summary

Motivated to measure a country's stability quantitatively and more accurately, our team builds a mathematical framework to identify the current status of a country. In the paper, we introduce a composite index processing comprehensive datasets that consist of different factors including economy, politics, demographics and climate change.

With the composite measure, we build a dynamic system simulating the fluctuation of the market as a result of the variations in different sectors. This system not only describes the current fragility of a country facing potential alternation in social and environmental factors, but also it predicts the equilibrium states that the country would approach overtime.

Moreover, we propose a bifurcation plot that depicts the tipping points between three states of a country in terms of its fragility: stable state, vulnerable state, and fragile state. We then further apply our model and bifurcation plot in real-life case analyses with three selected countries, Syria, Cuba and New Zealand.

After calibrating parameters and comparing different factors in each country, we find out that climate conditions play a significant role in Syria's fragile state due to factors such as limited water resources and food supply. We also find that factors of droughts and occurrence of natural disasters in Cuba caused huge market losses and Cuba would reach the tipping point under appropriate human intervention.

摘要

我们的团队为了定量地和更准确地衡量一个国家的稳定性，建立一个数学模型来确定一个国家的现状。在本文中，我们引入了综合指数处理综合数据集，其中包括经济，政治，人口统计和气候变化等不同因素。

通过综合测量，我们建立了一个动态系统，模拟了不同行业变化导致的市场波动。该系统不仅描述了一个面临社会和环境因素潜在变化的国家目前的脆弱性，而且还预测了该国将加速进入的均衡状态。

此外，我们提出了一个分岔图，描绘了一个国家在其脆弱性方面的临界点：稳定状态，脆弱状态和非常脆弱状态。然后，我们进一步将我们的模型和分叉图应用于与叙利亚，古巴和新西兰三个选定国家的实际案例分析。

在校准参数并比较每个国家的不同因素后，我们发现由于水资源和食物供应有限等因素，气候条件在叙利亚脆弱状态中发挥着重要作用。我们还发现，古巴的干旱和自然灾害发生的因素造成了巨大的市场损失，古巴将在适当的人为干预下达到临界点。

1. Introduction

Climate change includes increased droughts, shrinking glaciers, temperature rise and sea level rise. Despite a scientific consensus on global warming, climate change denial and doubts still exist and the impacts of climate change and the extent to which it is caused by humans are suspected. In our paper, we build a mathematical framework to determine a country's fragility with a composite measure considering multiple factors including economic, political and demographic indicators and climate change. In section 6, we select three countries, Syria, Cuba and New Zealand to do case studies and further analyze the idea of tipping points in the specific contexts. In section 7, we examine the effects of human intervention and estimate the total cost of intervention based on our model and research. In section 8, we discuss our limitations and strengths, consider the scenarios for smaller "states" and larger "states", and talk about potential future research on this topic and our framework.

2. Assumptions

- Our framework measures the market impacts of different factors such as climate change, economic status, political stability and demographic profiles in the unit of US dollars because we think it is more efficient to quantify and examine the extent of effects.
- We define the state as a country for consistency and data collection purpose.
- We assume all data we obtain are trustworthy since all of sources are reliable. Thus,we are confident that our metrics can reflect the accurate condition.

1、引言

气候变化包括干旱增加，冰川消融，气温上升和海平面上升。 尽管在全球变暖方面达成了科学共识，但对气候变化的否定和怀疑仍然存在，气候变化的影响以及人为因素对气候变化的影响程度仍然被质疑。本文在综合考虑经济、政治、人口指标和气候变化等多重因素的基础上，建立了一个综合评价模型来确定一个国家脆弱性。第六节选取了叙利亚、古巴和新西兰三个国家作为案例进行研究，并在具体背景下进一步分析了临界点的概念。在第 7 节中，我们验证了人类干预行为的效果，并基于我们的模型估计了干预的总成本。在第 8 节中，我们讨论了模型的局限性和优势，考虑小状态和大状态的情况，并讨论在该主题下，本文模型的潜在研究方向。

2、假设

- 我们的模型以美元为单位衡量气候变化、经济状况、政治稳定和人口状况等不同因素对市场的影响，因为我们认为其量化影响程度更有效。
- 我们将国家定义为一致的数据收集单位的地区。
- 假设我们获得的所有数据都是可信的，因为所有数据来源都是可靠的。因此，我们有信心，我们的评价模型可以准确反映评价对象。

3. Framework

3.1 Defining Fragility

Before devising our model, we first define three possible states of a country: stable state, vulnerable state, and fragile state.

Stable state A stable country should be less likely to be influenced by the incidents such as economic downturns, natural disasters, or political instability. Even if there is a crisis, a stable country can quickly recover and return to its equilibrium state.

Vulnerable state A vulnerable country is more susceptible then a stable country to the changes in the economy, politics, demographics and climate. A damaging event could cause the country leave its current state and gradually become a fragile state; a favorable event could, on the contrary, lead the country approach to the stable state.

Fragile state A fragile country is the currently experiencing fluctuations in economy and politics. It does not possess a strong economy or a well-regulated society. As a result, any small turbulence could bring large impacts on all factors. Moreover, even if the country manages to recover from these disturbances, it can only resume to its previous fragile state.

3.2 The Model

To quantify a country's fragility, we use a dynamic system, in terms of money (M), to estimate the impacts of changes in different factors on a country. However, we believe that money is not the sole predictor of the fragility of a

3、模型建立

3.1 脆弱性定义

在建立模型之前，我们首先定义了一个国家的三个可能状态：稳定状态、脆弱状态和非常脆弱状态。

稳定状态：一个稳定的国家应该不太可能受到诸如经济衰退、自然灾害或政治不稳定等事件的影响。即使有危机，一个稳定的国家也能迅速恢复并恢复到平衡状态。

脆弱状态：一个脆弱的国家比稳定的国家更容易受到经济、政治、人口和气候变化的影响。破坏性事件可以使国家脱离当前状态，逐渐成为非常脆弱状态；相反，有利的事件可以使国家接近稳定状态。

非常脆弱状态：一个非常脆弱的国家目前正经历着经济和政治的波动。它没有一个强大的经济或一个监管良好的社会体系。因此，任何小的湍流都会对诸多因素产生很大的影响。此外，即使国家设法从这些动乱中恢复过来，也只能恢复到以前的脆弱状态。

3.2 数学模型

为了量化一个国家的脆弱性，我们建立一个动态系统，用货币（M）来估计不同因素的变化对一个国家的影响。然而，我们认为，金钱不是一个国家脆弱性的唯一预测因素。因此，在我们的模型中，我们结合了经济、政治、人口和气候等因素。

country. Thus, in our model, we incorporate factors including economy, politics, demographics and climate.

$$M = f(E, P, D, C) \tag{1}$$

Here, M is a function of E; P; D; and C, where M represents the market impact of those factors, and E, P, D, C are the economic, political, demographical and climate change metrics respectively. In this way, we could comprehensively analyze a country's capability to combat unexpected events categorized under different sectors. We achieve this simulation by studying how the variation in one parameter would influence the overall fragility of the society.

