National Fragile Degree of Climate Change Based on Catastrophe Progression Method and Correlation Analysis

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Abstract. Nowadays, more and more attention is focused on climate change and environmental problems which are caused by human factors. In the meantime, climate change is directly or indirectly affecting the development of countries. There are plenty articles, which provide the definition about vulnerability of countries, have analyzed and evaluated the climate influence on different area. Quantitative index, however, are not obtained to reflect the impact of climate change on countries globally. This paper will discover the relationship between climate change and national fragile degree by using catastrophe progression method. Five levels of fragile degree are set to evaluate the national condition. After analyzing climate factors the precipitation, mean temperature and CO\textsubscript{2} emissions are the biggest factors which have dominant influence on national fragile degree. Then linear regression is used to establish precipitation-mean temperature-CO\textsubscript{2} emissions model (PMC), which shows how these factors affect fragile degree and how to reduce the effect.

1. Introduction
A fragile state is a low-income country characterized by weak state capacity and/or weak state legitimacy leaving citizens vulnerable to a range of shocks. While many countries are making progress toward achieving the Millennium Development Goals, a group of 35 to 50 countries (depending on the measure used) is falling behind. Climate change is basically a development issue, which should overall coordinate with economic growth, social development and environmental protection has a lot to do with the national stability and development of a country. As the important key to state development, climate change may be caused by internal progress of nature or external influence like human intervention. This paper chooses several countries to establish the relevant between climate changes with the indicators which can evaluate and reflect the state of the country.

2. Method and data
2.1. Catastrophe progression method
Catastrophe progression method is a kind of multi-level contradiction of evaluation target decomposition which combined with catastrophe theory and fuzzy mathematics mutations fuzzy membership function. Common types of mutant systems are fold catastrophe, cusp catastrophe, swallowtail catastrophe, and butterfly catastrophe. The normalization formulas are shown in Table 1.
Table 1. Normalization formulas

| Forms       | Dimensions of control space | Potential function                          | Normalization formula                  |
|-------------|-----------------------------|---------------------------------------------|----------------------------------------|
| Fold        | 1                           | $V(x)=1/3x^3 + ax$                          | $X_a = a^{1/2}$                        |
| Cusp        | 2                           | $V(x)=1/4x^4 + 1/2ax^2 + bx$                | $X_a = a^{1/2}$, $X_b = b^{1/3}$       |
| Swallow tail| 3                           | $V(x)=1/5x^5 + 1/3ax^3 + 1/2bx^2 + cx$     | $X_a = a^{1/2}$, $X_b = b^{1/3}$, $X_c = c^{1/4}$ |
| Butterfly   | 4                           | $V(x)=1/6x^6 + 1/4ax^4 + 1/3bx^3 + 1/2cx^2 + dx$ | $X_a = a^{1/2}$, $X_b = b^{1/3}$, $X_c = c^{1/4}$, $X_d = d^{1/5}$ |

2.1.1. Fragile degree index construction.

Climate change is caused by several factors which are either natural elements or human activities. In order to analyze how climate change may affect national situation, 11 factors are chosen to reflect the climate and environment of countries, which are divided into two levels. The first level is human activities and the second level is natural factors. The factors are shown in Table 2. The catastrophe model is shown in Figure 1. To obtain a relatively uniform dimension, each index is normalized by a range standardization method. Indicators positively related to fragile degree are transformed by Eq. (1), and indicators negatively related to fragile degree are transformed by Eq. (2).

\[ S_i = \frac{(X_i - X_{\text{min}})}{(X_{\text{max}} - X_{\text{min}})} \]  \hspace{1cm} (1)

\[ S_i = \frac{(X_{\text{max}} - X_i)}{(X_{\text{max}} - X_{\text{min}})} \]  \hspace{1cm} (2)

$X_i$ is the original value of index $i$, $X_{\text{min}}$ and $X_{\text{max}}$ are the minimum and maximum values of $X_i$. $S_i$ is the standard values of index $i$, and $S_i \in [0,1]$.

The data in this paper are derived from The World Bank data and Fragile States Index of Fund for Peace website. 263 countries are analyzed which data of climate are obtained. Each index should be evaluated for a period of time so the data from 1996 to 2015 are selected. According to the geographical location and the available data, 172 countries are selected to analyze the national fragile degree, which are including countries with different climates and geographic environments.

