\sum (GDP - \bar{GDP})^2}$$

$$= \sqrt{\sum (GDP - 11540.8620)^2}$$

$$= 11.9809$$

that is, the variance is 143.5418, the standard deviation is 11.9809.

Finally, we calculate the sum of the outlying product of the score and GDP by equation 32.

$$\text{cov}(E_{qk}, GDP) = \sum (E_{qk} - \bar{E}_{qk})(GDP - \bar{GDP})$$

$$= \sum (E_{qk} - 34.7227)(GDP - 11540.8620)$$

$$= 6.6509.$$  

The sum of the outlying product of the score and GDP is 6.6509. Substitute into equation 33.

$$\rho(E_{qk}, GDP) = \frac{\text{cov}(E_{qk}, GDP)}{\sigma_{E_{qk}} \sigma_{GDP}} = \frac{\sum_{i=1}^{n} (E_{qk} - \bar{E}_{qk})(GDP - \bar{GDP})}{\sqrt{\sum_{i=1}^{n} (E_{qk} - \bar{E}_{qk})^2} \sqrt{\sum_{i=1}^{n} (GDP - \bar{GDP})^2}}$$

$$= \frac{6.6509}{5.7147 \times 11.9809}$$

$$= 0.871$$

※ Test of Pearson’s Correlation Coefficient

After obtaining the correlation coefficient, we use the Pearson Correlation Coefficient Method to test it which using equation 34.

$$r = \frac{\sum_{i=1}^{n} (E_{qk} - 34.7227)(GDP - 11540.8620)}{\sqrt{\sum_{i=1}^{n} (E_{qk} - 34.7227)^2} \sqrt{\sum_{i=1}^{n} (GDP - 11540.8620)^2}}$$

$$= 0.78.$$ 

Next, we propose the hypothesis:

• $H_0 : P = 0$, score is not related to GDP;
• $H_1 : P \neq 0$, score is not related to GDP.

Meanwhile, we determine the corresponding significant level of 0.05.

Using equation 35, we obtain the value of r.

$$t_r = \frac{|r| - 0}{\sqrt{1 - r^2}/(n - 2)}$$

$$= \frac{0.78}{\sqrt{1 - 0.78^2}/(7 - 2)}$$

$$= 19.5894$$

Since we check the t-test adjacency table, we have obtain the threshold $P = 0.9$ and the linear correlation coefficient is 1.653. As a result, we accept the original hypothesis and deem that GDP has a significant impact on the global equity.

| Table 12: T-test Adjacency Table |
|----------------------------------|
| 0.25  | 0.1  | 0.05 |
| 100   | 0.677| 1.290| 1.660|
| 200   | 0.676| 1.653| 1.972|
| 500   | 0.675| 1.283| 1.648|