Further developing our model, we realize that the derivative of M is an autonomous function, that is growth rate of the market is not dependent on time. Yet, the growth rate of the market is described as the positive impact minus the negative impact.

$$\text{growth rate} = \text{positive}(\$) - \text{negative}(\$) \tag{2}$$

The positive impact considers the natural growth of the market itself accompanied with a limited capacity which varies depending on the parameters. The negative impact is composed of human intervention, disturbing climate change and other unfavorable variation in the parameters that we have defined.

$$p'(M) = m_1 M(1 - \frac{M}{km_2}),\ g'(M) = \frac{BM^2}{A^2 + M^2} \tag{3}$$

$$M = f(E, P, D, C)$$

其中，M 是 E，P，D，和 C 的函数，其中 M 代表这些因素的市场价值，并且 E、P、D、C 分别是经济、政治、人口和气候变化的度量。通过这种方式，我们可以综合分析一个国家抵抗各类意外事件的能力。我们通过研究一个参数的变化如何影响整个社会的脆弱性来实现这个仿真。

进一步展开我们的模型，我们发现 M 的导数是一个自治函数，即市场的增长率不依赖于时间。然而，市场增长率被描述为正向影响减去负向影响。

$$\text{growth rate} = \text{positive}(\$) - \text{negative}(\$)$$

积极影响认为市场本身的自然增长，而市场本身是有限的，而界限根据参数而变化。其负面影响包括人为因素干扰气候变化和其他不利的参数变化。

$$p'(M) = m_1 M(1 - \frac{M}{km_2}),\ g'(M) = \frac{BM^2}{A^2 + M^2}$$

Inspired by the outbreak system by Ludwig et al. (1978), we obtain the functions above. p′(M) represents the market growth with limited capacity, where m1 describes the growth rate, m2 represents the maximum of market capacity, and k is a scale factor that measures how economy, politics, demographics and climate change would affect the actual limit of the market. To come up with the value of k, we use a composite index consisting of metrics in economy, politics, demographics and climate change. g′(M) represents the negative impact that could potentially slow down the market growth. In the early development stage, M is small and the negative market impact would only show signs. However, when the market exceeds a critical level A, the negative impact would turn on quickly. This happens when the harmful events have built up to an extent that they cause a chain of reactions and the impact would finally reach to its limitation B. Therefore, we have the whole model:

$$\frac{dM}{dt} = m_1 M(1 - \frac{M}{km_2}) - \frac{BM^2}{A^2 + M^2} \tag{4}$$

In order for us to examine the model more easily, we have converted the function into a dimensionless form so that there are only two parameters, r and s.

$$\frac{dx}{d\tau} = rx(1 - \frac{x}{s}) - \frac{x^2}{1 - x^2} \tag{5}$$

Where $x = \frac{M}{A}$, $\tau = \frac{Bt}{A}$, $r = \frac{Am_1}{B}$, and $s = \frac{km_2}{A}$.

Next step, we define all parameters and the techniques of processing relevant data.

受 Ludwig 等人暴发系统的启发（1978），得到上述函数。表示容量有限的市场增长，其中 m1 表示增长率，m2 表示市场容量的最大值，k 是衡量经济、政治、人口和气候变化将如何影响市场实际极限的规模因子。为了得到 k 的值，我们使用一个由经济、政治、人口统计和气候变化等指标组成的综合指数。g′(M)代表可能减缓市场增长的负面影响。在发展初期，M 较小，负面的市场影响较小。然而，当市场超过临界水平 A 时，负面影响将迅速显现。当不利事件积累到一定程度后，以致它们引起一系列反应，最终达到其极限值 B。因此，我们建立综合模型：

$$\frac{dM}{dt} = m_1 M(1 - \frac{M}{km_2}) - \frac{BM^2}{A^2 + M^2} \tag{4}$$

为了更方便地检查模型，我们将函数转换为无量纲形式，因此只有两个参数，r 和 s。

$$\frac{dx}{d\tau} = rx(1 - \frac{x}{s}) - \frac{x^2}{1 - x^2} \tag{5}$$

其中，$x = \frac{M}{A}$, $\tau = \frac{Bt}{A}$, $r = \frac{Am_1}{B}$, and $s = \frac{km_2}{A}$.

下一步，我们定义所有参数和相关数据处理方法。

4. Metrics for Assessing Fragility

Our metrics are similar to indicators used in the Fragile States Index. But, instead of rating those factors, we target to collect both quantitative and qualitative data by country and by year. Besides, our metrics will be more concise because we find that there are some overlapping variables in FSI. For example, both Factionalized Elites of the Cohesion indicators and Uneven Development in Economic indicators have considered the wealth distribution and tries to assess the equality of wealth (Marshall and Cole, 2017). In the end, using RStudio, we process all the datasets and obtain a composite index.

4.1 Climate Change

Climate change is expected to have negative impacts on human societies and economies,which may bring huge economic losses.

- Occurrence of natural disasters

EM-DAT contains data on the occurrence and effects of different types of natural disasters worldwide from 1900 to present. However, the data is not publicly available. So we use *probabilistic risk results* provided by UNISDR. The probabilistic risk results provide results of an estimate of probable loss levels in a country based on historic events. This data is useful because it considers damages caused by small, moderate and severe events and obtains a robust metric for risking ranking and comparison.

