Climate Change Influences Regional Instability

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Abstract. We establish a Multiple Linear Regression Model to study the relationship between climate change and national vulnerability. Meanwhile, put forward the state driven interventions and estimate the total cost to reduce the national vulnerability.

1. Introduction
In the context of global climate change, we use the linear regression to analyze and predict national vulnerabilities. Assume that the climate change is only measured by temperature and precipitation, the temperature is defined as (0, 40°C). Then, we:

- Establish a multiple regression model to measure the country’s vulnerability.
- Select a most fragile country, Syria, and a vulnerable country, China, to test it.
- Forecast the total cost, and analyze the sensitivity of the model.

2. Terms and Definitions

| Symbol  | Symbolic meaning                      | Unit    |
|---------|---------------------------------------|---------|
| AMT     | Average Monthly Temperature           | °C      |
| T       | Temperature                            | °C      |
| P       | Precipitation                          | mm      |
| ŷ      | Predicted value of Fragile States Index| -       |
| FSI     | Fragile States Index                   | -       |

3. Multivariate Linear Regression Model

3.1. MY FSI
The Peace Fund provides four aspects, namely: 1) safety indicators, 2) economic indicators, 3) political indicators, 4) social indicators. Assuming the 12 index values are: X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, X_9, X_{10}, X_{11}, X_{12}, (0 ≤ X_i ≤ 10), and the weights are the same.
Table 2 Vulnerability level

| Index | State   |
|-------|---------|
| ∑₁≤ᵢ≤₂ Xᵢ ∈ (0, 60) | stable  |
| ∑₁≤ᵢ≤₂ Xᵢ ∈ (60, 90) | vulnerable |
| ∑₁≤ᵢ≤₂ Xᵢ ∈ (90, 120) | fragile   |

3.2. Model Establishment

Establish a Binary Linear Regression Model, \( y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 \). \( \beta_0, \beta_1, \beta_2 \) are the regression coefficients, \( y \) is the predicted value. Obtain \( n \) sets of independent observation data \((y_i, x_{i1}, x_{i2})\). \n
\[
\begin{align*}
Y_i &= \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \varepsilon_i \\
\varepsilon_i &\sim N(0, \sigma^2), i = 1, 2, \\
X &= \begin{bmatrix} x_{i1} \\ x_{i2} \end{bmatrix}, Y &= \begin{bmatrix} y_i \end{bmatrix} \\
\end{align*}
\]

Finally, we get

\[
\begin{align*}
\varepsilon &= [\varepsilon_1 \cdots \varepsilon_n]^T, \\
\beta &= [\beta_0 \beta_1 \beta_2]^T, \\
Y &= X\beta + \varepsilon_i, \\
\varepsilon &\sim N(0, \sigma^2 E_n) \\
\end{align*}
\]

Where \( E_n \) is an \( n \)-th unit matrix.

The parameters \( \beta_0, \beta_1, \beta_2 \) can be estimated by the least squares method, so

\[
\begin{align*}
Q &= \sum\varepsilon_i^2 = (y_i - \beta_0 - \beta_1 x_{i1} - \beta_2 x_{i2})^2 \\
\frac{\delta Q}{\delta \beta_j} &= 0, j = 0, 1, 2 \\
\end{align*}
\]

To get the normal equations

\[
\begin{align*}
2\beta_0 &+ \beta_1 \sum_{i=1}^{n} x_{i1} + \beta_2 \sum_{i=1}^{n} x_{i2} = \sum_{i=1}^{n} y_i \\
\beta_0 \sum_{i=1}^{n} x_{i1} + \beta_1 \sum_{i=1}^{n} x_{i1}^2 + \beta_2 \sum_{i=1}^{n} x_{i1} x_{i2} = \sum_{i=1}^{n} x_{i1} y_i \\
\beta_0 \sum_{i=1}^{n} x_{i2} + \beta_1 \sum_{i=1}^{n} x_{i1} x_{i2} + \beta_2 \sum_{i=1}^{n} x_{i2}^2 = \sum_{i=1}^{n} x_{i2} y_i \\
\end{align*}
\]

The formal form of the matrix is \( X^T X \beta = X^T Y \). Get \( \hat{\beta} = (X^T X)^{-1} X^T Y \) when the matrix column is out of rank. Thus a linear regression equation is obtained.

3.3. Model Solution

We will take July and December as examples because of the seasonal differences.
Taking it to $\hat{y} = \beta_0 + \beta_1 T + \beta_2 P$, the solution for July is $\beta = [-79.6, 7.2, -1.3]^T$, for December is $\beta = [-82.8, 8.9, -1.7]^T$, they are. So the seasonal difference has little effect.

3.4. Model Analysis
Temperature has a linear relationship with the national vulnerability index. The increase of Lack of water, epidemics and other secondary disasters, may make some oases disappear.

