Evaluation and Prediction Model for Exploring the Impact of Climate Change on National Vulnerability

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Abstract

Climate change's pervasive influence on human life has been an inevitable topic nowadays, especially the impacts on instability of a state has been attached with great importance recently. In this paper, we establish evaluation model and regression model to complete the missions. First, based on the scheme of Fragile State Indexwhose weights of 12 indicators are uncertain, we are aimed to decide them to complete the Evaluation Model. Fuzzy Analytic Hierarchy Process and Entropy Weight Method are adopted to combine the advantages of human knowledge and data pattern. Then, in order to find out how climate change affects the 12 indicators, Regression Model is established. We firstly identify 5 indicators including disaster, water, land, temperature and CO_2 to describe climate change. After that, we identify 6 control variables to reduce system error. Last but not the least, taking the difference between countries, we use fixed cross-section effects model to regress. Data of 115 countries from 2009 to 2019 is collected and all the R2 of the 12 regression models are above 0.9, indicating a good fitting result.Finally, we establish a Forecast Model to evaluate the actual effect of our work. Based on collected climate data, Time Series ARIMA Model is adopted.

Keywords*: Fragile State Index, climate change,evaluation and forecast.*

I Introduction

These days, climate change has been gathering international intensive attention because of its significant influence on human society in both short and long term [1,2]. Academically, three effects of climate change which includes natural disasters, sea-level rise, and resource scarcity are frequently viewed as factors that lead to many social problems like economic decline and collapse of a polity [1,3,4]. It is generally believed that the famous migration of Viking in 14th century is caused by famine induced by freezing climate.

After stepping into 21st century, with the civilization and industrialization process, we have seen 0.5℉temperature rise every decade. What's worse, in the harder hit regions, the rise reaches to 2℉per decade[5]. The acceleration of temperature increase is deadly threatening our life considering sea level rise, irregular precipitation and more frequent disasters, all of which can lead to a bankruptcy of one country. The imagination of this scenario is pushing us to establish a systematical model to solve the difficulty we may face in the future [6].

The Fund for Peace(FFP) raised Fragile State Index (FSI) in 2006 to assess a vulnerability of a country. Using data from three sources (Content Analysis, Quantitative Data and Qualitative Review), FSI scores are apportioned for 178 nations based on twelve indicators factoring in coherence, politics, economy and society [7]. While World Bank use another index called Country Policy and Institutional Assessment(CPIA) to assess a polity's stability and pressure based on answers for five aspects from questionnaires to governmental personnel.In our work, considering that CPIA considers more from government regulations, we use FSI to evaluate the vulnerability of a country because of its comprehensiveness.

II. Environmental Change Indicators for Assessing the National Vulnerability

Weighting Model of FSI. FFP proposed FSI based on Conflict Assessment System Tool (CAST) analytical approach in 2006 which consists of assessment to four aspects: cohesion, politics, economy and society [8]. Under each aspect, three indicators are raised to describe it. To be detailed, proposers recognize several specific things to consider. For example, when considering security apparatus, researchers need to collect quantitative and qualitative data about monopoly on use of force, relationship between security and citizenry, force and arms [9,10,11]. What's more, questionnaires about these things are designed to gather answers from experts to help researcher better understand the problem.

Table 1: The Structure of FSI

Aspects	Indicators	Content
Cohesion	Security Apparatus (C1)	• Monopoly on the Use of Force • Relationship Between Security andCitizenry • Force • Arms
	Factionalized Elites (C2)	• Representative Leadership • Identity • Resource Distribution • Equality and Equity
	Group Grievance (C3)	• Post-Conflict Response • Equality • Divisions • Communal Violence
Politics	State Legitimacy (P1)	• Confidence in the Political Process • Political Opposition • Transparency • Openness and Fairness of thePolitical Process • Political Violence
	Public Services (P2)	• General Provision of Public Services • Health • Education • Shelter • Infrastructure
	Human Rights and Rule of Law (P3)	• Civil and Political Rights & Freedoms • Violation of Rights • Openness • Justice • Equality
Economy	Economic Decline and Poverty (E1)	• Public Finances • Economic Conditions • Economic Climate • Economic Diversification
	Uneven Development (E2)	• Economic Equality • Economic Opportunity • Socio-Economic Dynamics
	Human Flight and Brian Drain (E3)	• Retention of Technical and • Intellectual Capital • Economics • Diaspora
Society	Demographic Pressures(S1)	• Population • Public Health • Food and Nutrition • Environment • Resources
	Refugees and IDPS(S2)	• Refugees • Internally Displaced Persons • Response to Displacement
Cross-cutting Factor	External Intervention(X1)	• Political Intervention • Force Intervention • Economic Intervention

Here, since we do not know the original value of each small questions and the process to calculate each indicator, we simply divide the system into two layers- four aspects and 12 indicators.Since the final FSI Index product is designed as an entry point into deeper interpretive analysis for the user [12,13], we need to determine the weights of each indicator. Here we use Fuzzy Analytic Hierarchy Process(FAHP) and Entropy Method(EWM) to get the weights of the 12 indicators to FSI. The value of each aspect (1st layer) is simply the sum of the 3 indicators listed below [14].