4、脆弱性评价指标

我们的度量指标类似于脆弱国家指数中使用的指标。但是，我们的目标不是对这些因素进行评级，而是按国家和年份收集定量和定性数据。此外，我们的度量指标将更加简洁，因为我们发现 FSI 中存在一些重叠的变量。例如，凝聚指标中的派系化精英和经济指标中的不均衡发展都考虑了财富分配并试图评估财富的均匀性(Marshall 和 Cole，2017)。最后，使用 RStudio 对所有数据集进行处理，得到一个复合索引。

4.1 气候变化

气候变化会对人类社会和经济产生负面影响，可能带来巨大的经济损失。

- 自然灾害的发生

EM-DAT 包含 1900 年至今世界各地不同类型自然灾害的发生和影响的数据。然而，数据不是公开可用的。因此我们使用 UNISDR 提供的概率风险结果。概率风险结果提供了根据历史事件估计一个国家可能损失水平的结果。这个数据是有用的，因为它考虑了由小型、中型和严重事件造成的损害，并且获得了用于风险排序和比较的度量指标。

- Deforestation

Food and Agriculture Organization (FAO) contains comprehensive forestry datasets such as forest coverage, reforestation, burned forest and economic value of the country's forestry value. Among them, we select the annual *Tree cover loss* rate by country with unit of hectare to reflect the deforestation rate as part of climate change.

- Droughts/floods

We use *Precipitation Anomaly* from World Bank to reflect occurrence of both droughts and floods. This dataset includes historical monthly precipitation worldwide from 1900 to present.

- Rising sea levels/shrinking glaciers

Although sea level rise is a major component of global climate change, it is not a typical question for all countries. Since rising sea level and green house effects are tightly related, we only consider temperature rises instead of rising sea level.

- Rising temperatures

We retrieve historical temperature data from World Bank. This data is called Global Historical Climatology Network version 2 station monthly mean temperatures and station metadata created by U.S. National Climatic Data Center. This dataset contains quality-controlled, adjusted monthly mean temperature in unit of degree Celsius.

- 森林砍伐

粮食及农业组织（粮农组织）包含全面的林业数据集，如森林覆盖率、重新造林、烧毁森林和该国林业价值的经济价值。其中，我们选择国家每年的单位面积森林覆盖损失率反映作为气候变化一部分。

- 干旱/洪水

我们使用世界银行的降水异常来反映干旱和洪水的发生。这个数据集包括 1900 年至今全世界的历史月降水量。

- 海平面上升/冰川缩小

虽然海平面上升是全球气候变化的一个主要组成部分，但并不是所有国家都面临的典型问题。由于海平面上升和温室效应密切相关，我们只考虑气温上升而不是海平面上升。

- 气温上升

我们从世界银行检索历史温度数据。这个数据被称为全球历史气候网络版本 2，由美国国家气候数据中心创建的月平均气温和站元数据。这个数据集包含以摄氏度为单位的质量控制、调整的月平均温度。

4.2 Economical Metrics

The economic meta-metrics considers factors related to economic decline within a country. Except for the economic factors listed below, we have also considered unequal development and other relevant factors including government debts/deficits, currency fluctuation, consumer confidence and foreign investment. More detailed descriptions of those variables are in the appendix.

- Real Gross National Product (GNP) per capita

Real GNP calculates the value of all final goods and services produced by the means of production owned by all domestic and overseas citizens of a country in a given period of time. It is different from the Gross Domestic Products (GDP) because GDP calculates the total values of products and services produced in the country. In other words, GNP measures the income of people within the country while GDP measures the economic productivity in a country (Stiglitz, 2009). Therefore, although GDP is more widely used, We think GNP works better in my model because we want to find a metric that can better represent the well-being of a country. So we obtain our data of annual GNP by country from Knoema over the period of 1998 to 2012.

- Unemployment rate

Our group has used the *unemployment rate, % of total labor force* dataset retrieved from Organization for Economic Co-operation and Development (OECD) over the period of 1953-2017. We use unemployment rate as a metric to reflect the economic decline within a country and to estimate the stability of a country.

4.2 经济指标

经济计量学考虑一个国家经济下滑的相关因素。除了以下列出的经济因素外，我们还考虑了不平等发展和其他相关因素，包括政府债务/赤字、货币波动、消费者信心和外国投资。附录中更详细地描述了这些变量。

- 人均实际国民生产总值（GNP）

实际国民生产总值计算在一定时期内由一国所有国内和国外公民拥有的生产资料所产生的所有最终产品和服务的价值。 它与国内生产总值（GDP）不同，因为 GDP 计算了该国生产的产品和服务的总价值。 换句话说，国民生产总值衡量的是国内人民的收入，而国内生产总值则衡量一个国家的经济生产率（Stiglitz，2009）。因此，尽管 GDP 使用得更广泛，但我们认为 GNP 在我的模型中效果更好，因为我们希望找到一个能更好地代表一个国家福祉的指标。 因此，我们从 1998 年到 2012 年期间从 Knoema 获得了我们的国家 GNP 年度数据。

- 失业率

我们小组使用的失业率，即经济合作与发展组织（OECD）在 1953-2017 期间检索到的劳动力总数据集的百分比。我们使用失业率作为衡量一个国家经济衰退和估计一个国家稳定性的指标。

- Inflation

Inflation, consumer prices (annul %) dataset is obtained from International Monetary Fund, International Financial Statistics and data files. This inflation rate measures the change in the prices of a basket of selected consumer goods and services. 2010 is the base year for the calculation of inflation rate in our dataset.

- Poverty level

Poverty headcount ratio at $3.20 a day (2011 PPP) (% of population) dataset is obtained from The World Bank. This dataset contains data in selected years from 1979 to 2016. An alternative dataset is *Poverty headcount ratio at $1.90 a day (2011 PPP) (% of population)*, but we think $3.30 reflect a normal level of spending better than $1.90. It is difficult for one to live with only $1.90 a day even if one lives in a country with low price level, while $3.30 a day should prevent one from starving in most countries.

4.3 Political and Demographic Indicators

Our team collects data of corruption, health, education, water, energy and freedom of speech to represent the political indicator of the state. We use those variables to not only reflect the basic level and quality of state functions and services but also indicate the openness of a government and its relationship with citizens. We have also taken account of demographical factors including population density, natural resources abundance, internally displaced persons, and brain drain. We believe that those variables reflect the pressures upon the state deriving from the population itself and those pressures caused by the forced displacement of large communities. Details of variables and data we select are in the appendix.

