Effects of Climate Change have aroused growing attention worldwide. The potential damages of Climate Change threaten most regions in the world, especially those fragile states. A fragile state cannot meet its people's demands, and is quite vulnerable to those climate shocks. As a result, how to measure the fragility of countries counts.

Our SPEC Model provides a quantitative analysis of fragility degree for most countries in the world. It considers multiple aspects, including security, politics, economics and Climate Change.

We use 20 individual indicators to measure each aspects. Considering the impact of time, we apply Latest-determine Method and Weighted Average Method to do data weighting for different indicators. Moreover, in Weighted Average Method, we use the exponential weighting pattern to have realistic time-relating weights to better measure the indicators in a long period.

We divide effects of Climate Change into two parts: General impacts and Extreme impacts. The general part refers to those indirect effects of Climate Change. We use four indicators to represent the influences of rising sea level, decreasing arable lands, deteriorating ecological environment and restrained water source.

The extreme part of Climate Change illustrates the potential damage of extreme weathers resulting from Climate Change. We apply Self-regulatory Factor to predict countries' ability to maintain their current condition facing extreme weathers. We use three indicators to further measure the self-regulatory factor. Moreover, self-regulatory factor also relates to the Tipping Point of a country, and we put forward the Tipping Model.

气候变化的影响引起了全世界越来越多的关注。气候变化的潜在危害威胁着世界上大多数地区，特别是那些脆弱的国家。一个脆弱的国家无法满足其人民的要求，而且很容易受到这些气候冲击的影响。因此，如何衡量各国的脆弱性。

我们的 SPEC 模型为世界上大多数国家提供了脆弱性的定量分析。它考虑了多个方面，包括安全，政治，经济和气候变化。

我们使用 20 个单独的指标来衡量每个方面。考虑到时间的影响，我们应用最新确定方法和加权平均方法对不同指标进行数据加权。此外，在加权平均法中，我们使用指数加权模式来获得实际的时间相关权重，以便在较长时期内更好地衡量指标。

我们将气候变化的影响分为两部分：一般影响和极端影响。一般部分是指气候变化的间接影响。我们用四个指标来表示海平面上升，耕地减少，生态环境恶化和水源受限的影响。

气候变化的极端部分说明了气候变化对极端天气造成的潜在破坏。我们应用自我调节因子来预测各国维持其面临极端天气的现状的能力。我们使用三个指标来进一步衡量自我调节因子。此外，自我调节因子也与一个国家的临界点有关，我们提出了临界点模型。

我们应用层次分析法（AHP）来确定指标的权重。我们指的是不同的数据库，例如 Worldbank。我们模拟我们的模型到世界上 178 个国家，我们计算出每个国家的自我调节因子和 SPEC 指数。

我们将 SPEC 模型应用于也门，这是最脆弱的国家之一，印度是一个普通脆弱的国家。我们预测印度国家驱动干预的总成本。

为了使我们的模型更适用，我们使用重新加权方法来修改我们的模型。通过这种方式，我们发现 SPEC 在"较小"或"较大"地区下运行良好。

最后，我们对 SPEC 模型进行敏感性分析，并讨论优势和劣势。

We apply Analytic Hierarchy Process (AHP) to determine the weights of indicators. We refer to different databases such as Worldbank. We simulate our model to 178 countries in the world, and we work out the self-regulatory factor and SPEC index of each country.

We apply the SPEC model to Yemen, one of the most fragile country and India, a country with ordinary fragility. We predict the total cost of state driven intervention of India.

In order to make our model more applicable, we use Re-weighting Method to modify our model. In this way, we find SPEC works well in "smaller" or "larger" states.

Finally, we do sensitivity analysis to the SPEC Model and discuss strengths and weaknesses.

1 Introduction

1.1 Problem Background

It is always an interesting experience in winter seeing passengers taking off their sweaters and heavy coats on the plane flying from north to south. Obviously, climate influence our life-style. Moreover, nowadays it significantly impact the stability, or saying conversely, the fragility of a country.

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 [1]. A state's fragility interplays with its social conditions and they can easily fall into a viscous cycle once one of the indexes becomes severe. Therefore, people often examine fragility to view as a comprehensive reflection of a country's conditions.

There are multiple ways to measure the fragility of a country. The existing fragility lists such as *Fragile States Index* [2] of Fund for Peace [3] put more focus on social indicators regarding politics, safety, economy, etc.. However, they **almost** neglect natural indicators such as climate shocks and global climate changes, whose influences have become remarkable today. Here we use "almost" to assume their weighting systems, considering climate to have minor impacts on fragility by indirectly affect the core indexes including security political, economical indicators.

1 简介

1.1 问题背景

冬天，乘客在从北向南飞行的飞机上脱掉毛衣和厚重的外套，这总是一种有趣的体验。显然，气候影响着我们的生活方式。而且，现在它对国家稳定性产生了重大影响，或者反过来说，也反映了一个国家的脆弱性。

脆弱国家是一个低收入国家，其特点是国家能力薄弱或国家立法薄弱，使公民容易受到一系列冲击[1]。一个国家的脆弱性与其社会条件相互作用，一旦其中一个指数变得严重，它们就很容易陷入粘性循环。因此，人们经常将脆弱性视为对国家条件的全面反映。

有多种方法可以衡量一个国家的脆弱性。现有的脆弱性榜单，如和平基金脆弱国家指数[2] [3]更加关注政治，安全，经济等社会指标。但是，它们几乎忽视了气候冲击和全球气候变化等自然指标，其影响力如今变得非常显著。在这里，我们使用“几乎”来假设他们的加权系统，考虑气候对脆弱性产生轻微影响，间接影响核心指标，包括安全政治，经济指标。

1.2 Our Efforts

To specify the climate impacts on fragility, we build a climate-based fragility model called the **SPEC** Model, which is able to analyse the impact of climate both directly and indirectly. In the model, we also quantify other important indicators concerning security, politics and economics.

In Section (2), we state the basic assumptions of the SPEC Model. In Section (4), we give detailed explanation and calculation for each indicator used in the model. Section (6) provides thorough analysis of the SPEC Model including sensitivity analysis and strengths & weaknesses review.

We also solve tasks listed as follows,

1. Build a model to determine the fragility of a country and analyse the influence of climate.
2. Apply our model on one of the top 10 most fragile states and quantify the impact of climate on fragility.
3. Apply our model on another state outside the top 10 most fragile list. Find distinct indicators and tipping point of its fragility trend.
4. Use our model to predict positive interventions to reduce negative impact of climate and avoid a fragile state.
5. Generalize our model on states of different sizes, small as cities, large as continents.

1.2 我们的工作

为了明确气候对脆弱性的影响，我们建立了一个名为 SPEC 的基于气候的脆弱性模型，该模型能够直接或间接地分析气候的影响。在该模型中，我们还量化了有关安全，政治和经济的其他重要指标。

在第（2）节中，我们陈述了 SPEC 模型的基本假设。在第（4）节中，我们给出了模型中使用的每个指标的详细解释和计算。第（6）节提供了对 SPEC 模型的全面分析，包括敏感性分析和优缺点评估。

我们还解决了如下任务，

1. 建立模型以确定一个国家的脆弱性并分析气候的影响。
2. 将我们的模型应用于十大最脆弱国家之一，并量化气候对脆弱性的影响。
3. 将我们的模型应用于前 10 个最脆弱国家之外的另一个地区。找出不同的指标和脆弱趋势的临界点。
4. 使用我们的模型预测积极的干预措施，以减少气候的负面影响，避免脆弱的状态。
5. 将我们的模型推广到不同大小的地区，小到城市，大到大陆。

2 Assumptions

We make the following assumptions for the SPEC Model:

1. States can exchange resources and communicate with neighbouring states.
2. Within a country, resources can be dispatched quickly from rich places to poor areas, especial when some parts of the country are suffering natural catastrophe.
3. The stability and strength of a country is largely depend on the political environment, economical conditions, social security, military power, national resources, etc..
4. The richness of national resources can be reflected by national territorial area.
5. Risk of extreme weather events increases with global climate change [4].

4 Statement of Our Model

In assessment of the fragility of a country, a state, or a city, we refer to multiple factors. We classify the factors into four main fields: **politics, economics, security and climate**. Factors in distinct fields contribute to fragility in different ways. We introduce the quantification of impact from various factors field-by-field.

Figure 1: SPEC Index

2、假设

我们对 SPEC 模型做出以下假设：

1. 各国可以交换资源并与邻国进行沟通。
2. 在一个国家内，资源可以迅速从富裕地区运往贫困地区，特别是当该国某些地区遭受自然灾害时。
3. 一个国家的稳定和力量在很大程度上取决于政治环境，经济条件，社会保障，军事力量，国家资源等。
4. 国家资源的丰富程度可以反映在国家领土范围内。
5. 极端天气事件的风险随着全球气候变化而增加[4]。

4、我们的模型描述

在评估一个国家，一个州或一个城市的脆弱性时，我们提到了多种因素。我们将这些因素分为四个主要领域：政治，经济，安全和气候。不同领域的因素以不同的方式导致脆弱性。 我们逐个地介绍各种因素对影响的量化。

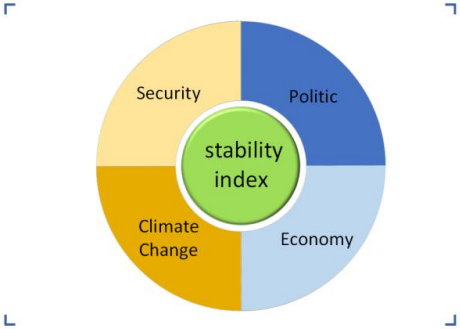

Figure 1: SPEC Index

4.1 Security

We use **five security indicators** in security fields. These five indicators measure the presence of different types of political violence in a country, from civil war to gross human rights violations on a scale of 0 (smallest) to 10 (greatest).

• **Social conflicts** is an indication of the state's ability to maintain peace within its borders and provide basic physical and human security. We refer to the data set *Major Episodes of Political Violence 1946-2016* that comprises a comprehensive accounting of all forms of major armed conflicts in the world.

• **Political stability and absence of violence** measures the perceptions of the likelihood that the government will be destabilized or overthrown by separatism or violent means, including terrorism.

• **Incidence of coups**. States that have experienced violent overthrow are by definition highly unstable, and likely to lack the political mechanisms that ensure peaceful transition of power. For this indicator, a country **score 0** if there have been any coups in the last fifteen years and **score 10** if else. We acquire the data from List-of-coups on *Wikipedia*.