We use three ways to calculate the weights which are normalization of the sum of rows(NM) (Equation 1), root method(RM) (Equation 2) and sorting method(SM) (Equation 3).

$$w_i = \frac{\sum_{j=1}^{n} r_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n} r_{ij}}, i = 1,2,...\mathrm{n} \tag{1}$$

$$w_i = \frac{\sqrt[n]{\prod_{j=1}^{n} r_{ij}}}{\sum_{i=1}^{n}\sqrt[n]{\prod_{j=1}^{n} r_{ij}}}, i = 1,2,...\mathrm{n} \tag{2}$$

$$w_i = \frac{1}{n} - \frac{1}{2\alpha} + \frac{\sum_{j=1}^{n} r_{ij}}{n\alpha}, i = 1,2,...\mathrm{n}$$

$$\alpha \geq \frac{n-1}{2} \tag{3}$$

Where, w_i denotes the weight of i th indicator, and r_{ij} denotes the value in Row i and Column j in judgement matrix.

By averaging the results from the three methods, we get the weights(Tab.2).

Last but not the least, we do the consistency test by calculating CI, where $CI = (\lambda - n)/(n-1)$. After calculation, we get $CI = 0.0408$, considering $RI = 1.54(12)$, we calculate CR by $CR = CI/RI$. We get $CR = 0.027 < 0.1$, which means the result passes the test.

However, FAHP is based on the knowledge that researchers have, meaning that it is subjective rather than objective. To get the weights more objectively, we apply Entropy Method(EWM) to mitigate the drawback.

We use the data of the 12 indicators from 2009 to 2019 to get the weights(Tab.2).While considering EWM is restricted to the patterns of collected data, we average the result from FAHP and that from EWM to get the weights from both subjective and objective perspectives.

Table 2: Weight values of 12 indicators

Method	w_1	w_2	w_3	w_4	w_5	w_6	w_7	w_8	w_9	w_{10}	w_{11}	w_{12}
FAHP-NM	0.08	0.07	0.08	0.08	0.09	0.07	0.09	0.09	0.08	0.09	0.10	0.06
FAHP-RM	0.08	0.07	0.08	0.08	0.09	0.07	0.10	0.10	0.08	0.09	0.10	0.06
FAHP-SM	0.08	0.07	0.08	0.08	0.09	0.06	0.10	0.10	0.08	0.09	0.11	0.06

EWM	0.10	0.08	0.06	0.07	0.05	0.08	0.08	0.11	0.09	0.07	0.12	0.09
Average	0.09	0.07	0.07	0.08	0.09	0.06	0.09	0.10	0.08	0.09	0.11	0.06

Overall, we can see that among them, Refugees and IDPs counts most in FSI. It fits our common sense since finite resources have to be shared with imigrants, which leads to the unsatisfaction of citizens to government, what's more, it is the unstability and collapse of their own country that makes emigrants flee away from homelands.

Regression Model. In order to figure out how climate change makes impacts on the 12 indicators, furthermore, we adopt fixed cross-section effects model using panel data to regress the relationship between every FSI indicator and independent variables which include the five climate change variables listed above and 6 control variables.

However, apart from the five climate change indicators, there are other factors accounting for the value of the 12 indicators. In other words, control variables need to be added into the model. Control variable is meant to those factors affecting dependent variable but is not related to explanative variables, which are five climate change variables in our model. The purpose of addition of control variable is to make model more comprehensive and practical, reducing system error at last. We categorize control variable into two, one is physically related and another is mentally related. Physical indicator consists of Investment of Public Service [15], GDP and Population. Here, Sanitation Facility is selected as a substitute variable of Investment of Public Service because it measures the level of public service provided by government to some degree. Besides, due to the different size of each country, Total Population cannot evaluate the situation of population of a country so we add Population Growth Per Year as another variable. What's more, the lagged term of GDP is considered into several models. Mental indicators include HDI and Inequality. HDI indicates the happiness of citizens to some extent and Inequality index is of great significance when comes to society problems [16].

The data put into regression model is panel data, which is also called longitudinal data is multi-dimensional data involving measurements over time. We present Figure 1. which contains C1 data of 9 countries and 11 years, to show the frame of panel data. To be summarized, there are 23 balanced panels in our model which are 5 explanative variables, 6 control variables and 12 indicators, all of which is data of 115 countries from 2009 to 2019.