- 通货膨胀

通货膨胀、消费价格（年率）数据集是从国际货币基金组织、国际金融统计数据文件中获得的。这个通货膨胀率衡量的是选定的消费品和服务的价格变化。2010 是我们数据集中通货膨胀率计算的基准年。

- 贫困程度

每天 3.20 美元的贫困率（2011 年购买力平价）（人口百分比）数据集来自世界银行。 该数据集包含 1979 年至 2016 年的数据。另一个数据集是贫困人口比率为每天 1.90 美元（2011 年购买力平价）（人口百分比），但我们认为 3.30 美元反映的正常支出水平优于 1.90 美元。即使一个人生活在一个价格低廉的国家，每天只有 1.90 美元的生活是很困难的，而每天 3.30 美元应该可以防止一个人在大多数国家挨饿。

4.3 政治和人口指标

我们的团队收集了腐败，健康，教育，水，能源和言论自由的数据，以代表国家的政治指标。 我们使用这些变量不仅反映了国家职能和服务的基本水平和质量，还表明了政府的公开性及其与公民的关系。我们还考虑了人口密度，自然资源丰富，国内流离失所者和人才流失等人口因素。我们认为，这些变量反映了国家对人口本身产生的压力以及大社区被迫流离失所造成的压力。我们选择的变量和数据的详细信息在附录中。

5. Equilibrium and Tipping Points

Not only do we want to analyze the impact of each parameters on the overall performance of a country, we are also interested in further studying the pattern of a country's state of fragility as our model exhibit several steady states. Hence, we introduce two terms, equilibrium and tipping points. The equilibrium describes a fixed point in the derivative function. In reality, this means a steady state of a country. The tipping point describes the watersheds between different stages of equilibrium and, in our model, the occurrence of a tipping point suggests the change in the steady states.

Equilibrium

Using the dimensionless form of the function, we set $dx/d\tau = 0$ equal to zero to find the fixed points.

$$\frac{dx}{d\tau} = 0 \ , \ rx(1-\frac{x}{s}) = \frac{x^2}{1-x^2} \tag{6}$$

We observe equation (6) has a fixed point at $x^* = 0$. Intuitively, $x^* = 0$ is always a unstable fixed point because when x is small, the negative impacts is fairly small so that the money supply would grow exponentially for small x near zero. Hence, we can obtain other fixed points from the solutions to equation.

$$r(1-\frac{x}{s}) = \frac{x}{1-x^2}. \tag{7}$$

5、平衡点和临界点

我们不仅要分析每个参数对一个国家整体绩效的影响，而且因为我们的模型呈现出若干稳态，我们也有兴趣进一步研究一个国家的脆弱状态模式。因此，我们引入了两个术语，平衡点和临界点。平衡描述了导数函数中的一个驻点。事实上，这意味着一个国家的稳定状态。临界点描述了不同平衡阶段之间的分水岭，在我们的模型中，临界点的出现表明稳态的变化。

平衡点

使用函数的无量纲形式，我们将 $dx/d\tau = 0$ 设置为零以找到驻点。

$$\frac{dx}{d\tau} = 0 \ , \ rx(1-\frac{x}{s}) = \frac{x^2}{1-x^2} \tag{6}$$

我们观察到等式（6）在 $x^* = 0$ 处有一个驻点。直观地说，$x^* = 0$ 总是一个不稳定的驻点，因为当 x 很小时，负面影响相当小，因此货币供应会以小指数的方式增长 x 接近零。 因此，我们可以从解方程获得其他驻点。

$$r(1-\frac{x}{s}) = \frac{x}{1-x^2}. \tag{7}$$

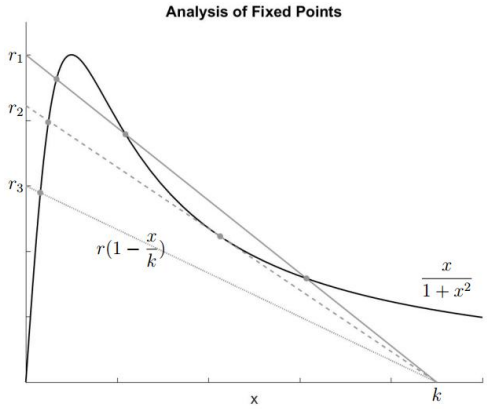


Figure 1: This figure shows the equilibriums corresponding to different values of r and k. The black curve represents $x/(1+x^2)$ and the gray lines represents $r(1-x/k)$ with different r values.

It is easier to analyze the equation graphically in that we could simply find the intersects of the two functions. Since the right-hand side only depend on x, we can alter parameters r; s on the left-hand side to see the changes in the fixed points. In Figure 1, we see that for a fixed k, shifts in r returns different types of solution curves. When r equals r_1, the equation returns three roots, which means the function has three fixed points. However, when r-value decreases to r_2, the latter two fixed points collapse into one fixed point, where the line $r(1-x/s)$ intersects the curve $x/(1-x^2)$ tangentially. As r continues decreasing, there remains only one fixed point. The similar pattern can be observed as well, as r values increases. To determine the stability of the fixed points, we recall that $x^*=0$ is an unstable and the stability of fixed points must alternate as x increases.

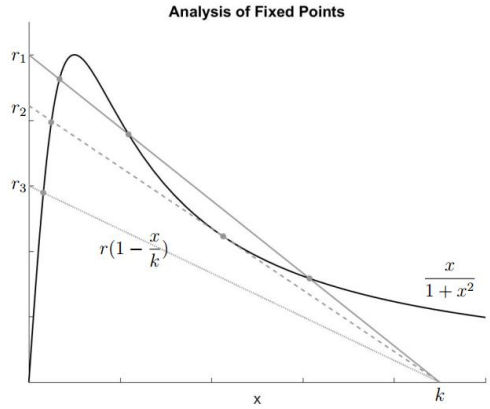


图 1：该图显示了 r 和 k 取不同值对应的平衡点。黑色曲线表示 $x/(1+x^2)$，灰色线表示具有不同 r 值的 $r(1-x/k)$。

以图形方式分析方程更容易，因为我们可以简单地找到两个函数的相交。由于右侧只依赖于 x，我们可以改变参数 r；在左侧看到驻点的变化。在图 1 中，我们看到对于固定 k，改变 r，返回不同的解。当 r 等于 r1 时，等式返回三个根，这意味着该函数有三个驻点。然而，当 r 值减小到 r2 时，后两个驻点塌陷成一个驻点，其中线 $r(1-x/s)$ 与切线 $x/(1-x^2)$ 相切。随着 r 继续减少，仍然只有一个驻点。随着 r 值的增加，也可以观察到类似的模式。为了确定驻点的稳定性，我们记得 $x^*=0$ 是不稳定的，驻点的稳定性随着 x 的增加而交替。

Tipping Points

The phenomenon described above corresponds to two saddle-node bifurcations, where two fixed points coalesce into one and then disappears. For easier understanding, we draw dM/dt versus M showing different solutions corresponding to different $(r; x)$ values in Figure 2.