• **Gross human rights abuses**. States that rely on widespread oppression to maintain control will be susceptible to internal discontent and instability. We assign a score for this indicator based on *Political Terror Scale 2015*.

• **Refugee & Terrorism** is the best available indicator for a state's ability to carry out its sovereignty and maintain a monopoly on the use of armed force across the entirety of its territory. Large numbers of refugees emerge in those countries which can not quell the revolutionary and ethnic wars started by challengers seeking major changes in their status.The database is provided by *Political Instability Task Force, 2017*.

4.1 安全

我们在安全领域使用五个指标。这五项指标衡量一个国家存在不同类型的政治暴力，从内战到严重侵犯人权行为，范围从 0（最小）到 10（最大）。

•社会冲突　表明国家有能力在其境内维持和平并提供基本的人身和人身安全。我们参考 1946 - 2016 年政治暴力主要事件的数据集，其中包括对世界上所有形式的重大武装冲突的全面记录。

•政治稳定和是否存在暴力事件　衡量政府将被分离主义或包括恐怖主义在内的暴力手段破坏或推翻的可能性。

•政变的发生率，根据定义，经历过暴力推翻的国家极不稳定，可能缺乏确保和平过渡权力的政治机制。对于此指标，如果在过去十五年中有任何政变，则国家/地区得分为 0，否则为 10。我们从维基百科上的政变列表中获取数据。

•严重侵犯人权，依靠广泛压迫来维持控制的国家将容易受到内部不满和不稳定的影响。我们根据 2015 年政治恐怖量表为该指标分配一个分数。

•难民和恐怖主义　是一个国家有能力实现其主权并在整个领土上保持对武装部队使用垄断的最佳指标。国家出现大量难民，表明其无法平息寻求重大变革的挑战者所发起的革命和种族战争。该数据库由 2017 年政治不稳定工作组提供。

The mathematical expression for security indicators in the SPEC Model equation has a form of

$$Security = \alpha_1 S_{conf} + \alpha_2 S_{abv} + \alpha_3 S_{coups} + \alpha_4 S_{abuse} + \alpha_5 S_{ref}$$

We will later assign weights α_1, α_2, α_3, α_4, α_5 to these indicators in Section (4.6).

4.2 Politics

We used four political indicators to quantify the impact of politics on fragility of a state.We define the four indicators to reflect the political appearance of a state to the same large extent and ignore other minor factors. We treat the four political indicators equally by grading the them from 0 (smallest) to 10 (greatest) in the fragility function.

- **Government effectiveness** directly shows the states' govern capability, including the public and civil service quality and policy executive ability. Facing with social crisis, a government's coping ability impacts the results greatly.
- **Rule of law** measures the confidence and efficiency of a government to build a legitimate country using strong regulations, and relate tightly to the long-term stability of a state.
- **Control of corruption** prevents the state from irrational resource distribution and institution erosion, which is a strong indicators to predict a state's public trust.
- **Voice & Accountability** measures the extent of citizens get involved in the construction of a government. It is the reflection of civil freedom and influence the stability of a government in the long-term.

SPEC 模型方程中安全指标的数学表达式为：

$$Security = \alpha_1 S_{conf} + \alpha_2 S_{abv} + \alpha_3 S_{coups} + \alpha_4 S_{abuse} + \alpha_5 S_{ref}$$

我们将在第（4.6）节中将权重α1，α2，α3，α4，α5 分配给这些指标。

4.2 政治

我们使用了四个政治指标来量化政治对一个国家脆弱性的影响。我们定义了四个指标，在很大程度上反映一个国家的政治稳定性，而忽略其他次要因素。我们平等地对待这四个政治指标，将它们从脆弱性函数中的 0（最小）到 10（最大）进行评级。

•政府效率　直接显示各地区的治理能力，包括公共管理人员与公务员素质和政策执行能力。面对社会危机，政府的应对能力会对结果产生重大影响。

•法治建设　衡量一个政府在立法、执法方面的信心和效率，并与国家的长期稳定紧密联系。

•控制腐败　可防止国家不合理的资源分配和机构侵蚀，这是预测国家公众信任的有力指标。

•语音和问责制　衡量公民参与政府建设的程度。民事自由的反映，长期影响政府的稳定。

In assessment of political indicators, We refer to the data set *Governance Matters VI, 2007* on the World Bank. The mathematical expression for political indicators in the SPEC Model equation has a form of

$$Politics = \beta_1 P_{gov} + \beta_2 P_{law} + \beta_3 P_{corpt} + \beta_4 P_{acc}$$

where $\beta_1, \beta_2, \beta_3, \beta_4$ are given in Section (4.6).

4.3 Economics

There are five economical indicators. These widely used indicators allow us to capture key aspects of national economic performance.

• **Gross National Income (GNI) per Capita**. We believe low per capita income is a proximate effect of state weakness, circumscribing a country's capacity to achieve essential government functions. The database is provided by *World Development Indicators, 2007*.

• **Growth of Gross Domestic Product (GDP)**. Like GNI per capita, average economical growth can be both a resulting effect and proximate cause of state weakness. Countries that manage to sustain economical growth generally exhibit relatively stable and secure societies. The same data set is available at *The World Bank*.

• **Inflation** may indicate an economy's susceptibility to external shocks or unsustainable fiscal policy. We use the absolute value of the annual change in consumer prices, allowing us to treat cases of deflation and inflation in the same manner. *World Economic Outlook Database, 2017* provides the data required.

在评估政治指标时，我们参考了世界银行关于 *Governance Matters* 2007 年的数据集。SPEC 模型方程中政治指标的数学表达式为：

$$Politics = \beta_1 P_{gov} + \beta_2 P_{law} + \beta_3 P_{corpt} + \beta_4 P_{acc}$$

其中 β1, β2, β3, β4 将在 4.6 节给出。

4.3 经济

我们采用了五个经济指标。这些广泛使用的指标使我们能够捕捉到国家经济表现的关键点。

•人均国民总收入（GNI）。我们认为低人均收入近似为一个国家的弱点，限制了一个国家实现基本政府职能的能力。该数据库由 2007 年世界发展指标提供。

•国内生产总值（GDP）的增长。与人均 GNI 一样，平均经济增长率也是一个国家的弱点。设法维持经济增长的国家通常表现出相对稳定和安全的社会状态。由世界银行提供数据集。

•通货膨胀 表明经济体容易受到外部冲击或不可持续的财政政策的影响。我们使用消费价格年度变化的绝对值，并以同样的方式处理通货紧缩和通货膨胀的情况。 2017 年世界经济展望数据库提供了所需的数据。

• **Income Inequality**. High income inequality has been linked to the likelihood of rebellion and other forms of political violence. We determine the score of each country based on its Gini coefficient which represents the wealth distribution of a country's residents.

• **Regulatory Quality**. Poor Regulatory Quality indicates a state's inability to foster an environment conducive to private-sector growth, which is essential to increasing national income. *Governance Matters VI, 2007* provides the data required.

The mathematical expression for political indicators in the SPEC Model equation has a form of

$$Economics = \gamma_1 E_{GNI} + \gamma_2 E_{GDP} + \gamma_3 E_{inf} + \gamma_4 E_{ineq} + \gamma_5 E_{reg}$$

We will later assign weights γ_1, γ_2, γ_3, γ_4, γ_5 to these indicators in Section (4.6).

4.4 Data Weighting Methods for Individual Indicators

We search for the data of the indicators in security, political and economical fields and operate the mass data with two fundamental methods: **weighted average methods** and **latest-determine methods**, and then we apply the operated indicators into the equation of fragility.

4.4.1 Latest-determine Method

Indicators acts differently to the fragility of a country, some of them has abrupt and sudden impact, while others has on-going influence. **We apply the latest-determine method on indicators that has sudden and short impact, and only use thelatest data to represent the indicator.**

• 收入差距。高收入不平等与叛乱和其他形式的政治暴力的发生概率有关。 我们根据其基尼系数确定每个国家的得分，该基尼系数代表一个国家居民的财富分布。

•监管质量。 监管质量差表明该地区无法营造有利于私营部门增长的环境，这对增加国民收入至关重要。 Governance Matters VI，2007 提供了所需的数据。

SPEC 模型方程中政治指标的数学表达式为：

$$Economics = \gamma_1 E_{GNI} + \gamma_2 E_{GDP} + \gamma_3 E_{inf} + \gamma_4 E_{ineq} + \gamma_5 E_{reg}$$

我们将在 4.6 节中为这些指标分配权重γ1、γ2、γ3、γ4、γ5。

4.4 指标数据加权方法

我们在安全，政治和经济领域查找指标数据，并用两种基本方法操作海量数据：加权平均法和最新确定法，然后我们将运行指标应用于脆弱性方程。

4.4.1 最新确定方法

指标对一个国家的脆弱性产生不同的影响，其中对一些国家具有短期的影响，而对另一些国家则具有持续的影响力。 我们对具有短期影响的指标应用最新确定的方法，并且仅使用最新数据来表示指标。

Among all 14 indicators introduced in the previous three fields, we use this latest-determine method on 9 of them, regarding them as instantaneous and transient factors. For only 5 indicators mentioned in the next part, we use the weighted average method to measure their relatively long-standing impact.

4.4.2 Weighted Average Method

We apply an exponential weighing pattern, showing the impact of a indicator decreases with time. We define the relative weight $(1 - a)^T$, where T is the time number in the time period falling between the integers from 1 to 5 or 1 to 15, and a is a mediate positive constant that falls in the interval [0; 1].

• A mediate constant a = 0.15 implies the weight decreases by 15 percent when we move back in time each year. Though the mediate constant a in the equation of relative weight can be a arbitrary constant in [0; 1], the value of a = 0.15 is rational to quantify the impact variation with time goes by.

• Time range of 5 years or 15 years are reasonable enough for the impact of indicators, when T with 15 year range measures long and continuous impact and 5 year range measures relatively small and continuous impact.

Then we scale the relative weight to make the sum equals to 1 and get the result of absolute weight that used in our method of averaging.

$$Weight_{absolute} = \frac{(1-a)^T}{\sum_{i=0}^{T}(1-a)^i} \tag{1}$$

where we define a = 0.15 and T = 5; 10.

