

# Vulnerability Index Based on Entropy Method under Climate Change

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**Abstract:** To evaluate the fragility of a state, we define the weighted average of GDP, net ODA received per capita, employment rate, population density and the number of intentional homicides as the fragility index. We calculate the weights by the entropy method and obtain the fragility indexes of 118 countries. To identify the fragility level of a state, we use K-means clustering analysis to divide the 118 countries into three categories. According to the value from high to low, we define the status as fragile, vulnerable or stable. The average of two critical fragility indexes for neighboring states is defined as the threshold of fragility index.

## 1. Introduction

Climate change will have significant negative impact on all around the world, including Africa, Asia, Australia, New Zealand, Europe, Latin America, North America, polar regions and small island areas. Some regions have more severely affected by climate change, including the polar region, the sub Saharan region of Africa, the small islands and the large River Delta region of Asia[1]. Climate change has an impact on the fragility of society. Many case studies have found that the fragility of climate change are highly associated with poverty[2]. The poverty-stricken area is the main impact area of climate change. Climate change through the impact on agricultural production, water resources, biodiversity, health and other aspects. Increasing the fragility of ecological environment which poor areas are facing, so that it brings more challenges for poverty alleviation work[3]. O'Brien and Leichenko proposed the "double exposure". The global politics and economic changes work with the climate risk interaction, it is also affect the livelihoods and development opportunities for specific populations. Thereby, redefining the "winners" and "losers", the global political and economic changes of the most vulnerable people may be most vulnerable to climate change[4].

## 2. Problem Analysis

In order to simplify the model and its calculation, we make the following assumptions:

- 1) The various factors affecting the national fragility are independent with each other, and not affect by each other.
- 2) The climate's various factors are independent with each other, and not affect by each other.
- 3) Climate's various factors on the assumption of climate said the fragility index can be superimposed.
- 4) The degree of association between the climate factors and all indexes affecting the fragility is unchanged. Because the correlation is the degree of similarity between the climate factors and the GDP index of the trend. If the emergency does not occur and change the development trend of climate factors or indexes, their changes are always similar.

### 3. Symbol Description

Table 1. Symbol Descriptio

Symbol	Description
$x_{ij}$	The $j^{th}$ indicator of the $i^{th}$ sample
$w$	Weight of GDP and other indicators
I	Fragility index
Z	The value of indicators (such as GDP) with climate change
Z'	The value of indicators (such as GDP) without climate change

### 4. Fragility Assessment Model

#### 4.1 Entropy Method

Entropy weight is an objective method of empowerment. We use the degree of variability of each index, it can calculate the entropy weight corresponding to each index by the information entropy<sup>[1]</sup>. Compared with AHP, entropy weight method reduces the subjectivity of weight determination and can better reflect the objective facts.

We assume that there are  $n$  evaluation objects,  $m$  evaluating indicators,  $x_{ij}$  is the  $j$ th indicator of the  $i$ th sample. The concrete steps of the entropy weight method are as follows<sup>[2]</sup>:

*STEP1: normalization:* Since the measurement units of various indexes are not unified, it is necessary to make standardized treatment before they are used to calculate the comprehensive index. In addition, the meaning of the positive and negative index values is different (the higher the positive index value is, which better it is. Hence, the negative index is the opposite situation). For them all, positive and negative indexes should use different algorithms to standardize the data.

Positive index:

$$x'_{ij} = \frac{x_{ij} - \min\{x_{1j}, \dots, x_{nj}\}}{\max\{x_{1j}, \dots, x_{nj}\} - \min\{x_{1j}, \dots, x_{nj}\}} \quad (1)$$

Negative index:

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

*STEP2: Calculate the proportion of the  $i^{th}$  sample value which of the  $j^{th}$  index::*

$$p_{ij} = \frac{x'_{ij}}{\sum_{i=1}^n x'_{ij}} \quad (3)$$

*STEP3: Calculate the entropy of the  $j$ th indexes::*

$$e_j = -k \sum_{i=1}^n p_{ij} \ln(p_{ij}), \quad j = 1, \dots, m \quad (4)$$

*STEP4: Calculate the redundancy of the information entropy:*

$$d_j = 1 - e_j, \quad j = 1, \dots, m \quad (5)$$

*STEP5: Calculate the weight of each index:*

$$w_j = \frac{d_j}{\sum_{j=1}^m d_j}, \quad j = 1, \dots, m \quad (6)$$

#### 4.2 Fragility Assessment Model

First, we understand indices and use the entropy weight method to determine the weight. In

terms of economy, we choose the National Net ODA received per capita (current US\$), GDP(current US\$) and employment rate. On the safety side, we choose Intentional homicides. In the social aspect, we consider the influence of the population density.