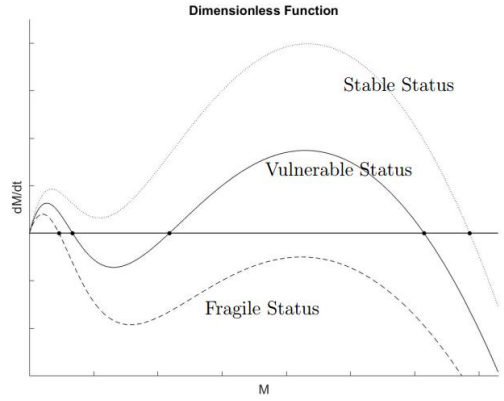


Figure 2: This figure depicts the relationship between dM/dt and M. The equilibriums occur when $dM/dt = 0$, which are the intersects on x-axis.

Interestingly, we find the connection between fragility states and the behaviors of different types of dM/dt curves. When a solution only has one smaller stable fixed point near zero, M would always approach that fixed point overtime. Notice that this fixed point is fairly close to zero. This implies that a country, who fits this solution curve, would have a weak economic condition and possibly a unstable political environment. As a result, this country would be defenseless when facing changes in social and environmental factors. So we think this solution curve exhibit similar behavior as a fragile country.

临界点

上述现象对应于两个鞍形节点分叉，其中两个固定点合并为一个，然后消失。为了便于理解，我们绘制 dM/dt 对 M，显示对应于图 2 中不同（r;x）值的不同解。

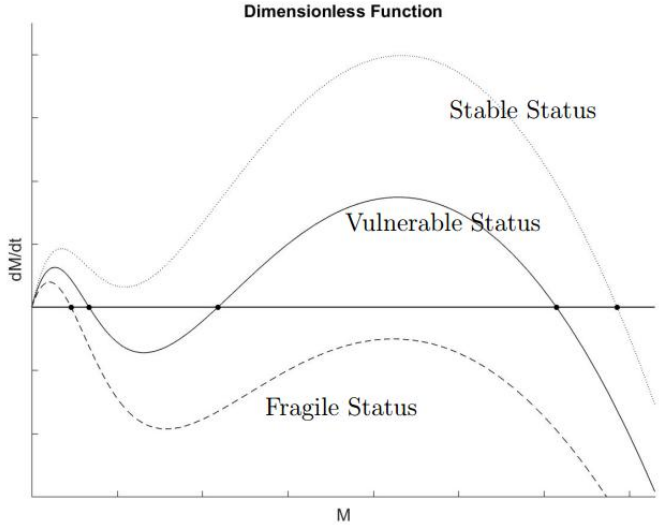


图 2：该图描绘了 dM / dt 和 M 之间的关系。当 dM / dt = 0 时，平衡发生，这是 x 轴上的交叉点。

有趣的是，我们发现脆弱状态与不同类型的 dM / dt 曲线的行为之间存在联系。当只有一个较小的稳定点接近零时，M 总是收敛于该驻点。请注意，此驻点非常接近于零。 这意味着一个符合这种解决方案曲线的国家经济状况不佳，政治环境可能不稳定。因此，当面对社会和环境因素的变化时，这个国家将毫无防御能力。因此，我们认为此解决方案曲线表现出与非常脆弱国家类似的行为。

Nevertheless, though there is another solution with only one fixed point, the second solution has a fixed point much away from zero and actually shares similar pattern as a stable country. This can be largely explained by two reasons. First, the solution is always attracted to this equilibrium which is much larger than a fragile state. This results from that a stable country has a strong economy and a suitable management. Changes in society or environment would not prevent the country return to its optimal state. Second, if a country deviates from the equilibrium because of some accidents, its rate of recovering is substantially greater than that of a fragile state. Finally, a solution with three fixed points (except $x^*=0$) is considered as a representative of a vulnerable country. We observe that there are two locally attracting fixed points in this curve. Thus, the solution curve could approach to either fixed points, one near zero representing a fragile state and one much larger representing a stable state. This suggests that when an incident happen in a vulnerable country, the country could improve its current condition and become more stable or decline to a more fragile state, depending on the nature of the incident.

Recall the previous equation (7), we know the derivatives are the same at intersections for two curves. Thus, we have the following:

$$\frac{d}{dx}\left(r(1-\frac{x}{s})\right)=\frac{d}{dx}\left(\frac{x}{1+x^2}\right) \tag{8}$$

$$-\frac{r}{s}=\frac{1-x^2}{(1+x^2)^2} \tag{9}$$

尽管如此，虽然还有另一个只有一个驻点的解决方案，但该解决方案有一个远离零的驻点，并且实际上与稳定的国家具有相似的模式。这可以在很大程度上解释为两个原因。首先，解决方案总是被这种平衡所吸引，这种平衡比脆弱状态大得多。这是因为一个稳定的国家拥有强大的经济和适当的管理。社会或环境的变化不会阻止该国恢复到最佳状态。其次，如果一个国家因某些事故而偏离均衡，其恢复速度远远大于脆弱国家。最后，具有三个驻点（$x^*=0$ 除外）的解决方案被视为脆弱国家的代表。我们观察到该曲线中有两个局部吸引的固定点。因此，解曲线可以接近驻点，一个接近零表示脆弱状态，一个大得多表示稳定状态。这表明，当一个事件发生在一个脆弱的国家时，该国可以根据事件的性质改善其现状并变得更加稳定或下降到一个更脆弱的状态。

回顾等式（7），我们知道两条曲线的相切处的导数是相同的。 因此，我们有以下内容：

$$\frac{d}{dx}\left(r(1-\frac{x}{s})\right)=\frac{d}{dx}\left(\frac{x}{1+x^2}\right) \tag{8}$$

$$-\frac{r}{s}=\frac{1-x^2}{(1+x^2)^2} \tag{9}$$

Then we can rewrite the parameters *k; r* each as a function of *x*.

$$r = \frac{2x^3}{(1+x^2)^2}\ ,\ k = \frac{2x^3}{x^2-1} \tag{10}$$

As a result, we come up with a parametric plot, Figure (3), of (*k*(*x*)*; r*(*x*)), where $x \geqslant 0$. As observed, the plane is partitioned into three regions by the *s* - *r* curve. According to previous analysis on fragility states, we can easily name each region by its corresponding fragility states.