在前三个领域引入的所有 14 个指标中，我们对其中的 9 个使用了最新确定法，将它们视为短期影响因素。对于剩下的 5 个指标，我们使用加权平均法来衡量它们相对长期的影响。

4.4.2 加权平均法

我们应用指数权重函数，显示指标的影响随时间减小。我们定义相对权重（1-a）^{T}，其中 T 是落在 1 到 5 或 1 到 15 之间的整数之间的时间数，a 是介于区间[0; 1]。

•当我们时间回溯时，中间常数 a = 0.15 意味着权重减少了 15%。虽然相对权重方程中的中间常数 a 可以是[0; 1]，a = 0.15 的值是合理的，以量化随时间变化的权重变化。

•对于指标的影响，5 年或 15 年的时间范围是合理的，用 15 年的时间范围衡量长期的连续影响和 5 年范围衡量相对短期的影响。然后我们缩放相对权重以使总和等于 1，并得到平均方法中使用的绝对权重的结果。

$$Weight_{absolute} = \frac{(1-a)^T}{\sum_{i=0}^{T}(1-a)^i} \tag{1}$$

其中，a=0.15，T=5;10。

Parameter Scheme for Indicators: We use the weighted average method to process the data of 5 indicators. Three indicators belong to security category: social conflicts, incidence of coups, human rights abuse. Two indicators belong to economy category: Growth of Gross Domestic Product (GDP), Inflation.

We assign 15 year time span for social conflicts, incidence of coups; 5 year time span for human rights abuse, GDP and inflation. A country suffering social conflicts and incidence of coups need a relatively longer time to recover from the mighty and widespread social destruction. Under this condition, there are still repercussions with decreasing impact to make a country fragile. We assign 5 year time span for human rights abuse since it is a more flexible indicator, which can be easily changed by policy or other instant law. GDP and inflation measures the economic appearance of a country. Since economic event happen frequently in modern world and their effects do not vanish instantly, we assume the latest 5 year data forecast the present economy.

4.5 Climate

We consider two aspects of climate impact on fragility of a state. General climate impact indicator measures the impact under global climate trend such as global warming and glacier melting. The general impact are largely determined by the state's dependence on agriculture, water source and its location (risk of being submerged by rising sea level), etc. Extreme weather condition indicator measures the possibility of a country to become fragile faced with natural catastrophe. It relates tightly with the state's possibility of suffering a natural disaster and resistance of destruction.

指标参数：我们使用平均加权方法处理 5 个指标的数据。三个指标属于安全类别：社会冲突，政变发生，人权滥用。两个指标属于经济类别：国内生产总值（GDP）增长，通货膨胀。

我们为社会冲突，政变发生率分配了 15 年的时间跨度; 人权滥用，国内生产总值和通货膨胀时间跨度为 5 年。一个遭受社会冲突和政变发生的国家需要相对较长的时间才能从强大而广泛的社会破坏中恢复过来。在这种情况下，仍然会产生影响，使一个国家变得脆弱。我们为人权滥用分配了 5 年的时间跨度，因为它是一个更灵活的指标，可以通过政策或其他即时法律轻易改变。 GDP 和通货膨胀衡量一个国家的经济外观。由于经济事件在现代世界经常发生，其影响不会立即消失，我们假设最新的 5 年数据预测当前经济。

4.5 气候

我们考虑气候影响一个国家脆弱性的两个方面。 一般气候影响指标衡量全球变暖和冰川融化等全球气候趋势下的影响。 一般影响在很大程度上取决于国家对农业的依赖，水源及其位置（被海平面上升淹没的风险）等。极端天气状况指标衡量一个国家面临自然灾害的可能性。 它与国家遭受自然灾害和破坏抵抗的可能性密切相关。

4.5.1 General Climate Impact

From 1990s, people become more clear about the negative trend of climate and put more efforts on researches and control of the global climate change. Results of climate change including increased droughts, shrinking glaciers and other ecological problems, are blocking the development of many countries.

In this section, we employ four indicators to quantify the general climate impact on a country caused by the current global climate trend.

We process the raw data and normalize the values of four indicators to fall in a range from 0 to 5, and then give them different weights in the SPEC Model equation.

• Population living in areas where elevation is below 5 meters (% of total population)

Population living in areas where elevation is below 5 meters (% of total population) shows the risk of a country to become fragile faced with global warming and glacier melting. Once the sea level rises, and if a country has a large population living in the place with elevation lower than 5 meters, the residential condition in the country will meet with crisis. We calculate the indicator result as Equation (2), showing that more population living in areas where elevation is below 5 meters, smaller the value of the indicator is, and more fragile the country is.

$$C_{elv} = (1 - D_{elv}\%) \times 5 \tag{2}$$

where

– Celv is the normalized result of the indicator ranging from 0 − 5.

– Delv is the population percentage in the source which ranging from 0 − 56.18.

4.5.1 一般气候影响

从 20 世纪 90 年代开始，人们对气候的消极趋势认识的更加清晰，并更加努力地研究和控制全球气候变化。气候变化的结果，包括干旱加剧，冰川萎缩和其他生态问题，阻碍了许多国家的发展。

在本节中，我们采用四个指标来量化当前全球气候趋势对一个国家的总体气候影响。

我们处理原始数据并将四个指标的值归一化到 0 到 5 的范围内，然后在 SPEC 模型方程中给它们不同的权重。

• 居住在海拔低于 5 米的地区人口（占总人口的百分比）

生活在海拔低于 5 米（占总人口的百分比）的地区的人口显示出一个国家面临全球变暖和冰川融化的脆弱风险。 一旦海平面上升，如果一个国家有大量人口居住在海拔低于 5 米的地方，该国的居住条件将迎来危机。 我们将指标结果计算为公式（2），表明生活在海拔低于 5 米的地区的人口越多，指标值越小，国家越脆弱。

$$C_{elv} = (1 - D_{elv}\%) \times 5 \tag{2}$$

其中， Celv 是指标的归一化结果，范围从 0 到 5。Delv 是人口百分比，范围从 0 到 56.18。

• Forest area (% of land area)

Forest area reflects the animal and plant ranges and is a measurement of species richness. A larger forest area build a more stable and adaptable ecological environment when a state faced with climate change. We calculate the forest area indicator value in SPEC model using Equation (3), showing faster the growth of forest land, higher the indicator value is, and less fragile the country is.

$$C_{frst} = \exp\left(\frac{D_{t,frst}\%}{D_{T,frst}\%}\right) \tag{3}$$

C_{frst} is the normalized result of the forest area indicator ranging from 0 - 5.$D_{t,frst}$ is the forest area percentage in the latest year source ranging from 0-73.1.$D_{T,frst}$ is the forest area percentage in the reference year.

• Arable land (% of land area)

Frequent draughts and floods nowadays are the result of climate change and they diminish the area of arable land. Observing the change of arable land we can predict a country's resistance towards climate change. Equation (4) calculate the arable land indicator value in the SPEC model, showing lower the decreasing speed of arable land area, higher the arable land indicator value is, and less fragile the state is.

$$C_{ara} = \exp\left(\frac{D_{t,ara}\%}{D_{T,ara}\%}\right) \tag{4}$$

$\boldsymbol{C_{ara}}$ is the normalized result of the forest area indicator ranging from 0 - 5.$\boldsymbol{D_{t;ara}}$ is the arable land area percentage in the latest year source ranging from 0 - 56.175.$\boldsymbol{D_{T;ara}}$ is the arable land area percentage in the reference year.

•森林面积（占土地面积的百分比）

森林面积反映了动植物的范围，是物种丰富度的衡量标准。 当一个国家面临气候变化时，较大的森林面积可以建立一个更稳定和适应性更强的生态环境。 我们使用公式（3）计算 SPEC 模型中的森林面积指标值，林地的增长速度越快，指标值越高，国家的脆弱程度越低。

$$C_{frst} = \exp\left(\frac{D_{t,frst}\%}{D_{T,frst}\%}\right) \tag{3}$$

C_{frst} 是森林面积指标的归一化结果，范围从 0 到 5。$D_{t,frst}$ 是最近年份森林面积百分比，范围从 0-73.1。$D_{T,frst}$ 是参考年份的森林面积百分比。

•耕地（占土地面积的百分比）

如今频繁的干旱和洪水是气候变化的结果，它们减少了耕地面积。观察耕地面积的变化，我们可以预测一个国家对气候变化的抵御能力。公式（4）计算 SPEC 模型中的耕地指标值，显示耕地面积的下降速度越低，耕地指标值越高，状态越不脆弱。

$$C_{ara} = \exp\left(\frac{D_{t,ara}\%}{D_{T,ara}\%}\right) \tag{4}$$

C_{ara} 是森林面积指数在 0-5 之间。$D_{t,ara}$ 是最近一年的耕地面积百分比，范围是 0-56.175。$D_{T,ara}$ 是参考年份的耕地面积百分比。

• People using basic drinking water service (% of population)

Global climate change give rise to the possibility of floods and droughts. Draughts especially, threaten the daily water supply for residence. Water resource is also one of the core inducement of region conflicts. Change of the population using basic drinking water service measures the state's dependence on water. We use Equation (5) to calculate the drinking water indicator in the SPEC Model. If the population using drinking water service rises with time, the state depends less on water resource and thus less on climate, and appears less fragile.

$$C_{drk} = \exp\left(\frac{D_{t,drk}\%}{D_{T,drk}\%}\right) \tag{5}$$

C_{drk} is the normalized result of the drinking water indicator ranging from 0 - 5. $D_{t,drk}$ is the drinking water service population in the latest year source ranging from 0 - 100. $D_{T,drk}$ is the drinking water service population in the reference year.