The National Net ODA received per capita, GDP, employment rate, Intentional homicides and the population density have contained the influence of climate change. Hence, the entropy weight method evaluation model which constructed by the five indicators we selected, is considering about the climate change.

We import the latest data[3] of five indicators into MATLAB and use the steps of the entropy weight method above. Then, we obtain the weight of the National Net ODA received per capita, Intentional homicides, the population density employment rate, GDP(current US\$), that is  $w = \{0.274554, 0.16082, 0.162131, 0.03714, 0.365356\}$ .

Then, we normalize the values of five indicators for each country. Similarly, we assume that there are  $n$  evaluation object,  $m$  evaluating indicators, let  $x_{ij}$  denote the  $j$ th indicators of the  $i^{th}$  sample. The fragility index of the  $i^{th}$  country  $I_i$  is

$$I_i = 100 \times \sum_{j=1}^m q_{ij} w_j, \quad i = 1, \dots, n \quad (7)$$

where,

$$q_{ij} = \frac{x_{ij}}{\sum_{j=1}^m x_{ij}}, \quad i = 1, \dots, n$$

The fragility index of all countries is in Table 1, then we use the SPSS software to analyze the fragility index by K-MEANS cluster analysis and select the average value of two index data as the dividing line to identify the boundaries of a country's fragility. Results show that, if the fragility index is in the range of 20.41 to 93.5, then the country is vulnerable; if the index is higher than 93.5, then the country is fragile; if the index is lower than 20.1, then the country is stable.

### 4.3 Climate Change Impact Measure Model

The evaluation model which was constructed directly including the impact of the climate change. Therefore, if we want to measure the impact of climate change on national fragility, the key is to remove the impact of the climate change in the evaluation model, compare with GDP and other indicators without the climate impact, and the numerical change of climate indicators. We consider the influence of the climate change on annual precipitation (mm), annual mean temperature (°C), grain yield (kg/ hectare) and forest area (percentage).

#### 4.3.1 The Degree of Grey Incidences

As usual, we use the grey correlation method to measure the close connection degree between two factors when information is incomplete or uncertain. The greater the correlation is, the greater the correlation is between them. On the contrary, the smaller the index of GDP is, the more uncertain factors are. In this question, the indices we choose, like GDP, are affected by a variety of uncertain factors. The factors which determine the indices are complicated (not just including climatic factors). Therefore, we use grey correlation analysis to measure the relationship between climatic factors and indicators.

The basic steps of grey correlation analysis are as follows [9]:

**STEP1** : Determine the comparison object and the standard data array.

We assume that there are  $m$  evaluation objects, and  $n$  evaluation indices,

Reference Series is  $x_0 = \{x_0(k) | k = 1, 2, \dots, n\}$ ,

Comparison series is  $x_i = \{x_i(k) | k = 1, 2, \dots, n\}$ ,  $i = 1, 2, \dots, m$  Let  $i$  denotes the object of evaluation.

**STEP2**: Calculate the grey correlation coefficients

$$\xi_i(k) = \frac{\min_s \min_t |x_0(t) - x_s(t)| + \rho \max_s \max_t |x_0(t) - x_s(t)|}{|x_0(k) - x_i(k)| + \rho \max_s \max_t |x_0(t) - x_s(t)|} \quad (8)$$

Where,  $\rho \in [0,1]$  is a resolution factor.

**STEP3:** Calculate The Degree of Grey Incidences

$$r_i = \frac{1}{n} \sum_{k=1}^n \xi(k) \quad (9)$$

### 4.3.2 Remove the Effects of the Climate Change

The grey correlation degree represents the association degree between two factors. The greater the grey correlation degree, the closer the two factors. So as to, the greater the impact of one factor on another. We import four factors which reflect the climate change, and the index data that affect the national fragility into MATLAB. In order to calculate the correlation degree between climatic factors and indicators. So as to, we obtain an incidence matrix. Each of the elements represents the degree of association of the row factors corresponding, respectively. As shown by Table 3..

The greater the correlation is, the closer the relationship between climatic factors and indicators is. Consequently, we regard the value of grey correlation as the influence of each climatic factor on the corresponding index. We only consider that the climate change is an inactive effect of climate. Like: the decrease of forest area, the reduction of grain yield, the reduction of precipitation and the increase of temperature. When we remove climatic factors, the positive index will increase, meanwhile, the reverse index will decrease. Therefore, each element in the matrix is  $a_{ij}$ . Let  $Z$  denote the indicators for climate impact, let  $Z'$  denote the index that after removing the impact of climate,  $A$  represents the  $a$  index. Let  $i$  denote  $i^{th}$  indicator.