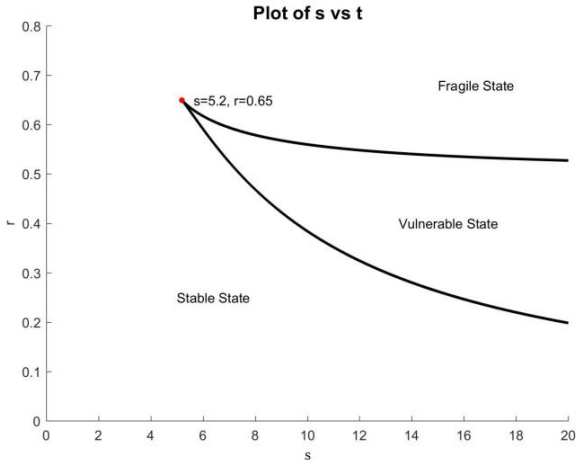


Figure 3: This figure is a parametric plot of (*s; r*), where *s* and *r* are expressed as a function of *t*. The *s* - *r* curve represents the occurrence of a saddle-node bifurcation. In the *Stable State*, there is only one equilibrium; in *Vulnerable State*, there are three; in *Fragile State*, there is one.

然后我们可以重写参数 k；r 各自作为 x 的函数。

$$r = \frac{2x^3}{(1+x^2)^2}\ ,\ k = \frac{2x^3}{x^2-1} \tag{10}$$

我们可以得出一个参数图，图（3），（k（x） r（x）），其中 x⩾ 0。如所观察到的，平面被 s － r 曲线划分为三个区域。根据先前对脆弱状态的分析，我们可以通过其相应的脆弱状态轻松命名每个区域。

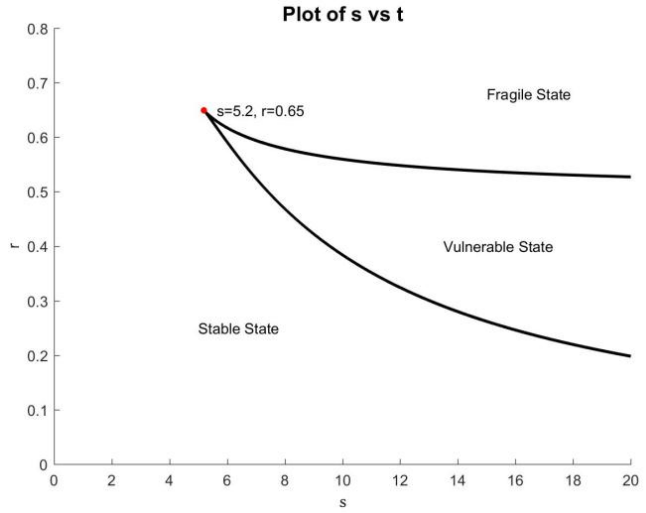


图 3：该图是（s；r）的参数图，其中 s 和 r 表示为 t 的函数。 s －r 曲线表示驻点数目分割曲线。在稳定状态，只有一个驻点；在脆弱国家，有三个；在非常脆弱国家，有一个。

This graph is crucial to analyze a country's fragility state. As long as we obtain the enough information on each required parameters for a country, we can convert the data to (*s; r*) using our composite index. Thus, we can immediately tell the current state of that country using this graph. For further application of this graph in the real world, we have conducted three case analyses in the next section.

6 Country Analysis

6.1 Syria

Syria is one of the top 10 most fragile countries in the world. The relatively weak economy system is one reason that makes it weak. Syria's GDP per capita was slightly less than $3000 and ranked at 194 out of 229 countries, according to CIA's record. Besides, the economy system of Syria depends highly on oil production. As IMF points out, oil exportation contributes to more than 25% of national income (International Monetary Fund, 2010). Hence, the declination of oil exploration had a major impact on Syria's economic status. After the regulation on oil exploration and the decreasing amount of oil supply, the oil production in Syria has decreased rapidly from 2005 to 2015. It suffers from an annual growth rate of -24.5% during the decade from 2005 to 2015, and does not show any sign of resuming (BP Global, 2017). Furthermore, the increasing consumption of oil turned Syria to an oil importer rather than an exporter in 2013.

该图对于分析一个国家的脆弱状态至关重要。只要我们获得
国家/地区的每个必需参数的足够信息，我们就可以使用我们的复
合索引将数据转换为（s；r）。因此，我们可以使用此图表立即
告知该国家/地区的当前状态。为了在实践中进一步应用该图，我
们在下一节中进行了三个案例分析。

6、国家分析

6.1 叙利亚

叙利亚是世界上十大最脆弱的国家之一。相对疲弱的经济体系是使其脆弱的一个 0 原因。根据中央情报局的记录，叙利亚的人均国内生产总值略低于 3000 美元，在 229 个国家中排名第 194 位。此外，叙利亚的经济体系在很大程度上依赖于石油生产。正如国际货币基金组织指出的那样，石油出口占国民收入的 25％以上（国际货币基金组织，2010 年）。因此，石油勘探的衰退对叙利亚的经济地位产生了重大影响。在石油勘探监管和石油供应量减少之后，叙利亚的石油产量从 2005 年到 2015 年迅速下降。在 2005 年至 2015 年的十年期间，它的年增长率为-24.5％，并未显示任何恢复的迹象（BP Global，2017）。此外，石油消费的增加使叙利亚在 2013 年成为石油进口国而非出口国。

Another major reason that makes Syria fragile is its political situation. The civil war in Syria caused approximately 100,000 civilian death and more than 400,000 total death (Syrian Observatory for Human Rights, 2017). More than 4 million Syrians became refugees because of the civil war. The climate condition in Syria also restricts its economic development. With a large proportion of desert, Syria suffered heavily from scarce of water supply. More than half of the area in Syria has less than 25 centimeter of annual rainfall, and drought was not uncommon in Syria. Although Syrian could plant olives and cottons, which are the major exportation of agricultural goods in Syria, agriculture was very much restricted in variety and quantity because of the rarity of water. The climate condition in the region around Syria also causes regional tension because of the water supply, and this further causes problem in economic development (Gleick, 2014).

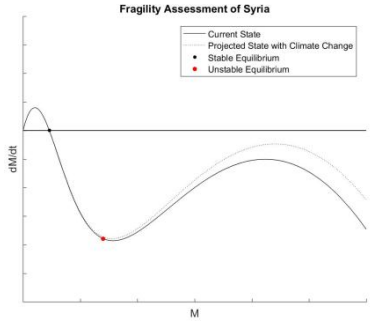


Figure 4: This figure shows the fragility assessment of Syria and its current status in dM/dt - M plot. The model predicts that Syria would have a negative growth rate and become more fragile.