Table 2. Index system of fragile degree

| Element                  | No | Items              | No | Indices             | No |
|--------------------------|----|--------------------|----|---------------------|----|
| Human activities         | A1 | air                | B1 | CO2 emissions       | C1 |
|                          |    |                    |    | PM2.5 air pollution | C2 |
|                          |    | land               | B2 | agricultural area   | C3 |
|                          |    | Fresh water        | B3 | Forest area         | C4 |
| Natural factors          | A2 | population growth  | B4 |                     |    |
|                          |    | precipitation      | B5 |                     |    |
|                          |    | mean temperature   | B6 |                     |    |
|                          |    | fauna              | B7 | bird threatened     | C5 |
|                          |    |                    |    | fish threatened     | C6 |
|                          |    |                    |    | mammal threatened   | C7 |
2.1.2. Determination of evaluation criteria.

Since it is difficult to define the fragile degree by abstract conceptions like fragile, vulnerable or stable, the grade criteria suitable for catastrophe progression method should be developed. The fragile degree is divided into five levels, which are high level, medium high level, medium level, medium low level and low level. It is assumed that when the corresponding relative membership of the underlying control index is \( X_i \) (\( X_i = 0/0.33/0.67/1 \)), the total degree of membership can obtained by catastrophe progression method. The grade criteria are shown in Table 3.

Table 3. Grade criteria of fragile degree

| Grade | Fragile degree | General value | Catastrophe progression method |
|-------|----------------|---------------|--------------------------------|
| I     | Stable         | 0.67~1        | Total value: 0.95~1            |
|       |                |               | A1: 0.92~1                     |
|       |                |               | A2: 0.88~1                     |
| II    | Vulnerable     | 0.33~0.67     | Total value: 0.87~0.95         |
|       |                |               | A1: 0.80~0.92                  |
|       |                |               | A2: 0.73~0.88                  |
| III   | Fragile        | 0~0.33        | Total value: 0~0.87            |
|       |                |               | A1: 0~0.80                     |
|       |                |               | A2: 0~0.73                     |

2.1.3. Evaluation results and analysis.

Through the catastrophe progression method, national fragile degree is calculated for each country selected. Then countries are divided into five levels. There are about 5.8% countries are in the stable level. There about 34.8% countries are in the vulnerable level. China is in this level, which may due to the vast land area and complex geographic environment, the various climate change as well as massive environmental problems need more attention. There are 59.4% countries are in the fragile degree level. Countries like Finland and Sweden have low fragile degree which can be the other countries’ study and the model object.

2.2. The Correlation Analysis and Precipitation-Mean Temperature-CO2 Emissions Model (PMC)

Climate change affects a country in many ways, thus affecting the fragility of the country. This influence can be divided into two kinds: directly and indirectly. To measure the impact of climate change, this paper thought that climate change can directly affect the data of agriculture such as the index of precipitation and mean temperature in the World Bank, and indirectly affect the data of economy and political such as GDP.

2.2.1. The Correlation Analysis.

First of all, in order to develop the model \( y = \beta_0 + \beta_1 x_1 \), this paper chooses 10 states randomly. In addition to the Fragile States Index (FSI), other climatic data such as Precipitation (Pre) and Droughts-floods-extreme temperatures (ET), and agricultural data such as Crop Production index (CP), cereal yield (CY), arable land (CL) and GDP of each country were extracted, and the correlation analysis was carried out in SPSS analysis software. Results are in Figure 2.
The correlation between the Precipitation (Pre) and the 9 data of FSI and cereal yield (CY) is significant, which directly make the influence of climate for FSI. The correlation between precipitation and GDP has also passed a significant test, which is the indirect influence between the climate and the economy for FSI.