3.5. Model Test
3.5.1. Take Syria as an example. We take data from 2006 to 2017 12 years as an example.

| Table. 3 July data | AMT  | P    | FSI  |
|--------------------|------|------|------|
| Yemen              | 31.369 | 25.254 | 111.1 |
| Turkey             | 2.445  | 80.653 | 80.8  |
| Australia          | 26.56  | 52.69  | 22.3  |

| Table. 4 December data | AMT  | P    | FSI  |
|------------------------|------|------|------|
| Yemen                  | 21.571 | 7.635 | 111.1 |
| Turkey                 | 22.324 | 31.611 | 80.8  |
| Australia              | 14.897 | 24.586 | 22.3  |

Taking it to $\hat{y} = \beta_0 + \beta_1 T + \beta_2 P$, the solution for July is $\beta = [-79.6, 7.2, -1.3]^T$, for December is $\beta = [-82.8, 8.9, -1.7]^T$, they are. So the seasonal difference has little effect.

| 2006  | 2007  | 2008  | 2009  | 2010  | 2011  |
|-------|-------|-------|-------|-------|-------|
| $T$   | 29.611 | 31.129 | 30.637 | 30.177 | 31.278 | 31.106 |
| $P$   | 0.58  | 0     | 0.32  | 0.44  | 0.62  | 0.31  |
| $\hat{y}$ | 90   | 89.6  | 91    | 89.8  | 86.9  | 85.7  |
| $FSI$ | 88.6  | 88.6  | 90.1  | 89.8  | 87.9  | 85.9  |

| 2012  | 2013  | 2014  | 2015  | 2016  | 2017  |
|-------|-------|-------|-------|-------|-------|
| $T$   | 31.382 | 29.777 | 30.472 | 31.722 | 32    | 31.321 |
| $P$   | 0     | 0.11  | 0.23  | 0     | 0.42  | 0.14  |
| $\hat{y}$ | 94.5 | 97    | 101.8 | 101.8 | 110   | 111   |
| $FSI$ | 94.5  | 97.4  | 101.6 | 107.8 | 110.8 | 110.6 |

| 2006  | 2007  | 2008  | 2009  | 2010  | 2011  |
|-------|-------|-------|-------|-------|-------|
| $T$   | 7.237  | 9.232  | 9.232  | 10.691 | 10.265 | 9.41  |
| $P$   | 51.326 | 54.336 | 52.834 | 51.327 | 52.432 | 52.342 |
| $\hat{y}$ | 89.6 | 88.9  | 89.3  | 90.3  | 89.1  | 86.7  |
| $FSI$ | 88.6  | 88.6  | 90.1  | 89.8  | 87.9  | 85.9  |

| 2012  | 2013  | 2014  | 2015  | 2016  | 2017  |
|-------|-------|-------|-------|-------|-------|
| $T$   | 9.12  | 8.523  | 9.024  | 8.762  | 8.342  | 9.235 |
| $P$   | 50.232 | 51.424 | 50.243 | 51.453 | 51.241 | 50.271 |
| $\hat{y}$ | 95.2 | 96.8  | 102   | 110.8 | 109.9 | 110.5 |
| $FSI$ | 94.5  | 97.4  | 101.6 | 107.8 | 110.8 | 110.6 |
The national vulnerability index has ties with climate change, we further analyze:

As can be seen from the figures, the monthly average temperature in Syria has been gradually increasing from 2006 to 2010, resulting in strong evaporation in arid and semiarid regions and large amount of water loss, aggravating the degree of drought.

The population and the CO$_2$ emission are on the rise. The population plunges around 2012, maybe due to the increase of population and drought.

3.5.2. Taking China as an example
We take data from 2006 to 2015 into the regression equation $\hat{y} = \beta_0 + \beta_1 T + \beta_2 P$. 
As can be seen from the figure 7 and 8, the climate has a very close relationship with China’s national vulnerability index. The predicted values calculated from temperature and precipitation are basically in line with the FSI values of the United States Peace Fund. When climate change is greater, the country’s production will be affected, causing political turmoil in the country and slow economic growth. Eventually leading to an increase in the national fragility index.

**Table. 7** July data, China

|       | 2006 | 2007 | 2008 | 2009 | 2010 |
|-------|------|------|------|------|------|
| $T$   | 23   | 22.9 | 23.2 | 23.3 | 22   |
| $P$   | 200  | 210  | 195  | 188  | 231  |
| $\hat{y}$ | 81.9 | 80   | 82.3 | 84.3 | 82.1 |
| $FSI$ | 82.5 | 81.2 | 80.3 | 84.6 | 83   |

|       | 2011 | 2012 | 2013 | 2014 | 2015 |
|-------|------|------|------|------|------|
| $T$   | 23.3 | 24   | 23.5 | 24.2 | 23.5 |
| $P$   | 217  | 209  | 180  | 192  | 204  |
| $\hat{y}$ | 78.5 | 79.7 | 82.1 | 78.3 | 77.1 |
| $FSI$ | 80.1 | 78.3 | 80.9 | 79   | 76.5 |