On the basis of accessible data, we use different ways to process the data and let the indexes fall in the value interval [0*;* 5]. Then we weigh the indexes Ψ_1, Ψ_2, Ψ_3, Ψ_4 and get the value of general climate impact indicator as Equation (6).

$$Climate_{gen} = \varphi_1 C_{elv} + \varphi_2 C_{frst} + \varphi_3 C_{ara} + \varphi_4 C_{drk} \tag{6}$$

•使用基本饮用水服务的人（占人口的百分比）

全球气候变化导致洪水和干旱的可能性。 特别是干旱，威胁到居住的日常供水。水资源也是地区冲突的核心诱因之一。使用基本饮用水服务的人口数量，体现了国家对水的依赖程度。 我们使用公式（5）来计算 SPEC 模型中的饮用水指标。 如果使用饮用水服务的人口随着时间的推移而增加，那么地区对水资源的依赖程度较低，因此对气候的依赖程度较低，而且脆弱性较低。

$$C_{drk} = \exp\left(\frac{D_{t,drk}\%}{D_{T,drk}\%}\right) \tag{5}$$

C_{drk} 是饮用水指标的标准化结果，范围从 0 到 5。$D_{t,drk}$ 是最近一年的饮用水服务人口，范围从 0 到 100。$D_{T,drk}$ 是参考年份的饮用水服务人口。

在可访问数据的基础上，我们使用不同的方式处理数据，让索引落在值区间[0;5]。然后通过权重指数Ψ1，Ψ2，Ψ3，Ψ4，得到一般气候影响指标的值。

$$Climate_{gen} = \varphi_1 C_{elv} + \varphi_2 C_{frst} + \varphi_3 C_{ara} + \varphi_4 C_{drk} \tag{6}$$

4.5.2 Extreme Weather Events

There is little doubt that the Earth's climate is changing and weather is becoming more extreme. Future warming will bring more dangerous condition, even if the world manages to keep temperature rises within a 2◦C limit to which governments have committed. The state's ability to cope with extreme weather has shown an increasing role in safeguarding economic and social stability. The full formula for country scoring in extreme condition is given by

$$Climate_{ext} = e^{-R} \cdot \ln \frac{CO_{2t}}{CO_{2T}} \cdot p \tag{7}$$

where p% is the universal probability of extreme weather. At current time, it's reasonable to set the value of p to 5%. CO_{2t} is national CO_2 emissions(kt) that year. CO_{2T} is national CO_2 emissions(kt) in year 1990. R refers to self-regulation factor. It is originally a measure of the stability of the ecosystem and here it indicates country's ability to effectively carry out disaster relief and disaster prevention work. This factor is synthesized from three parts which we discuss later.

Extreme weather events is of small probability, but can be catastrophic. In the process of increasing overall national strength, the state's response capability to extreme weather conditions is also on the rise. However extreme heatwaves and heavy rain storms are already happening with increasing regularity worldwide because of man-made climate change. Therefore a proportional item CO_{2t} / CO_{2T} is of necessity in the formula to indicate the increasing difficulty of disaster relief and the increase of probability.

4.5.2 极端天气事件

毫无疑问，地球的气候正在发生变化，天气变得更加极端。即使设法将温度升高控制在政府承诺的 2°C 范围内，未来气候变暖也将带来更加危险的状况。国家应对极端天气的能力在保障经济和社会稳定方面发挥着越来越大的作用。 不同国家在极端天气指标下的家得分由下式给出

$$Climate_{ext} = e^{-R} \cdot \ln \frac{CO_{2t}}{CO_{2T}} \cdot p \tag{7}$$

其中，p 为极端天气的发生概率。目前，将 p 的值设置为 5%是合理的。 CO2t 是当年的国家二氧化碳排放量（kt）。 CO2T 是 1990 年的国家二氧化碳排放量（kt）. R 指的是自我调节因子。 它最初是衡量生态系统稳定性的指标，它表明了国家有效开展救灾和防灾工作的能力。 该因子由我们稍后讨论的三个部分合成。

极端天气事件概率很小，但可能是灾难性的。在提高综合国力的过程中，国家对极端天气条件的反应能力也在不断提高。然而，由于人为因素导致的气候变化，极端的热浪和大暴雨已经在全球范围内日益增加。因此，公式中使用比例项 $CO2t / CO2T$ 来表示救灾难度的增加和概率的增加。

4.5.3 Self-regulatory factor *R*

Self-regulatory factor *R* is synthesized from three parts: national land area, per capita income, security. The self-regulatory factor *r* is determined by Equation (8).

$$\begin{aligned} R &= \theta_1 r_1 + \theta_2 r_2 + \theta_3 r_3, && R \in (0,1) \\ r_1 &= \ln \frac{s(n)}{s(USA)}, && r_1 \in (0,1) \\ r_2 &= \ln \frac{i(n)}{i(L)}, && r_2 \in (0,1) \\ r_3 &= security/50, && r_3 \in (0,1) \end{aligned} \tag{8}$$

where s(n) is national land area, s(USA) is the land area of America. For Russia and Canada, whose land area is bigger than America, we set its r1 to 1 to avoid inaccuracy.

***i*(*n*)** is per capita income, and ***i*(*L*)** is the per capita income of Luxembourg. According to *World Bank*, Luxembourg's per capita income ranks first in the world. Security score is already obtained, we divide it by 50 to have the value fall in the range of zero to one.

Security factors is the basic guarantee for dealing with extreme weather events. Relatively large land area enhance disaster prevention capabilities to some extent for its rich resources and manpower. Per capita income is the embodiment of the current economic strength that support disaster prevention and relief work.

4.6 Calculation

The score of the SPEC Model measures the fragility of a state. Higher scores show less fragility while lower scores show more fragility. The $SPEC_{score}$ has the equation form as

$$SPEC_{Score} = \frac{Security + Politics + Economics + Climate_{gen}}{Climate_{ext}} \tag{9}$$

4.5.3 自我调节因子 R

自我调节因子 R 由三部分组成：国土面积，人均收入，安全。 自调节因子 r 由等式（8）确定。

$$\begin{aligned} R &= \theta_1 r_1 + \theta_2 r_2 + \theta_3 r_3, && R \in (0,1) \\ r_1 &= \ln \frac{s(n)}{s(USA)}, && r_1 \in (0,1) \\ r_2 &= \ln \frac{i(n)}{i(L)}, && r_2 \in (0,1) \\ r_3 &= security/50, && r_3 \in (0,1) \end{aligned} \tag{8}$$

其中 s（n）是国土面积，s（美国）是美国的陆地面积。对于其土地面积大于美国的俄罗斯和加拿大，我们将其 r1 设置为 1 以减小误差。

i（n）是人均收入，i（L）是卢森堡的人均收入。根据世界银行的数据，卢森堡的人均收入位居世界第一。安全指标得分上文已经定义，我们将其除以 50 以使值落在零到一的范围内。

安全因素是应对极端天气事件的基本保证。 由于资源和人力资源丰富，相对较大的土地面积在一定程度上增强了防灾能力。 人均收入是当前支持防灾救灾工作的经济实力的体现。

4.6 计算

SPEC 模型的得分衡量一个国家的脆弱性。分数越高表示脆弱性越低，而分数越低表示脆弱性越强。SPEC 得分的计算公式为

$$SPEC_{Score} = \frac{Security + Politics + Economics + Climate_{gen}}{Climate_{ext}} \tag{9}$$

Equation (9) shows the relation between the SPEC score and indicators of four core fields regarding fragility: security, politics, economics and climate, where climate consists of general climate change and extreme weather condition. The five security indicators, the four political indicators, the five economical indicators and four general climate indicators have positive correlation with the SPEC score. Bigger the value of the indicators, bigger the value of the SPEC score and less fragility of a state.

We only put the indicators considering extreme weather condition in the denominator, showing the negative correlation with the SPEC score. Bigger the value of extreme weather indicator, smaller the value of the SPEC score and more fragile of a state.

We span the item of $Climate_{ext}$ referring to Equation (8), since its calculation differs from the other four items in the numerator of Equation (9).

$$SPEC_{score} = \frac{Security + Politics + Economics + Climate_{gen}}{e^{-R} \cdot \ln \frac{CO_{2t}}{CO_{2T}} \cdot p} \tag{10}$$

where the self-regulatory factor ***R*** has the detailed form of Equation (11) with coefficients determined by AHP. The analytic hierarchy process (AHP) is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology [5].

$$R = (31.89\%)\left(\ln \frac{s(n)}{s(USA)}\right) + (22.11\%)\left(\ln \frac{i(n)}{i(L)}\right) + (46.00\%)\,(security/50) \tag{11}$$

We prioritize the indicators and employ AHP to get the coefficients for every indicator. Results are listed in Table (2).

公式（9）显示了 SPEC 得分与脆弱性四个核心领域的指标之间的关系：安全，政治，经济和气候，其中气候包括一般气候变化和极端天气条件。五项安全指标，四项政治指标，五项经济指标和四项一般气候指标与 SPEC 得分呈正相关。 指标的得分越大，SPEC 得分的值越大，国家的脆弱性就越小。

我们仅在分母中考虑极端天气条件指标，与 SPEC 分数呈负相关。极端天气指标的得分越大，SPEC 得分的值越小，状态越脆弱。

参考等式（8），因为它的计算与等式（9）的分子中的其他四个项目不同。

$$SPEC_{score} = \frac{Security + Politics + Economics + Climate_{gen}}{e^{-R} \cdot \ln \frac{CO_{2t}}{CO_{2T}} \cdot p} \tag{10}$$

其中自调节因子 R 计算方式见等式（11），其中系数由 AHP 确定。层次分析法（AHP）是一种基于数学和心理学的组织和分析复杂决策的结构化技术[5]。

$$R = (31.89\%)\left(\ln \frac{s(n)}{s(USA)}\right) + (22.11\%)\left(\ln \frac{i(n)}{i(L)}\right) + (46.00\%)\,(security/50) \tag{11}$$

我们采用 AHP 来获得每个指标的系数。 结果列于表（2）中。

Table 2: The weight of indicators

Indicators	weight (%)
Social conflicts	20.69
Political stability and absense of violence	17.24
Incidence of coups	27.59
Gross human rights abuses	10.34
Refugee	24.14
Government effectiveness	25.00
Rule of law	25.00
Control of corruption	25.00
Voice & Accountability	25.00
Gross National Income (GNI) per Capita	25.93
Growth of Gross Domestic Product (GDPïijL′	29.63
Inflation	11.11
Income Inequality	18.51
Regulatory Quality	14.86
Population living in areas where elevation is below 5 meters	11.31
Forest area	35.43
Arable land	22.61
People using basic drinking water service	30.65

Then, We have precise Equations (12) to calculations each indicator, and plug them in Equation (9) to get the SPEC score. We conclude the results in Figure (2).

$$
\begin{aligned}
Security &= (20.69\%)S_{conf} + (20.69\%)S_{abv} + (20.69\%)S_{coups} + (20.69\%)S_{abuse} + (24.14\%)S_{ref} \\
Politics &= (25.00\%)P_{gov} + (25.00\%)P_{law} + (25.00\%)P_{corpt} + (25.00\%)P_{acc} \\
Economics &= (25.93\%)E_{GNI} + (29.63\%)E_{GDP} + (11.11\%)E_{inf} + (18.51\%)E_{ineq} + (14.86\%)E_{reg} \\
Climate_{gen} &= (11.31\%)C_{elv} + (35.43\%)C_{frst} + (22.61\%)C_{ara} + (30.65\%)C_{drk}
\end{aligned}
\tag{12}
$$

Table 2: The weight of indicators

Indicators	weight (%)
Social conflicts	20.69
Political stability and absense of violence	17.24
Incidence of coups	27.59
Gross human rights abuses	10.34
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Income Inequality	18.51
Regulatory Quality	14.86
Population living in areas where elevation is below 5 meters	11.31
Forest area	35.43
Arable land	22.61
People using basic drinking water service	30.65