For Positive term index:

$$Z_i' = \frac{Z_i}{\prod_{j=1}^4 a_{ij}}, \quad i = 1, 3, 4, 5 \quad (10)$$

For Negative term index:

$$Z_i' = Z_i \cdot \prod_{j=1}^4 a_{ij}, \quad i = 2 \quad (11)$$

What we can see is that, climate change will affect the values of GDP etc. Then, it will affect fragility. In other words, the climate indirectly affects one country's fragility by influencing the values of GDP and other indicators. We can obtain the indicators before and after the climate impact. Meanwhile, it reflects the impact of climate change on various indicators.

## 5. Analysis of Yemen

### 5.1 How Climate Change Influence Fragility

By using the model of us, we put the indicators of Yemen (Table 4) into type (10), (11). Then, we obtain the values of every index before the impact of climate change, which is comparing each index data before and after and will be affected by the weather. Shown as Figure 1 to Figure 6.



Figure 1 The impact of climate change on net income per cap



Figure 2 The Impact of Climate Change on Intentional Homicide

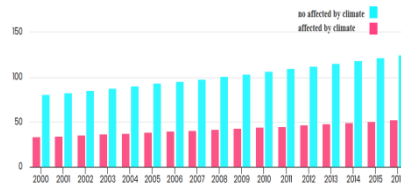


Figure 3 Impact of climate change on population density



Figure 4 The Impact of Climate Change on Employment

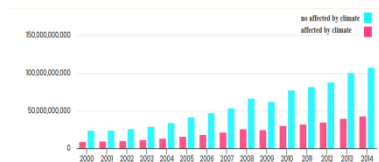


Figure 5 The impact of climate change on GDP

## 5.2 How to be less fragile

Based on the fragility assessment model, we can see that without the indirectly influence of climate factors, the direct index of fragility can be changed to make the country less fragility.

- The government introduced to encourage trade policy or change the industrial structure to improve GDP.
- The introduction of population policy. Then, population density change.
- Enact and improve laws and regulations, in order to decreasing the number of criminal cases
- By increasing expenditure to increase employment and improve the employment rate.

It is known from the weight  $w = \{0.274554, 0.16082, 0.162131, 0.03714, 0.365356\}$ , that the economic growth of GDP and net income per capita have the most significant impact on reducing vulnerability.

## 6. State Driven Interpretation

There are many countries in order to reduce the risks of climate change over the world. Various countries take different measures, such as: the reform and restructuring of energy production industry in South Africa, introduced the hydropower and natural gas to promote the diversification of energy supply; Japan, through the government subsidies, tax incentives and etc. to both develop environmental protection and economic goals. Here, we take China as an example to introduce how China can reduce the risk of climate defense by means of reasonable measures, and then reduce the fragility of the country.

In order to reduce the negative effects of climate change, China has taken many measures. We

mainly study the adjustment of industrial structure, the influence of afforestation and the two-child policy. According to the fragility assessment model we have constructed, these policies affect GDP and population density indicators. Also, we change the forest coverage in climate factors.

### 6.1 Industrial Restructuring

Starting in late 1980s, Chinese government pays more attention to the transformation of economic growth mode and the adjustment of economic structure. These acts will reduce the consumption of resources and energy, promote cleaner production and industrial pollution prevention and control as an important part of China industrial policy. Through the implementation of a series of industrial policies, accelerate the development of the third industry, adjust the structure of the second industry, make the structure of industry has undergone significant changes. The proportion of the first industry continued to decline, the third industry has made great progress, especially in telecommunications, tourism, finance and other industries. Although, the proportion of the second industry has increased, the internal structure of the industry changes. The rapid development of electronic information, machinery, and other industries to improve the products with high proportion the added value of the industrial structure change to Chinese profit is quite big, mainly in the following two aspects<sup>[10]</sup>:

- Increased the employment rate. Chinese employment rate will increase by 6.78 percent each year, because of the adjustment.
- After the industrial adjustment, Chinese GDP will get a big increase each year.

First of all, we analyze the impact of increasing employment rate on Chinese fragility: based on the data of Chinese original employment rate, we expand the annual data by 6.78%, and get a set of new employment rates affected by the industrial structure. Taking the employment rate into the fragility assessment model, a set of fragility data.such as Figure 7 obtained.