REFERENCES

[1] Egle Butkevičienė and Florian Rabitz. 2022. Sharing the Benefits of Asteroid Mining. Global Policy 13, 2 (2022), 247–258.
[2] Carol Dahl, Ben Gilbert, Ian Lange, et al. 2021. Prospects for mining asteroids: Into this world or out of the question. Technical Report.
[3] Francis X Diebold and Kamil Yilmaz. 2009. Measuring asset return and volatility spillovers, with application to global equity markets. The Economic Journal 119, 534 (2009), 158–171.
[4] Longjian Dong, Daoyuan Sun, Weiwei Sun, and Xibing Li. 2020. Exploration: Safe and clean mining on Earth and asteroids. Journal of Cleaner Production 257 (2020), 120899.
[5] Martin Ferus, Jano Zakba, Nikola Schmidt, and Alan Heays. 2022. Asteroid Prospecting and Space Mining. In Governance of Emerging Space Challenges. Springer, 217–232.
[6] Erika Frost, Gowtham Boyala, Adam Gremm, Ahmet Ungor, Amiroshin Taghipour, Massimo Biella, Jiawei Qu, Athip Thirupathi Raj, Arjun Chhabra, Adam Geer, et al. 2022. Project Khepr: Mining Asteroid Bennu for Water. (2022).
[7] Srdžar Gopinath, Nikhil Ghanathe, Vivek Seshadri, and Rahul Sharma. 2019. Compiling KB-sized machine learning models to tiny IoT devices. In Proceedings of the 40th ACM SIGPLAN Conference on Programming Language Design and Implementation. 79–95.
[8] Andreas M Hein, Michael Sadanii, and Hortense Tollia. 2018. Exploring potential environmental benefits of asteroid mining. arXiv preprint arXiv:1810.04749 (2018).
[9] Vide Hellgren. 2016. Asteroid mining: a review of methods and aspects. Student thesis series INES (2016).
[10] Volker Hessel, Nam Nghiop Tran, Sanar Orandi, Mahdreh Razi Asrami, Michael Goodsie, and Hung Nguyen. 2021. Continuous-Flow Extraction of Adjacent Metals—A Disruptive Economic Window for In Situ Resource Utilization of Asteroids? Angewandte Chemie International Edition 60, 7 (2021), 3368–3388.
[11] Matthew J Horsey, Kelly S Fielding, Emily A Harris, Paul G Bain, Tim Grice, and Cassandra M Chapman. 2022. Protecting the Planet or Destroying the Universe? Understanding Reactions to Space Mining. Sustainability 14, 7 (2022), 4199.
[12] Hongsheng Li, Rui Zhao, and Xiaogang Wang. 2014. Highly efficient forward and backward propagation of convolutional neural networks for pixelwise classification. arXiv preprint arXiv:1412.4526 (2014).
[13] Hongfu Liu, Ziping Wei, Hengsheng Zhang, Bin Li, and Chenglin Zhao. 2022. Tiny machine learning (Tiny-ML) for efficient channel estimation and signal detection. IEEE Transactions on Vehicular Technology 71, 6 (2022), 6795–6800.
[14] Kevin MacWhorter. 2015. Sustainable mining: Incentivizing asteroid mining in this world or out of the question. Understanding Reactions to Space Mining. Sustainability 14, 7 (2022), 4199.
[15] Alexiz Matter, Marco Delbo, Benoit Carry, and Sebastiano Ligori. 2013. Evidence of a metal-rich surface for the Asteroid (16) Psyche from interferometric observations in the thermal infrared. Icarus 226, 1 (2013), 419–427.
[16] Volkan Ogban and Murat Çak. 2022. The Public Frontier of Space: Reasons for State Intervention in Asteroid Mining. In Handbook of Research on Challenges in Public Economics in the Era of Globalization. IGI Global, 95–105.
[17] David L Olson. 2004. Comparison of weights in TOPSIS models. Mathematical and Computer Modelling 40, 7-8 (2004), 721–727.
[18] N Pashiouru and E Yalovik. 2021. Asteroid Mining. (2021).
[19] Brian Plancher and Vijay Janapa Reddi. 2022. TinyMLedu: The tiny machine learning open education initiative. In Proceedings of the 53rd ACM Technical Symposium on Computer Science Education V. 2, 1159–1159.

[20] Stelios Psarakis and J Panaretos. 1990. The folded t-distribution. Communications in Statistics-Theory and Methods 19, 7 (1990), 2717–2734.

[21] Haoyu Ren, Darko Anicic, and Thomas Runkler. 2022. How to Manage Tiny Machine Learning at Scale: An Industrial Perspective. arXiv preprint arXiv:2202.09113 (2022).

[22] Jung P Shim. 1989. Bibliographical research on the analytic hierarchy process (AHP). Socio-Economic Planning Sciences 23, 3 (1989), 161–167.

[23] Athulkrishna Shreya Mane. 2022. Asteroid Mining: Opportunities and Challenges. Eduzone: International Peer Reviewed/Refereed Multidisciplinary Journal 11, 1 (2022), 13–16.

[24] Olaf Steffen. 2022. Explore to Exploit: A Data-Centred Approach to Space Mining Regulation. Space Policy 59 (2022), 101459.

[25] Anthony J Taylor, Jonathan C McDowell, and Martin Elvis. 2022. Phobos and Mars orbit as a base for asteroid exploration and mining. Planetary and Space Science 214 (2022), 105450.

[26] Songyu Wang, Haochen Wang, Shilong Liu, and Jian Wen. 2022. Principal component analysis model of the impact of asteroid mining on global equity. In 2nd International Conference on Applied Mathematics, Modelling, and Intelligent Computing (CAMMIC 2022), Vol. 12259. SPIE, 715–720.

[27] Ruida Xie, Nicholas James Bennett, and Andrew G Dempster. 2021. Target evaluation for near earth asteroid long-term mining missions. Acta Astronautica 181 (2021), 249–270.

[28] Ruida Xie, Serkan Saydam, and Andrew Dempster. 2022. A framework for campaign level asteroid mining pre-feasibility study. In AIAA SCITECH 2022 Forum, 2583.

[29] Rui Lin Ye, Haoyi He, Yiqi Duan, Jiahe Liu, et al. 2022. Asteroid Mining Boom, Where Will Global Equity Go? Information Systems and Economics 3, 2 (2022), 11–17.

[30] Wei Zhang and Mo Guo. 2021(02):49-54. Analysis on Several Issues of Fair Taxation in Digital Economy. Tax Research (2021(02):49-54).