然后，我们以等式（12）来计算每个指标，并将它们插入等式（9）以获得 SPEC 得分。 我们在图（2）中得出结论。

$$
\begin{aligned}
Security &= (20.69\%)S_{conf} + (20.69\%)S_{abv} + (20.69\%)S_{coups} + (20.69\%)S_{abuse} + (24.14\%)S_{ref} \\
Politics &= (25.00\%)P_{gov} + (25.00\%)P_{law} + (25.00\%)P_{corpt} + (25.00\%)P_{acc} \\
Economics &= (25.93\%)E_{GNI} + (29.63\%)E_{GDP} + (11.11\%)E_{inf} + (18.51\%)E_{ineq} + (14.86\%)E_{reg} \\
Climate_{gen} &= (11.31\%)C_{elv} + (35.43\%)C_{frst} + (22.61\%)C_{ara} + (30.65\%)C_{drk}
\end{aligned}
\tag{12}
$$

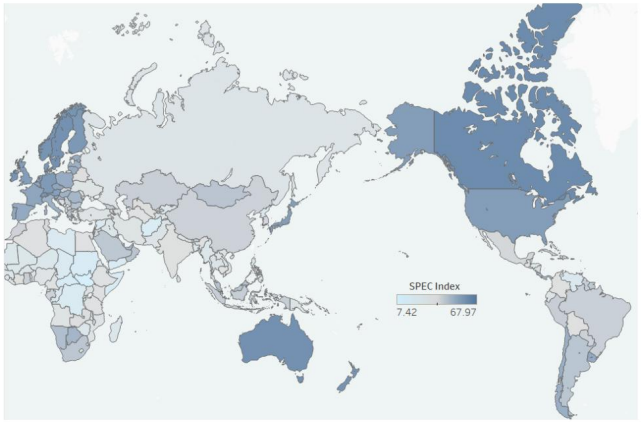

Figure 2: World map for SPEC score. Higher score means means a state less fragile, and lower score means a state more fragile.

Figure 2: World map for SPEC score. Higher score means means a state less fragile, and lower score means a state more fragile.

5 Answers to Tasks

5.1 Task 1

We use the SPEC Model to determine the fragility of a state. Fragility classification depends on the value of the SPEC score. SPEC score falls between 0 to 27 belongs to fragile category; SPEC score falls between 27 to 50 belongs to vulnerable category; SPEC score falls between 50 to 70 belongs to stable category.

Table 3: Fragility classification

SPEC score	Fragility
$[0, 27)$	Fragile
$[27, 50)$	Vulnerable
$[50, 70)$	Stable

To measure the climate impact on fragility, we evaluate the values of $Climate_{ext}$ to see direct impacts and $Climate_{gen}$ to analyse indirect impacts.

5 问题解答

5.1 问题 1

我们使用 SPEC 模型来确定一个国家的脆弱性。脆弱性分类取决于 SPEC 得分的值。 SPEC 得分在 0 到 27 之间属于脆弱类别; SPEC 得分在 27 到 50 之间属于较脆弱类别; SPEC 得分在 50 到 70 之间属于稳定类别。

Table 3: Fragility classification

SPEC score	Fragility
$[0, 27)$	Fragile
$[27, 50)$	Vulnerable
$[50, 70)$	Stable

为了衡量气候对脆弱性的影响，我们评估了 $\text{Climate}_{\text{ext}}$ 得分，以分析直接影响和 $\text{Climate}_{\text{gen}}$ 来分析间接影响。

$Climate_{ext}$ measures the intensity of direct extreme climate impacts. According to statical data generated by the SPEC Model, $Climate_{ext}$ larger than 2.70, indicating a state's extreme weather conditions impacts the fragility to a great extent. $Climate_{ext}$ between 2.00 and 3.70 is normal. $Climate_{ext}$ below 2.00 means the state has little impact from extreme weather conditions.

$Climate_{ext}$ is influence by two main factors: **i)** self-regulatory factor R: R below 0.60 means a country is not capable of fighting extreme climate impacts and existence of extreme weather lead to more fragility; 0.60 to 0.75 is the normal range; R above 0.75 means a country is very powerful to cope with extreme weather, and acts less sensitive to destruction of extreme climate. **ii)** probability of extreme weather events $\ln(CO_{2t} / CO_{2T})\ p$, which is influence by the emission of the greenhouse gases. CO2 emission index larger than 0.80 is a serious phenomenon saying that a country is having too much CO2 emission to promote the possibility of having extreme weather and thus increase its fragility.

$Climate_{gen}$ measures the indirect impacts of climate. According to SPEC Model statistical data, $Climate_{gen}$ above 5.00 is having large indirect impact of climate by affecting other indicators in security, political, economical fields. $Climate_{gen}$ between 3.00 and 5.00 is normal. $Climate_{gen}$ below 3.00 appear to have little indirect impact from climate change.

5.2 Task 2

We choose Yemen to discuss its fragility causes. Yemen ranks seven in our SPEC fragility list, which agrees well with its rank in the fsi list.

$Climate_{ext}$ 表征极端气候直接影响的强度。根据 SPEC 模型生成的数据，$Climate_{ext}$ 大于 2.70，表明该地区的极端天气条件在很大程度上影响了脆弱性。 $Climate_{ext}$ 在 2.00 和 3.70 之间是正常的。$Climate_{ext}$ 低于 2.00 意味着该地区对极端天气条件的影响很小。$Climate_{ext}$ 受两个主要因素的影响：i）自我调节因子 R：R 低于 0.60 意味着一个国家不能应对极端气候影响，极端天气的存在导致更加脆弱; 0.60 到 0.75 是正常范围; R 高于 0.75 意味着一个国家应对极端天气非常强大，对极端气候的破坏行为不那么敏感。ii）极端天气事件的概率 $\ln(CO_{2t} / CO_{2T})p$，其受温室气体排放的影响。二氧化碳排放指数大于 0.80 是一个严重的现象，即一个国家的二氧化碳排放量太大，以促进极端天气的可能性，从而增加其脆弱性。$Climate_{gen}$ 衡量气候的间接影响。根据 SPEC 模型统计数据，5.00 以上的 $Climate_{gen}$ 通过影响安全，政治，经济领域的其他指标，对气候产生巨大的间接影响。$Climate_{gen}$ 在 3.00 和 5.00 之间是正常的。低于 3.00 的 $Climate_{gen}$ 似乎没有受到气候变化的间接影响。

5.2 问题 2

我们选择也门来讨论它的脆弱性原因。也门在我们的 SPEC 脆弱性排行榜中排名第七，这与其在 fsi 榜单中的排名非常吻合。

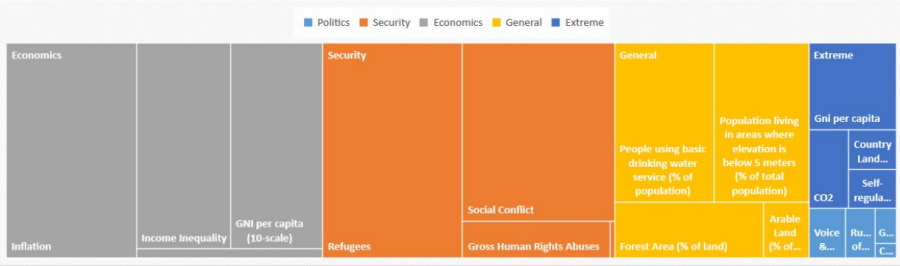

Figure 3: yemen

The direct climate indicator $Climate_{ext}$ = 2.83 is larger than 2.70, which means the fragility of the country is greatly influenced by the extreme climate events. The reason behind is that Yemen has a low self-regulatory factor R = 0.60, indicating its poor resistance before natural catastrophe. R made up of an item $r3$ = *security*=50, and since there are social conflicts and coups inside the country, Yemen owns a poor ability to recover itself once encounter climate shocks. Extreme climate conditions can easily drive Yemen to be fragile.

The indirect climate indicator $Climate_{gen}$ = 3.67 is a normal value for according to SPEC's statistical data. Therefore, it contributes little to Yemen's fragility.

How to be less fragile

- Improve political conditions and stop coups.
- Improve security conditions by stopping social conflicts.
- Live in harmony with the neighbouring countries to help when faced with climate problems.
- Increase self-regulatory factor to promote the state's capability to cope with extreme climate events.

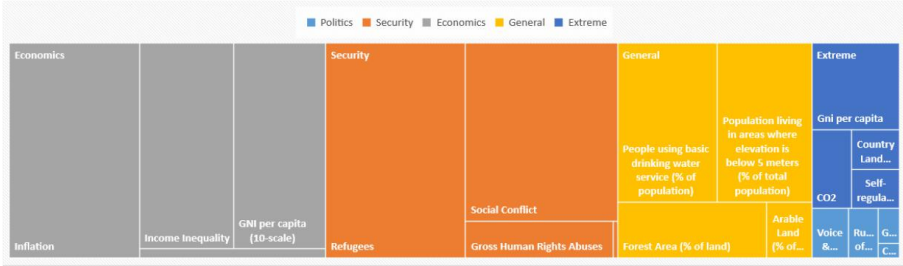

Figure 3: yemen

直接气候影响指标 $Climate_{ext}$ = 2.83 大于 2.70，这意味着该国的脆弱性极大地受到极端气候事件的影响。其原因是也门的自我调节因子 R = 0.60，表明其在自然灾害面前的抵抗力较差。R 的其中一个子项 r3 = security = 50，由于国内存在社会冲突和政变，也门一旦遇到气候冲击，其自我恢复能力很差。极端气候条件很容易使也门变得脆弱。

根据 SPEC 的统计数据，间接气候指标 $Climate_{gen}$ = 3.67 是正常值。因此，它对也门的脆弱性贡献很小。

如何降低脆弱性

- 改善政治条件并停止政变。
- 通过制止社会冲突改善安全状况。
- 在遇到气候问题时与邻国和睦相处。
- 增加自我监管因素，以提高国家应对极端气候事件的能力。

5.3 Task 3

As is shown above, Climate Change effects a country's fragility from two aspects, including general part and extreme part. As we have mentioned, the general part refers to the indirect impacts of Climate Change. According to available sources, we find indirect impacts only has slight influence on the fragility of a country in a short period.

Therefore, we conclude that the general part effects the fragility in a long period. That period will be at least twenty-year-scaled. In this case, we mainly consider the impacts of the extreme part when measuring the fragility of a country.