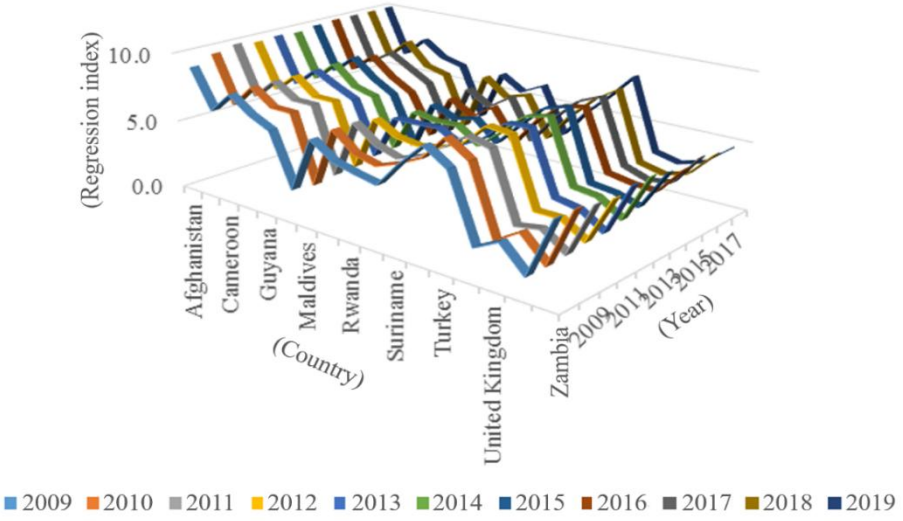


Fig.1: Data Description

There are three basic models we can turn to when comes to panel data, which is pooled regression, fixed effects model and random effects model. With quick estimation, we can know that coefficient is different and related with

cross-section and the results of redundant fixed effects tests and correlated random effects-Hausman test support our judgment.

In addition, we select logistic function as the regression format since we need to ensure all the values of the dependent variable is between 0 and 10. So in conclusion, the regression formula is (4).

$$y = \frac{k}{1+e^{f(x_1,\ldots,x_{11})}}$$

$$f_{it}(x_1,\ldots x_{11}) = a_i + b_1 x_{1,it} + \ldots + b_{11} x_{11,it} + \mu_{it}, i = 1,2,\ldots,115, t = 1,2,\ldots,8 \quad (4)$$

Where a_i is related to $x_1,\ldots,x_{11}$.Here, we set k as 10.01, which is the maximal value, because if we set k as 10, there will be overflow when we do regression.

We use *Eviews 10* to regress the 12 fixed cross-section effects models and we retain independent variable that passes t-test and consistent with facts. Plus, each of the of the 12 models is above 0.9, which indicates a great fitting result. Results and details can be found in Appendix. Figure. shows the effects of each climate change indicator on the 12 indicators directly, in which dash line indicates a direct influence while line indicates indirect influence. As noted above, disasters and lack of resource is viewed as direct factor so that the three indicators-disaster, water and land has direct influence while CO_2 and temperature has indirect effect. It is easy to understand the impacts of CO_2 and temperature are indirect since compared with other factors which can be discussed from regional angle, CO_2 and temperature change is much more macro.

III. Predictive Model of National Vulnerability

In this section, our aim is to establish a model to forecast the trend of future climate, so that we can predict the potential values of 12 indicators, FSI at last. What's more, with the help of prediction of future FSI, we can know how stable a country is in the near future. To be extended, we can propose some intervention measures to help government to mitigate the influence of climate change.We need to predict the future trend of disaster, water, land, temperature and CO_2.

Grey Prediction Method.Grey Prediction Method is prediction method to forecast through a small amount of information. It is based on grey system and it follows the principal (5) to generate new series.

$$x^{(1)}(k) = \sum_{i=1}^{k} x^{(0)}(i) \quad (5)$$

Specifically, GM (1, 1) is a basic grey prediction method among grey prediction method. We use the GM (1,1) toolbox in *Matlab* to generate the 5 climate indicators. All the generated series pass the precision test.

Time Series ARIMA Model. Time series ARIMA model is a widely used time series analysis method. All the forecast models except CO_2 prediction pass stationery test. Further, we identify disaster model as ARMA (1,1) and other models as AR (1).