使叙利亚变得脆弱的另一个主要原因是其政治局势。 叙利亚内战造成大约 10 万平民死亡，总死亡人数超过 40 万（叙利亚人权观察站，2017 年）。 由于内战，400 多万叙利亚人成为难民。 叙利亚的气候条件也限制了其经济发展。 由于沙漠占很大比例，叙利亚因供水稀缺而遭受严重损失。 叙利亚一半以上的地区年降雨量不到 25 厘米，叙利亚的干旱情况并不少见。 虽然叙利亚可以种植橄榄和棉花，这是叙利亚农产品的主要出口产品，但由于水的稀缺性，农业的种类和数量受到很大限制。 由于供水问题，叙利亚周边地区的气候条件也造成了地区紧张局势，这进一步导致了经济发展中的问题（Gleick，2014）。

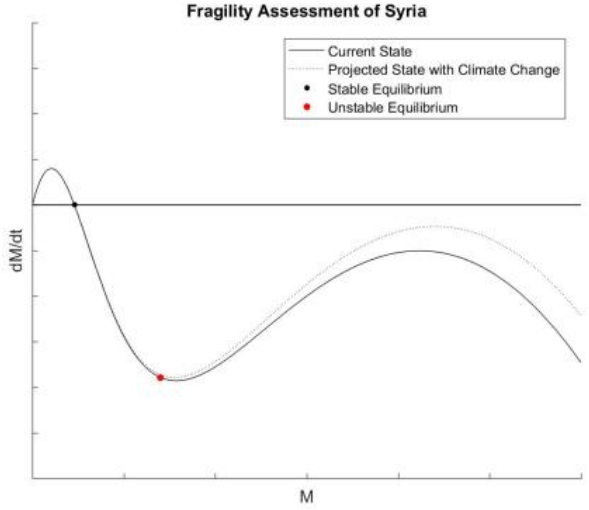


图 4：该图显示了叙利亚的脆弱性评估及其在 dM / dt-M 图中的现状。 该模型预测叙利亚将出现负增长并变得更加脆弱。

Now, to determine how the climate change increased fragility of Syria, we omitted climate change from our variable, and the resulting graph is as shown below. The graph shows that although Syria is still in a fragile state, its fixed point becomes higher, which indicates that in the long term, the economic status of Syria will be better if it does not suffer from harsh climate. Also, we can see that the curve shifts upward compared to the one accounting for climate condition, and this implies that its rate of decrease will be much slower than it is right now.

Looking back at our equation, since we omitted climate conditions, the parameter k and A will change consequently. Since k is positively associated with climate condition, k value will increase after we omitted negative effect of climate. This is similar for A. Hence, we would expect r to increase because of increase in A, and s will not increase by much because both k and A will increase although k increases slightly more than A. This corresponds to our s - r plot as well. As can be seen from the s - r plot, the point becomes closer to the vulnerable state than when we considered climate. This also corresponds to our research that harsh climate condition played a significant role on making Syria fragile, causing conflicts with neighboring countries as well as restricting economic growth. For example, limited water resources could cause a potential shortage of water supply and food supply, which will cause internal displacement and even panic (Gleick, 2014).

现在，为了确定气候变化如何增加叙利亚的脆弱性，我们从
中省略了气候变化，结果如图所示。 图表显示，虽然叙利亚仍然
处于脆弱状态，但其稳定点变得更高，这表明从长远来看，如果
没有遭受恶劣气候，叙利亚的经济地位会更好。此外，我们可以
看到，与气候条件的一个因素相比，曲线向上移动，这意味着它
的减少速度将比现在慢得多。

回顾我们的等式，由于我们省略了气候条件，因此参数 k 和 A 将
发生变化。 由于 k 与气候条件正相关，因此在忽略气候的负面影
响后 k 值会增加。 这与 A 类似。因此，我们预计 r 会因为 A 的增
加而增加，并且 s 不会增加太多，因为 k 和 A 都会增加，尽管 k
增加略多于 A。这对应于我们的 s - r 图 同样。 从 s-r 图中可
以看出，与我们考虑气候时相比，这一点更接近脆弱状态。 这也
与我们的研究相对应，即恶劣的气候条件对使叙利亚变得脆弱，
与邻国发生冲突以及限制经济增长发挥了重要作用。 例如，有限
的水资源可能导致供水和粮食供应的短缺，这将导致国内流离失
所甚至恐慌（Gleick，2014）。

6.2 Cuba

Fragile state index of Cuba ranks 119th out of 178 countries. FSI categorizes Cuba in the list of \warning" countries and describes Cuba as the most improved country of the past 10 years due to its economic and political reforms launched by Cuban President Raul Castro who firstly assumed power in 2006 (Marshall and Cole, 2017).

In 2008, restrictions on owning mobile phones were lifted and in 2009, U.S. former President Obama removed restrictions on Cuban Americans and allowed money transfer. In 2011, President Raul Castro enacted economic reforms to stimulate small business and entrepreneurs and to provide opportunities for individuals to increase their incomes. In the same year, he also instituted a two-term limit for running the office of president and when he was re-elected in 2013, he announced that he would leave politics at the end of his second term.

During President Raul Castro's second term, the political tensions between U.S. and Cuba were eased. Both Castro and Obama announced in 2014 that they were working to normalize diplomatic relations, underlining these efforts by exchanging political prisoners (Peters, 2012). In 2015, Cuba renegotiated a major portion of its official debt. After reaching agreement of multiple debtors such as China, Mexico and Russia and a high percentage of debts were forgiven, Cuba's risk rating by Moody increased from stable to positive.

6.2 古巴

古巴脆弱国家指数在 178 个国家中排名第 119 位。由于古巴总统劳尔·卡斯特罗于 2006 年首次执政，将古巴列为“警告”国家名单，并将古巴描述为过去十年来改善最大的国家（马歇尔和科尔，2017 年） 。

2008 年，取消拥有移动电话的限制，2009 年，美国前总统奥巴马取消了对古巴裔美国人的限制并允许转账。 2011 年，劳尔·卡斯特罗总统颁布了经济改革措施，以刺激小企业和企业家，并为个人提供增加收入的机会。同年，他还设立了总统职位的两个任期限制，并在 2013 年再次当选时，他宣布他将在第二任期结束时离开政坛。

在劳尔·卡斯特罗总统任期内，美国和古巴之间的政治紧张局势有所缓解。卡斯特罗和奥巴马都在 2014 年宣布他们正在努力使外交关系正常化，并通过交换政治犯来强调这些努力（Peters，2012）。 2015 年，古巴重新谈判了其大部分官方债务。在达成中国，墨西哥和俄罗斯等多个债务人的协议后，高额债务被宽恕，穆迪的风险评级从稳定上升至正值。

In terms of sustainable development, researchers agreed that Cuban government should prioritize the sustainability to provide long-term growth in social, economic and environmental facets (Davis and Piccone, 2017).