5.3.1 Tipping Model Based on Self-regulatory Factor

From the above conclusion, we find that Climate Change pushes a country to become more fragile mostly via its extreme part. According to what is discussed in the Model Section, we come to determine the definitive indicators.

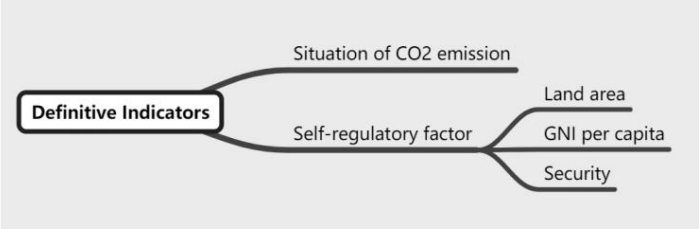

Figure 4: Definitive indicators of impacts of Climate Change.

Since the situation of $CO2$ emissions of a country is limited to its current technology and has close relation to its future development, it might be steady in a long term. So our major work is to discuss the self-regulatory factor.

5.3 任务 3

如上所示，气候变化从两个方面影响一个国家的脆弱性，包括一般部分和极端部分。正如我们所提到的，一般部分是指气候变化的间接影响。根据现有资料，我们发现间接影响只会在短期内对一个国家的脆弱性产生轻微影响。

因此，我们得出结论，极端部分长期影响脆弱性，至少达到二十年。在这种情况下，我们主要考虑衡量一个国家脆弱性时极端部分的影响。

5.3.1 基于自我调节因子的模型

从上述结论中，我们发现气候变化推动一个国家变得更加脆弱，主要是通过它的极端部分。根据模型部分讨论的内容，我们来确定最终指标。

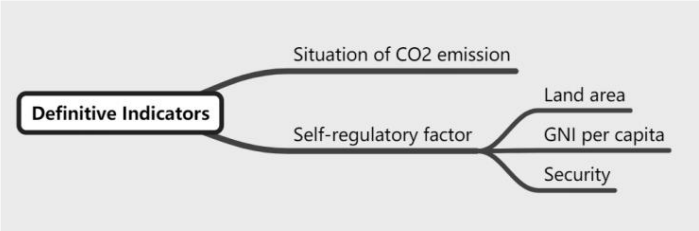

图 4：气候变化影响指标。

由于一个国家的二氧化碳排放情况仅限于其现有技术，并且与其未来发展密切相关，因此从长远来看相对是是稳定的。 所以我们的主要工作是讨论自我调节因子。

Moreover, we use our SPEC data calculated above to see the relation between SPEC index and the self-regulatory factor.

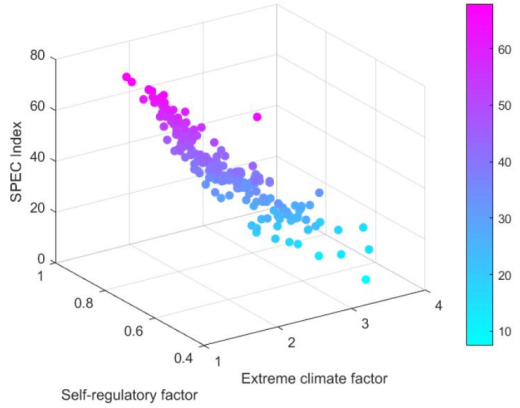

Figure 5: Relation of SPEC Index

From the Figure (7), we find that SPEC index and the self-regulatory factor has a beautiful linear relation. When the self-regulatory factor increases, the relevant SPEC also increases. This relation confirms our assumption and discussion above.

Since the self-regulatory factor measures the ability of countries to maintain their current condition facing extreme situations, it is valid for us to put forward a Tipping Model based on Self-regulatory Factor.

From the relation between SPEC index and self-regulatory factor, we have the following definition:

Tipping Point: The Tipping Point of a country is the time when its self-regulatory factor decrease to reach the very value 0:6, and becomes lower.

此外，我们使用上面计算的 SPEC 数据来查看 SPEC 指数与自我调节因子之间的关系。

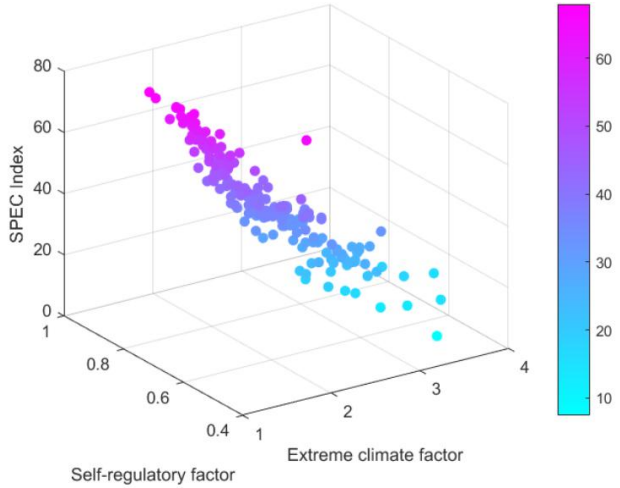

图 5：SPEC 指数的关系

从图（5）可以看出，SPEC 指数与自我调节因子具有良好的线性关系。当自我调节因子增加时，相关的 SPEC 也会增加。这种关系证实了我们上面的假设和讨论。

由于自我调节因子衡量的是各国在极端情况下保持现状的能力，因此我们提出一个基于自我调节因子的模型是有效的。

从 SPEC 指数和自我调节因子之间的关系，我们有以下定义：

临界点：一个国家的临界点是其自我调节因子减少到达 0.6 的值的时间，并且有变低的趋势。

Due to the indicators self-regulatory factor use, it well illustrates slight changes of security, political, economical conditions of a country under Climate Change. When the value of self-regulatory factor is smaller than 0:6, it is impossible for those countries to keep them safe from extreme climate shocks. Also, from the results of our model above, we find that such countries with small self-regulatory factor mostly are fragile, and some vulnerable. This shows our definition of Tipping Point is quite reasonable.

5.3.2 Application of Our Model to India

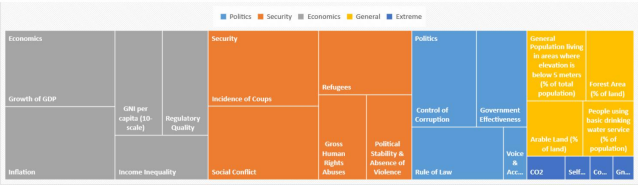

Figure 6: India

From Figure (7) , we have the following conclusions:

• India is a **vulnerable** country.

• Politics in India is stable, but not strong.

• India exists **gross human rights abuses**, especially to females.

• Due to the geographical position of India, large amount of population of India living in areas where elevation is below 5 meters face the severe threaten of rising sea level.

• The yearly rising CO2 emissions put India at higher risk of extreme weathers.

• Although India has self-regulatory factor 0.735, it is at quite high risk facing extreme weathers as a result of Tropical Monsoon Climate.

由于指标自我调节因子的作用，它很好地说明了在气候变化情况下，一个国家的安全、政治和经济条件的微小变化。 当自我调节因子的值小于 0.6 时，这些国家不可能保护它们免受极端气候冲击的影响。此外，从我们上述模型的结果来看，这些自调节因子较小的国家大多是脆弱的，有些是较脆弱的。这表明我们对临界点的定义是非常合理的。

5.3.2 我们的模型应用于印度

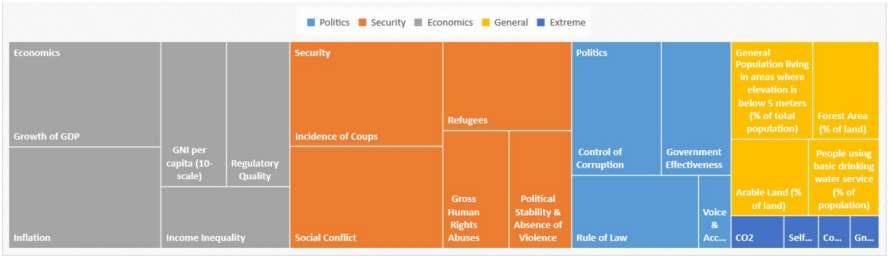

图 6：印度

从图（7）中，我们得出以下结论：

•印度是一个较脆弱的国家。

•印度的政治稳定，但不强大。

•印度存在严重的侵犯人权行为，特别是对女性而言。

•由于印度的地理位置，生活在海拔低于 5 米的地区的大量印度人口面临海平面上升的严重威胁。

•每年二氧化碳排放量的增加使印度处于极端天气的高风险之中。

•虽然印度的自我调节因子为 0.735，但由于热带季风气候，极端天气面临极高的风险。

Therefore, India is becoming more vulnerable to extreme weathers. If India do not take effective measures to solve gross human rights abuses, India may face more social conflicts, which negatively affect economics and security of India. This adverse trend will bring down the self-regulatory factor of India, and India might reach the Tipping Point in a short period.

5.4 Task 4

According to SPEC Index, climate change has direct and indirect effects on states' stability. Initiatives is needed to deal with these two aspects respectively. Our eight proposed state driven interventions for India is in appliance with the climate indicators in SPEC Index.

For general climate impact:

• Set strict control over the rezoning of cultivated land during urbanization.

• Promote agricultural transformation and upgrading, increase water use efficiency and equity.

• Develop desalination technology.

• Carry out old town renovation and reasonably increase the urban density. Urban planning has to focus on tall buildings.

• Increase the income of the forestry sector, focus on the renewal and reforestation of natural forests and reduce artificial forests of single tree species.

For extreme weather events:

• Promote accurate poverty alleviation and attach more importance to the consistency of poverty alleviation policies.

• Strengthen infrastructure construction in rural areas and promote housing safety for lower-class residents.

• Add medical expenses to local health insurance plan and focus on reducing under-5 deaths rate.

因此，印度越来越容易受到极端天气的影响。如果印度不采取有效措施解决严重的侵犯人权行为，印度可能会面临更多的社会冲突，这会对印度的经济和安全产生负面影响。这种不利趋势将降低印度的自我调节，印度可能在短期内达到临界点。

5.4 问题 4

根据 SPEC 指数，气候变化对国家稳定具有直接和间接影响。需要采取措施分别处理这两个方面。

我们针对印度提出的八项国家驱动干预措施与 SPEC 指数中的气候指标有关。

对于一般气候影响：

•严格控制城市化过程中耕地的分配。

•促进农业转型升级，提高用水效率和公平性。

•开发海水淡化技术。

•进行旧城改造，合理增加城市密度。城市规划必须关注高层建筑。

•增加林业部门的收入，重点关注天然林的更新和重新造林，减少单一树种的人工林。

对于极端天气事件：

•促进准确的扶贫，更加重视扶贫政策的一致性。

•加强农村基础设施建设，促进下层居民的住房安全。

•将医疗费用添加到当地健康保险计划中，并将重点放在降低 5 岁以下儿童死亡率上。

These initiatives closely respond to the impact of general climate factors as follows.