ARMA (1,1) can be described as

$$y_t = c + a_1(y_{t-1} - \mu) + \mu_t + b_1\mu_{t-1} \quad (6)$$

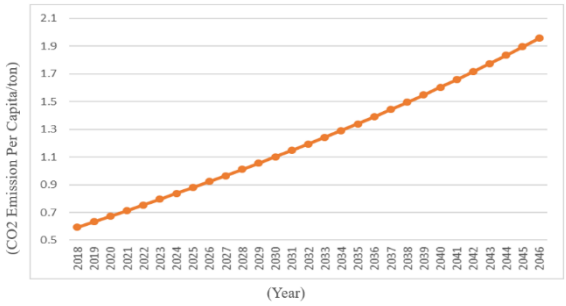
AR (1) can be described as

$$y_t = \phi_1 y_{t-1} + \mu_t \tag{7}$$

We use *Eviews 10* to get the fitting results and all the models pass the Q test, F test and t test. With the help of fitting results, we can generate the future years' value of the five climate change variables. Last but not the least, we average the results predicted by GM and those by ARIMA to take the two models together to reduce error.

Case Study: Bangladesh. We use our forecast model to forecast the value of the five climate changes of Bangladesh. Then we put it into our regression model with control variables constant with 2014. Finally, all the values are put into evaluation model to get FSI.

CO_2 and water change from2018 to 2046 is presented in Figure 2 &3.



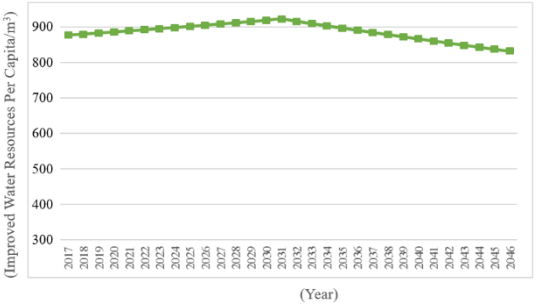


Fig.2: The Future Trend of CO2 ***Fig.3: The Future Trend of Water***

We can see that CO_2 is driving all the way up while water at first is increasing gradually, but after reaching a maximum, it begins to decline.

By putting the predicted value into regression model, we can get the value of the 12 indicators, and then we use evaluation model to get every year's FSI. According to FFP, FSI above 110, meaning very high alert (including countries like South Sudan and Somalia), indicates that the country is in unrest , approaching to the collapse. While 100 meaning high alert, indicates that if the government does not take measures, the country will be sliding into very high alert class. Seen from Figure4, we can know that if Bangladesh does nothing to the current climate situation, the FSI of Bangladesh takes a fluctuated increasing process and in 2064, it will reach100, stepping into high alert class and in 2113, it will reach 110, becoming a very high alert class.

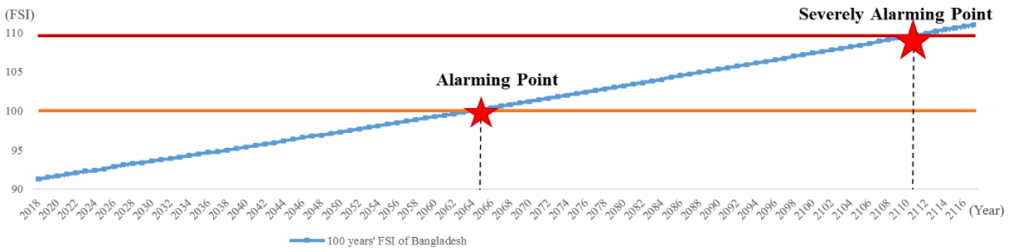


Fig.4: Prediction of Bangladesh in the Near 100 Years

IV Conclusions

To evaluate the stability of a country, we firstly establish an evaluation model factoring in 12 indicators proposed by FSI. In evaluation model, we take FAHP and EWM together to calculate the weights, taking advantages of subjective knowledge and objective pattern of data. This combination makes our model more credible. Same as evaluation model, we also use two methods to forecast the trend of climate indicators in the future and the

predicted result is similar, which confirms the reliability of our model.

Furthermore, we establish a forecast model to predict the trend of climate change. We take GM(1,1) and Time Series ARIMA Model to predict how climate change will further affect the country's vulnerability indicators. Finally, we use Bangladesh's data as input to measure how the country will be affected if no climate protection measures are taken.

The frame of FSI is based on country level. However, as for a deeper research, it may focus on a smaller unit like a city or a larger unit like a continent. By scanning the indicators of FSI, we can see that cities' data satisfies the requirements. For example, as for P1, state legitimacy, we can use the local government' transparency and efficiencyand citizens' confidence to local government to understand how it performs. What's more, data of climate change of a small unit can be collected so that the regression model can be fitted again to get the local version. To say the least, data of a small unit demonstrates similarly with its nation to some extent. So, for a micro administrative unit, our evaluation model, regression model and forecast model is also suitable for a smaller unit.

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