2.2.2. PMC Model.
It shows that extreme temperatures (ET) are not significant to the 12 indexes of FSI, probably because the World Bank's record update on this item lags behind. For this reason, the paper extracted two environmental factors, Mean Temperature (MT) and CO2 Emissions (CO2) from the World Bank, together with the Precipitation; build the PMC model \( y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 \), and uses Eviews to build the FSI model. Results are in Table 4. The indexes are shown with the symbol: PMC(y) means Precipitation-Mean Temperature-CO2 emissions, Pre(x1) means Precipitation, ET means Extreme Temperature, MT(x2) means Mean Temperature, CO2(x3) means CO2 emissions.

| Variable | Coefficient | Prob. | Result |
|----------|-------------|-------|--------|
| C        | 121.6554    | 0.0002| Pass   |
| X1       | -0.011401   | 0.0253| Pass   |
| X2       | -1.558878   | 0.0479| Pass   |
| X3       | 0.000828    | 0.0080| Pass   |

The result shows that the p-value is less than 0.05 which passed the significant test, the PMC model is successful. \( y = 121.6554 - 0.011401 x_1 - 1.558878 x_2 + 0.000828 x_3 \)

2.2.3. Level of fragility with climate change factor index (LFC).
Combining the catastrophe progression method and Precipitation-Mean Temperature-CO2 Emissions Model (PMC) model, unknown type of states can be sorted and their fragile degree as well as climate affection can be estimated. By synthesizing and putting the countries’ data into model, FSI tipping tops are summarized to determine the FSI grade. The FSI grade is shown in Table 5.

| Variable | Coefficient | Prob. | Result |
|----------|-------------|-------|--------|
| Adjusted R-squared | 0.824022 |        |        |
Table 5. FSI grade

| FSI grade | FSI     |
|-----------|---------|
| Stable    | <62.2   |
| Vulnerable| 62.7~102.2 |
| Fragile   | >102.2  |

3. Example analysis
The total of fragility reflects the general fragile degree of Afghanistan from 2006 to 2017. The higher total number is, the more fragile country is. The data shows that 2010 is the year in which Afghanistan is the most fragile. However, the ranking in 2010 is the same as it in 2012 of all the countries. So there have to be some other factors that influence the fragility of all countries. From our research we deem that weather have an effect on it most likely, especially the rainfall and the temperature.

According to the model, CO2 emissions are positively correlated with the total of fragility and the data has high consistency, which will increase the fragility of the country. In addition, precipitation has negative effects on the fragile degree of the country. Besides, the temperature is negatively correlated with the total of fragility from 2006 to 2009, while it is positively correlated with the total of fragility after that, which has complicate relationship with fragility.

In order to investigate the impact of improving precipitation, average temperature and CO2 emissions on fragility in Afghanistan, the data is changed to put into model and evaluate the changes. The average precipitation of Afghanistan to the world average is raised of 1156.59 mm, and numerical value of FSI reduced from 104.24 to 94.57. The average temperature is raised to the average temperature of 14.68℃ and the numerical value of FSI reduces from 104.24 to 94.57. CO2 emissions are increased to the global average of 36288.09 and the numerical value of FSI rises from 104.24 to 104.24. By comparing the data with FSI grade, Afghanistan will become less fragile when raising the average precipitation and the average temperature, while becoming more fragile when the CO2 emissions are raised. The range of the data changing shows that average temperature and CO2 emissions have much more influence on national fragile degree, which should be pay more attention to improve the situation of countries.

4. Conclusion
A fragile state is one where the state government is not able to, or chooses not to provide the basic essentials to its people. The climate change, including increased temperature and CO2 emissions, will directly influence or change the way of life of human beings, thus changing the fragility of a country. For example, the rising of temperature will cause increased droughts, reduce the vitality of plants and animals, which will affect the country’s annual crop output and GDP. At the same time, it will increase the death rate of a country’s population and changing the proportion of the country’s available Labor, which changes the fragility of the country as well. And the increase of co2 emissions, affect plant and animal survival, to a certain extent has also changed the fragility of the country.

To reduce the country's fragility, here are four suggestions. Firstly, the state should save energy, improve energy utilization efficiency, develop clean energy, plant trees, and use land rationally. Secondly, the agricultural sector should accelerate the improvement of crop varieties, adjust the structure and distribution of the food industry, and develop water-saving agriculture. Thirdly, the state shall strengthen the management of water resources, save water while using, and develop the air-water resources. At last, the government should improve the public health infrastructure and establish an early-warning system for diseases caused by climate change.

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