1. According to the World Bank collection of development indicators, arable land in India was reported at 156463000 ha in 2015,about 500,000 hectares les than year 2004. To deal with dwindling arable land, India must set strict control over the rezoning of cultivated land. Land other than agricultural use needs to be more efficiently utilized.

2. Faced with increasing population, density in residential neighbourhoods has to be increased by decreasing lot sizes and replacing old houses with town-houses.

3. Report[6] claimed that India's population is growing faster than its ability to produce rice and wheat. To feed its growing population, India should raise its farm productivity by reducing food staple spoilage and improving its infrastructure.

4. Affected by the southwest monsoon, grain output fluctuates every few years. From 1999 to 2005, the minimum grain output reached 1.74 billion tons, the highest at 213 million tons, a difference of 390 million tons [7]. Thus, under the influence of continued climate change, the pressure on food security in India is likely to increase.

5. India has already carried out Forest regeneration program, but many are single-species plantations. Large-scale afforestation in degraded forest areas, including monoculture, can not create the ecosystems and biodiversity needed for abundant animal and plant ranges [8].

这些举措与一般气候因素的影响紧密相关。

1.根据世界银行的发展指标，2015 年印度的耕地面积为 156463000 公顷，比 2004 年减少约 50 万公顷。为应对耕地减少，印度必须严格控制耕地的重新划分。需要更有效地利用农业用途以外的土地。

2.面对不断增长的人口，增加住宅区的密度，减少地块面积和用楼房取代旧房屋。

3.报告[6]声称印度的人口增长速度快于其生产大米和小麦的能力。为了满足不断增长的人口需求，印度应通过减少食物腐败和改善其基础设施来提高其农业生产力。

4.受西南季风影响，粮食产量每隔几年波动一次。从 1999 年到 2005 年，最低粮食产量达到 17.4 亿吨，最高为 2.13 亿吨，相差 3.9 亿吨[7]。因此，在持续气候变化的影响下，印度的粮食安全压力可能会增加。

5.印度已经开展了森林更新计划，但许多是单一种植园。退化森林地区的大规模植树造林，包括单一栽培，无法创造丰富的动植物范围所需的生态系统和生物多样性[8]。

6.In 2015, implementation of a universal health care system was delayed due to budgetary concerns. Penetration of health insurance in India is low by international standards and most health care expenses are paid out of pocket by patients and their families, rather than through insurance [9]. The add to the vulnerability of low-class residents facing extreme weather events.

5.4.1 Predict the total cost of intervention

It's quite diffcult to accurately predict the expenses these measures for India required. We first determine the field to these measures belong and refer to *The Expenditure of Government of India 2016-2017* to get access to the government's total spending in this area.

Then we compare and estimate the ratio of expenditures on this measure to major items in this area. The estimated expenditure of our 8 proposed intervention is listed below. (Unit:hundred million dollars)

Table 4: Estimated expenditure of each intervention

Intervention	Expenditure
Control of rezoning	18.7
Agricultral upgrading	77.9
Desalination	50
Rural renovation	1558
Forestry sector	20
Poverty alleviation	468
Housing safety	1000
Healthcare	100

5.5 Task 5

We notice that only a few countries cover extra large land areas equivalent of continents. If measured by population, countries that own 20 million to 50 million people is equivalent to the scale of a medium-sized city and only 25 countries is under that size. When coming to smaller states and larger states, to be more mathematically precise, we have to adjust the coefficient of our SPEC Model.

6.2015 年，由于预算问题，全民医疗保健制度的实施被推迟。按照国际标准，印度的医疗保险普及率很低，大多数医疗保健费用由患者及其家庭自掏腰包，而不是通过保险[9]。这增加了低收入居民面对极端天气事件的脆弱性。

5.4.1 预测干预的总成本

准确预测这些措施对印度所需的费用是非常困难的。我们首先确定这些措施属于哪个领域，并参考 2016-2017 印度政府支出，以获得政府在该领域的总支出。

然后，我们比较、估计这一措施的支出与该领域主要项目支出的比率。我们 8 项拟议干预措施的预计支出如下。（单位：亿美元）

Table 4: Estimated expenditure of each intervention

Intervention	Expenditure
Control of rezoning	18.7
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Desalination	50
Rural renovation	1558
Forestry sector	20
Poverty alleviation	468
Housing safety	1000
Healthcare	100

5.5 问题 5

我们注意到只有少数几个国家覆盖了相当于大陆的超大陆地面积。 如果以人口来衡量，拥有 2000 万至 5000 万人口的国家相当于一个中等规模城市的规模，只有 25 个国家的人口规模不足。当用于较小的州和较大的州时，为了在数学上更精确，我们必须调整我们的 SPEC 模型的系数。

What's noteworthy is that it's never merely the change in land area, indicators in security, politic and economic fields are all affected.

5.5.1 Larger "states"

To obtain a modification of SPEC Model, a ex-State model is required. The following facts need special consideration.

• Big countries have more human and energy resources and can be fully deployed during times of emergency.

• As a combination of countries, continents have inherent advantages in developing resilient and flexible policy-making. All regions have a higher degree of coordination and complementarity of policies when faced with unrest.

• Policy silos are more impossible to exist, it is essential rearrange evaluation system in a broader context of education, healthcare, good governance, and societal resilience.

5.5.2 Ex-State model

As noted above, we already have each country's score on fragility and now we need to weight each of them. The scoring formula is

$$F_{cop} = \frac{\sum_{k=1}^{n} R_i F_i}{\sum_{k=1}^{n} R_i} \tag{13}$$

Where F_{cop} is the fragility of the hole continent. F_i is the fragility of the hole continent. R_i is the earlier determined self-regulation factor of each country.

Notice that countries rank high in SPEC fragility index has high likelihood of future political and economic instability. In broader view, these countries take on more responsibility in face of difficulties. Therefore we determine the expression of continent's fragility by a weighted average expression. This approach is concise and effective.

值得注意的是，它不仅仅是土地面积的变化，安全，政治和经济领域的指标都受到影响。

5.5.1 更大的"地区"

为了对 SPEC 模型进行修改，需要使用前评价模型。以下条件需要特别考虑。

•大国拥有更多的人力和能源资源，可以在紧急情况下全面部署。

•作为一个国家组合，各大洲在制定弹性和灵活的政策制定方面具有先天优势。 面对动乱时，所有地区都有更高程度的协调和政策互补。

•政策孤岛更不可能存在，它是在更广泛的教育，医疗保健，良好治理和社会复原力背景下重要的重新评估系统。

5.5.2 前状态模型

如上所述，我们已经拥有每个国家对脆弱性的评分，现在我们需要对每个国家进行加权。计算公式为：

$$F_{cop} = \frac{\sum_{k=1}^{n} R_i F_i}{\sum_{k=1}^{n} R_i} \tag{13}$$

其中 F_{cop} 是大陆的脆弱性。F_i 是国家的脆弱。 R_i 是每个国家较早确定的自我调节因子。

请注意，SPEC 脆弱指数排名靠前的国家很有可能出现未来的政治和经济不稳定。 从更广泛的角度来看，这些国家在面临困难时承担更多责任。 因此，我们通过加权平均表达式确定国家脆弱性的表达。这种方法简洁有效。

5.5.3 Dealing with missing data

Though our SPEC indicators have relatively good data coverage worldwide, there are missing data points. In this ex-State model where multiple area needs to be included, we don't filling these data gaps with imputed estimates.

Instead we calculate with available country data using the formula above. Our rationale is that neither the accuracy of the overall continent weakness score, nor the credibility, are significantly affected by the missing data. Furthermore, most countries have data for all SPEC indicators.There is a risk that imputed data would amount to an implausible estimate of a country's performance on certain indicators.

5.5.4 Smaller "states"

Cities have less industrial diversity and abundance of resources compared with states. here we explain how to rearrange the weight of each SPEC fields. The following facts need special consideration.

• With globalization providing a net benefit to nations around the world, regions are linked closer with each other.

• The city's basic climatic conditions can be obtained from the country's data.

• Each city has its own major industry which reflect the city's overall strength and significantly affect its vulnerability to economic fluctuations and climate events.

5.5.5 Re-weighting for SPEC index

Here are the principles for re-weighting.

5.5.3 处理缺失的数据

虽然我们的 SPEC 指标在全球范围内具有相对较好的数据覆盖率，但缺少数据点。在这个需要包含多个区域的前国家模型中，我们没有用估计值来填补这些数据空白。

相反，我们使用上面的公式计算可用的国家数据。我们的理由是，缺失数据不会严重影响整体大陆脆弱性评分的准确性和可信度。此外，大多数国家都有所有 SPEC 指标的数据。估算数据可能会对某个国家在某些指标上的表现产生难以置信的估计。

5.5.4 较小的"地区"

与各州相比，城市的工业多样性和资源丰富性较差。这里我们解释如何重新排列每个 SPEC 指标的权重。以下条件需要特别考虑。

•随着全球化为世界各国提供净利益，各地区之间的联系更紧密。

•城市的基本气候条件可以从该国的数据中获得。

•每个城市都有自己的主要产业，反映了该城市的整体实力，并显着影响其对经济波动和气候事件的脆弱性。

5.5.5 SPEC 指标的重新加权

以下是重新加权的原则。

1. Four general climatic indicators apply to both cities and states, therefore, scoring formula for general climte conditions doesn't change.2. As explained earlier, scoring formula for extreme climate condition consist of extreme weather events(EWE) probability, *CO*2 emission and self-regulatory factor(R). EWE probability doesn't change with land area size. R is determined by the same formula expressed earlier and *CO*2 emission is available in data set.3. The weight for security(S),politic(P) and economic(E) fields is rearranged using Analytic Hierarchy Process based on city's major industry.

5.5.6 Examples: Guangzhou and Cape Town

We take Guangzhou and Cape Town as examples to reweight its SPEC index in compliance with principles above.

• Guangzhou is the capital and most populous city of the province of Guangdong in southern China. Its urban development characteristics is embodied in following areas.

1)main manufacturing hub of one of mainland China's leading commercial and manufacturing regions;2)rivers and streams improve the landscape and keep the ecological environment of the city stable;3)top ten container ports in the world.