**Table. 8** December data, China

|       | 2006 | 2007 | 2008 | 2009 | 2010 |
|-------|------|------|------|------|------|
| $T$   | 1.1  | 1    | 1.5  | 1.3  | 0.7  |
| $P$   | 3    | 5    | 6    | 2    | 8    |
| $\hat{y}$ | 80.7 | 80.6 | 83.2 | 85   | 83.4 |
| $FSI$ | 82.5 | 81.2 | 80.3 | 84.6 | 83   |

|       | 2011 | 2012 | 2013 | 2014 | 2015 |
|-------|------|------|------|------|------|
| $T$   | 1.5  | 2.1  | 2.3  | 2.7  | 2.1  |
| $P$   | 11   | 5    | 8    | 4    | 6    |
| $\hat{y}$ | 78.9 | 79.2 | 82.4 | 78.2 | 76.4 |
| $FSI$ | 80.1 | 78.3 | 80.9 | 79   | 76.5 |

**Figure. 7** The change of $y$ and FSI (Jul.)

**Figure. 8** The change of $y$ and FSI (Dec.)
Taking July as an example, we plotted the trend of temperature and precipitation in China in recent years and predicted the change of climate in the past 20 years. According to Chao Qingchen, the average surface temperature of China’s land from 1909 to 2011 was between 0.9 °C and 1.5 °C, higher than the global average.

Surface from 1909 to 2011 was between 0.9 °C and 1.5 °C, higher than the global average. From the 1970s to the beginning of this century, the glacier area of China shrunk by about 10.1% and the permafrost area decreased by about 18.6%.[1] Data on precipitation and temperature from 2016 to 2036 based on linear fit. The vulnerability of China is constantly increasing.

### 3.6. Model Predictive Analysis

#### Table 9 Forecast data, July

|       | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|-------|------|------|------|------|------|------|------|
| T     | 24.5 | 24.6 | 24.7 | 24.8 | 24.9 | 25.0 | 25.1 |
| P     | 198.8| 198.0| 197.3| 196.6| 195.9| 195.2| 194.5|
| ŷ     | 77.4 | 78.3 | 79.2 | 80.1 | 81.0 | 81.9 | 82.8 |
|       | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 |
| T     | 25.2 | 25.3 | 25.5 | 25.6 | 25.7 | 25.8 | 25.9 |
| P     | 193.8| 193.1| 192.4| 191.7| 191.0| 190.3| 189.6|
| ŷ     | 83.7 | 84.6 | 85.5 | 86.4 | 87.3 | 88.2 | 89.1 |
|       | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 |
| T     | 26.0 | 26.1 | 26.2 | 26.3 | 26.4 | 26.5 | 26.6 |
| P     | 188.9| 188.2| 187.5| 186.8| 186.1| 185.4| 184.7|
| ŷ     | 90.0 | 90.9 | 91.8 | 92.7 | 93.6 | 94.5 | 95.4 |

For global warming over the past 50 years, 90% of the potential is caused by human activities. [2] Since the economic development patterns in different countries and the problems are different, the formulation of low-carbon measures should be based on social justice and human civilization and finally meet the needs of comprehensiveness. [3] We estimate that the damage to the national cost of GDP is in the range of 0.51%-0.1%. [4] We should make full analysis of the beneficial the state can adjust the industrial structure.

### 4. Model improvement

We take state Heilongjiang as an example, it is affected by the temperature and precipitation. Use \( x_1 \) and \( x_2 \) to represent their interaction, get \( \hat{y} = \beta_0 + \beta_1 T + \beta_2 P + \beta_3 TP \).
Table 10 July data, state Heilongjiang

|       | 2014 | 2015 | 2016 | 2017 |
|-------|------|------|------|------|
| $T$   | 24.6 | 24.8 | 24.9 | 25.1 |
| $P$   | 159  | 163  | 162  | 164  |
| $\hat{y}$ | 78.9 | 76.7 | 75.2 | 75   |
| $FSI$ | 79   | 76.5 | 74.9 | 74.7 |

Table 11 December data, state Heilongjiang

|       | 2014 | 2015 | 2016 | 2017 |
|-------|------|------|------|------|
| $T$   | -14.7| -14.8| -14.9| -15.2|
| $P$   | 7.4  | 7.5  | 8.1  | 8.2  |
| $\hat{y}$ | 78.7 | 76.9 | 75.1 | 74.4 |
| $FSI$ | 79   | 76.5 | 74.9 | 74.7 |

$\beta = [-81.2, 6.2, -1.2, 0.075]^T$, so $\beta_0$ and $\beta_1$, $\beta_2$, $\beta_3$ are significant, and the linear relationship is also significant. $\hat{y} = \beta_0 + \beta_1 T + \beta_2 P + \beta_3 TP$ is more reasonable.

5. Conclusion
By collecting temperature and precipitation data, we set up a linear regression model and solved the linear regression coefficient. The results show that in the range of human beings suitable for living, the temperature and the vulnerability index are positively correlated, and the precipitation and the vulnerability are negatively correlated. In the analysis of Syria and China, this conclusion has been confirmed.

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