In the same way, we get the GDP data that is affected by the industrial structure on the basis of the percentage of the industrial structure adjustment of GDP in China. Taking this data into our fragility assessment model, we obtain the fragility data under the influence of another group of industrial structures. As shown by Figure 6

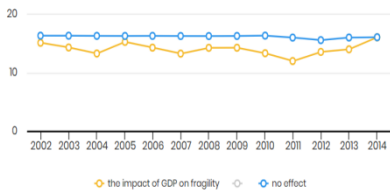


Figure 66 The impact of the change of employment rate on fragility

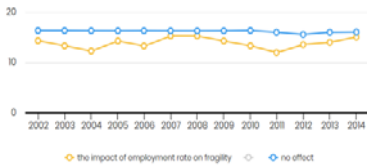


Figure 7 The impact of the change of employment rate on fragility

### 6.2 Afforestation

According to the sixth Chinese forest resource survey report, artificial afforestation Chinese preservation area reached 54 million hectares, volume 1 billion 505 million cubic meters, plantation area ranks first in the world. The national forest area reached 174 million 910 thousand hectares, the forest coverage rate from early 13.92% in 1990s increased to 18.21%. According to the experts estimated, from 1980 to 2005, China afforestation activities cumulative net absorption of about 30.6 million tons of carbon dioxide, forest management cumulative net absorption of 16.2 tons of carbon dioxide, and reduce 4.3 tons of carbon dioxide emissions from deforestation<sup>[12]</sup>. Thus, afforestation risk plays a significant role in climate change.

We calculate and predicte the cost of future index forestation in China based on the area of

afforestation and the cost of per hectare in recent years, such as Figure 8.

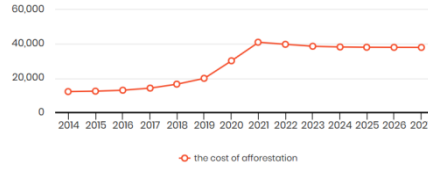


Figure 7 Government tree planting costs

### 6.3 The Two-child Policy

China began to open the two-child policy in 2016. The opening of the two-child policy will inevitably increase the number of Chinese population and increase population density, which will ultimately affect the fragility of the country.。

According to the available data, we obtain the population data<sup>[15]</sup> and the number of without opening the two-child policy<sup>[13]</sup>. We predict the number of future population based on the existing data. We use it to make a contrast with the open the two-child policy of the population, and obtain the population growth rate in the two-child policy situation, now and in the future some years. Then, we get population density, growth rate, and the population density of new data by two-child policy under the influence of the growth rate. Ultimately, we obtain the fragility of the country under the two-child policy.

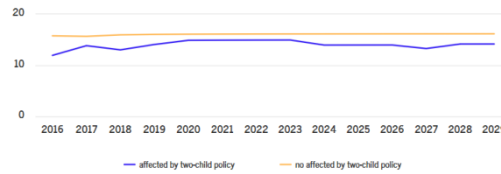


Figure 9 Fragility under the influence of a second child

## 7. Sensitivity Analysis

### 7.1 Sensitivity Analysis of Fragility Assessment Model

Since data statistics may be distorted, we need to analyze the impact of the data changes on the results of the model. We use MATLAB to increase the random disturbance to the number of input indexes, such as: GDP in the fragility assessment model and change it to the original 90%~100%. Then, we obtain the new fragility index. Shown in Table2.

Table 2. The change of value after distribution

	No disturbance	The first disturbance	The second disturbance	The third disturbance
Tanzania	7.79	7.09	7.38	7.22
Uruguay	11.58	11.07	11.42	11.37
Uzbekistan	9.62	9.22	9.61	9.32

### 7.2 Sensitivity analysis of the Climate Change Impact Measure Model

The corresponding changes from 90% to 100%, GDP and other indexes of the grey relational degree in the model have been changed. The result is shown in Table 3

Table 3. The change of value after distribution

	No disturbance	The first disturbance	The second disturbance	The third disturbance
Net ODA received per capita	13.8	15.15	14.89	15.13
Intentional homicides	0.7	0.77	0.76	0.77
Population density	74.32	81.61	80.2	81.5
Employment rate	42.2	46.34	45.54	46.28
GDP	82924503943	91060527608	89490172721	90937616215

## 8. Strengths and Weakness

### 8.1 Strengths

- The establishment of a national fragility evaluation standard, only need to know a few specific indicators of the country, they can determine the fragility of the country
- The calculation model is simple, strong generalization ability
- The establishment of a national fragility evaluation standard
- The application of entropy method to avoid the influence of subjective weights
- The response of the climate of our model can clearly influence the degree of fragility index for each

### 8.2 Weakness

- The measurement for the time limit, the climatic influence on the fragility of the model without the accuracy of test results may have deviation
- due to data limitations, our model considering the influencing factors, the national fragility number is too small, will affect the fragility evaluation.

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