• Cape Town is the legislative capital of South Africa. Its urban development characteristics is embodied in following areas.

1)noted for its architectural heritage and natural setting, once named the best place in the world to visit;2)serves as the regional manufacturing centre;3)Encountering freshwater crisis, affecting sustainable development.

1、四个一般气候指标适用于城市和国家，因此，一般气候条件的评分公式不会改变。

2、如前所述，极端气候条件的评分公式包括极端天气事件（EWE）概率，CO2 排放和自我调节因子（R）。 EWE 概率不随土地面积大小而变化。R 由前文表达的公式确定，数据集中有 CO2 排放。

3、安全（S），政治（P）和经济（E）领域的权重使用基于城市主要行业的分析层次过程重新排列。

5.5.6 示例：广州和开普敦

我们以广州和开普敦为例，按照上述原则重新调整 SPEC 指数。

•广州是中国南方广东省的首府和人口最多的城市。其城市发展特征体现在以下几个方面。

1）中国大陆主要商业和制造业区域之一的主要制造业中心;

2）河流和溪流改善景观，保持城市生态环境稳定;

3） 3）世界十大集装箱港口。

•开普敦是南非的立法首都。其城市发展特征体现在以下几个方面。

1）以其建筑遗产和自然环境而闻名，曾被评为世界上最佳地点;

2）作为区域制造中心;

3）遇到淡水危机，影响可持续发展。

With careful consideration of each field, the new SPEC coefficient is determined through AHP method.

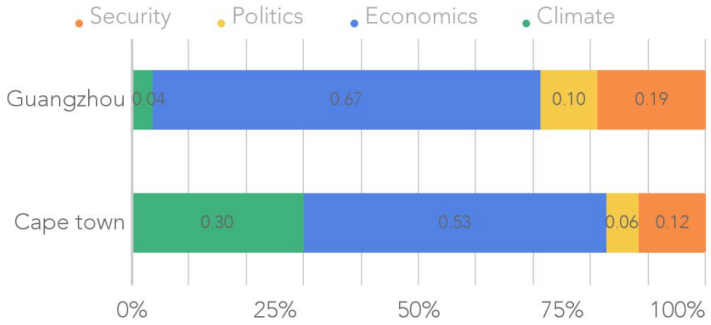

Figure 7: Rearranged weight for small "states"

6 Model Analysis

6.1 Sensitivity Analysis

The SPEC model contains several constant parameters. We referred to on-line database and various accessible literature when deciding on the parameters. In this section, we test and sensitivity of the SPEC Model by changing the values of the parameters to show its reliability.

6.1.1 Impact of Mediate Constant *a* in Weighted Average Method

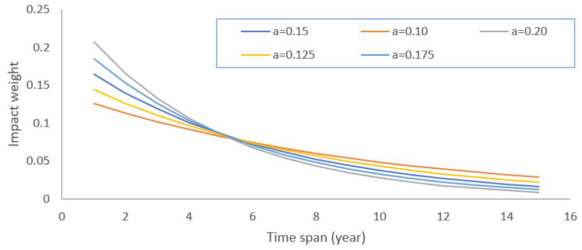

Figure 8: Weight variation with time span for different *a*.

仔细考虑每个地区，新的 SPEC 系数通过 AHP 方法确定。

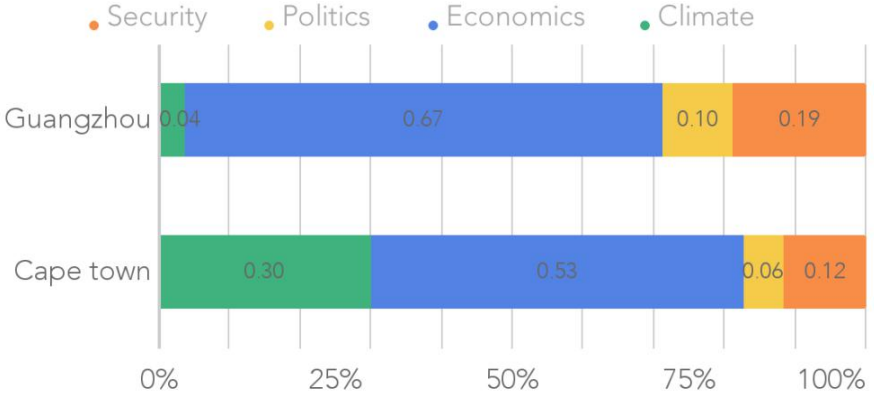

Figure 7: Rearranged weight for small "states"

6 模型分析

6.1 灵敏度分析

SPEC 模型包含几个常量参数。在决定参数时，我们提到了在线数据库和各种可访问的文献。 在本节中，我们通过更改参数值来测试 SPEC 模型的灵敏度，以显示其可靠性。

6.1.1 中间常数 a 在加权平均法中的影响

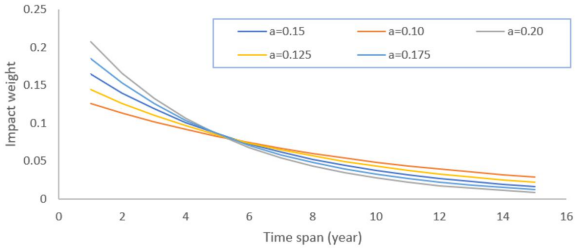

Figure 8: Weight variation with time span for different *a*.

We set *a* to be 0.15 and never changed again in when using weighted average method to give weight of every indicator. We choose constant 0.15 based on the same calculations in *Index of State Weakness In the Developing World* [10]. In Figure (8), we have value of *a* to vary from 0.10 to 0.20 by 0.25. Every curve representing a certain value of *a* shows the same trend. Therefore, the SPEC Model is not sensitive to the value of mediate constant *a*.

6.1.2 Impact of Universal Extreme Weather Probability *p*%

We set the universal extreme weather probability *p*% to be 5% and remain it constant in the SPEC Model. We referred to the on-line statics and find the current possibility of extreme weather events falls in the range from 5% - 10%. We choose the smallest value 5% and multiply it by a correction term ln CO_{2t} / CO_{2T} to keep the whole estimation precise. Due to the annually growing emission of green house gases, we have the ln CO_{2t} / CO_{2T} larger than 1 buffer the effect of choosing a small possibility of extreme weather. With the dilution of ln CO_{2t} / CO_{2T}, the impact of extreme weather probability *p*% is not sensitive in the SPEC Model.

6.2 Strengths & Weaknesses

6.2.1 Strengths

• The SPEC Model uses accurate and latest databases to guarantee the reliability of results. The results have high reference value and can be applied in real life immediately.

• We employ 19 indicators of 4 fields in the SPEC Model to measure the fragility of a state. In this way the SPEC Model is able to avoid abrupt influence of a single indicator, and the results are more integrated.

我们将 a 设置为 0.15，并且在使用加权平均法给出每个指标的权重时再也没有改变。 我们根据发展中国家的国家弱势指数[10]中的相同计算选择常数 0.15。 在图（8）中，我们得到 a 的值从 0.10 到 0.20 变化 0.25。每条曲线表示 a 的不同值且都显示相同的趋势。因此，SPEC 模型对中间常数 a 的值不敏感。

6.1.2 极端天气发生概率的影响 p％

我们将极端天气概率 p％设置为 5％并在 SPEC 模型中保持不变。我们参考了网络资料，并发现目前极端天气事件的可能性在 5％-10％之间。我们选择最小值 5％并乘以校正项 ln CO2t / CO2T 以保持整个估算的精确性。由于温室气体的年排放量逐年增加，我们使 ln CO2t / CO2T 大于 1 作为缓冲，因此出现极端天气的可能性很小。 随着 ln CO2t / CO2T 的稀释，极端天气概率 p％的影响在 SPEC 模型中不敏感。

6.2 模型的优点和缺点

6.2.1 优点

•SPEC 模型使用准确和最新的数据库来保证结果的可靠性。结果具有很高的参考价值，可以立即应用于现实生活中。

•我们在 SPEC 模型中使用了 19 个指标来衡量一个国家的脆弱性。通过这种方式，SPEC 模型能够避免单个指标的突然变化产生的剧烈影响，并且结果更加集成。

• We apply two kinds of data weighting methods (Latest-determin Method and Weighted Average Method), according to the characteristic of the indicator, making the SPEC Model more scientific.

• We explore the climate indicators and divide the impacts into indirect ones and direct ones. Calculations on items of climate indicators is straightforward quantifications of their impacts on fragility.

6.2.2 Weaknesses

• We neglect some indicators such as terrorism because we lack the accurate database, which may result in large fragility errors of some country.

• Some indicators of a states are missing. To get the SPEC score, it requires extra weighting of the indicators, which means the SPEC Model can be complex sometimes.

7 Conclusion

We build the SPEC model to analyse countries' fragility, considering the aspects of security, politics, economics and climate. We employ different data weighting methods do quantify individual indicators. Analytic Hierarchy Process is applied to determine weight numbers. We propose the Self-regulatory Factor to better measure the Tipping Point of different countries. Also, we modify our model to ensure it applicable to "larger" or "smaller" states. Then we refer to databases such as Worldbank, and we work out detailed and quantified SPEC indicators of **178** countries and regions in the world. Our final SPEC Score corresponds to the Fragile States Index. Finally, we do sensitivity analysis, discuss strengths and weaknesses and prove the credibility of our SPEC model.

•我们根据指标的特点应用两种数据加权方法（最新确定方法和加权平均方法），使 SPEC 模型更加科学。

•我们探索气候指标，并将影响分为间接影响和直接影响。 对气候指标项目的计算可直接量化其对脆弱性的影响。

6.2.2 缺点

•我们忽略了恐怖主义等一些指标，因为我们缺乏准确的数据库，这可能会导致某些国家出现大的脆弱性错误。

•缺少某些地区的指标。要获得 SPEC 分数，需要额外加权指标，这意味着 SPEC 模型有时会很复杂。

7 结论

考虑到安全，政治，经济和气候等方面，我们建立 SPEC 模型来分析各国的脆弱性。我们采用不同的数据加权方法来量化个别指标。应用层次分析法来确定权重。我们提出自我调节因子来更好地衡量不同国家的临界点。此外，修改我们的模型以确保它适用于“更大”或“更小”的地区。然后我们参考世界银行等数据库，我们制定了世界上 178 个国家和地区的详细和量化的指标。最终 SPEC 分数对应于脆弱国家指数。最后，我们进行敏感性分析，讨论优势和劣势，并证明我们的 SPEC 模型的可信度。