Nevertheless, from 2008 to 2015, investment in Cuba has decreased by 17%, exports has fallen by 5% and real GDP has dropped by approximately 1 percent. Moreover, largely due to the financial crisis in Venezuela, Cuba still has a fiscal deficit of 10.1% of GDP, while the deficit in U.S. is 3.4% of GDP in 2017 according to Central Intelligence Agency Database. Therefore, despite of the large improvements in the last decade, Cuba's remaining debts, the U.S. embargo, restrictions on eligibility of Foreign Direct Investment and Cuba's dual currency system still pose a huge challenge to the country's economic development and growth in the future.

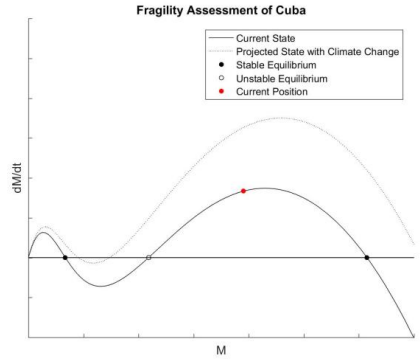


Figure 5: This figure shows the fragility assessment of Cuba and its current status in *M* - *dM / dt* plot. The model predicts that Cuba would maintain a high growth rate.

在可持续发展方面，研究人员一致认为，古巴政府应优先考虑
持续性，以便在社会，经济和环境方面实现长期增长（Davis 和
Piccone，2017 年）。

尽管如此，从 2008 年到 2015 年，对古巴的投资减少了 17%，出口减少了 5%，实际国内生产总值减少了大约 1%。 此外，主要由于委内瑞拉的金融危机，古巴仍有财政赤字占 GDP 的 10.1%，而根据中央情报局数据库，2017 年美国的赤字占 GDP 的 3.4%。因此，尽管过去十年有了很大的改善，但古巴的剩余债务，美国的禁运，对外国直接投资资格的限制以及古巴的双重货币体系仍然对该国未来的经济发展和增长构成巨大挑战。

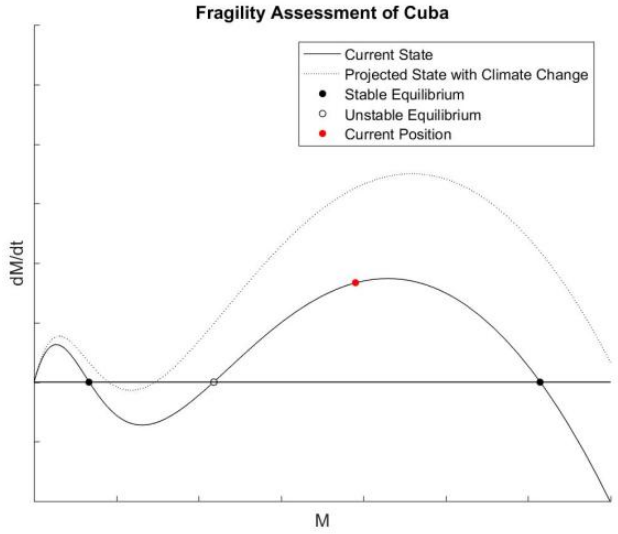


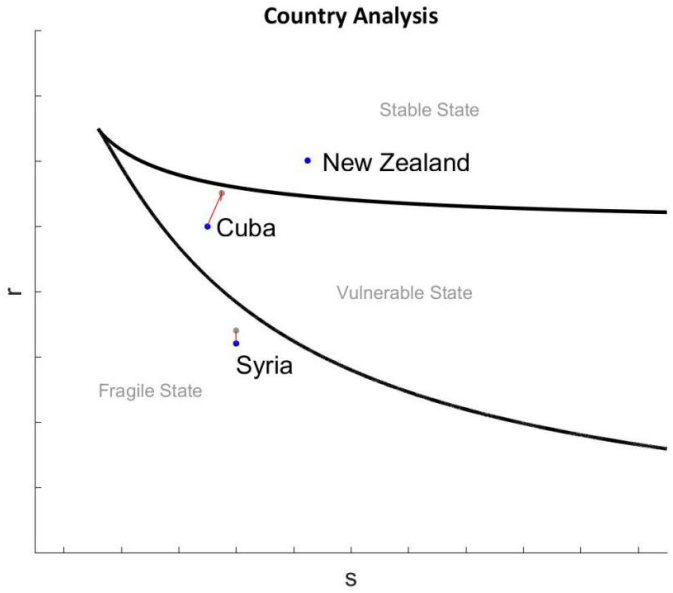
图 5：该图显示了古巴的脆弱性评估及其在 M - dM / dt 图中的现状。 该模型预测古巴将保持高增长率。

Now, we shall look at the data to see how climate change makes Cuba fragile. Our data shows that the main reasons that drag down Cuba's climate parameter are occurrence of natural disasters and droughts. By replacing these two factors with global average, we can see a increase in climate parameter, which will then increase parameter k and A. With a similar analysis as in the case of Syria, we would expect both r and s to increase slightly, and this will help Cuba to approach the stable state. As can be seen from the graph below, we see a slight upward shift of the curve, which shows that Cuba will become slightly more stable if its amount of rainfall is normal and does not suffer from unusual natural disasters. The r - s plot further confirms this.

As for the tipping point, Cuba will reach a tipping point where it becomes a stable state when r or s increases. Since $r = Am_1 / B$, $s = km / A_2$, to increase r or s we shall increase k, A, or decrease B. Since B is relatively robust, we will only consider how we can increase k and A. Since k is positively associated with climate, policy and demographic, we would expect Cuba to reach tipping point if it could implement better political environment. Because of structure and natural resources of Cuba, it is difficult to change the climate and demographic, so we will not further discuss change of these two variables. As for A, since it is positively associated with the economic status, climate, policy and demographic, Cuba will reach tipping point if the economic status and political environment are improved.

现在，我们将查看数据，看看气候变化如何使古巴变得脆弱。我们的数据显示，拖累古巴气候参数的主要原因是自然灾害和干旱的发生。通过用全局平均值替换这两个因子，我们可以看到气候参数的增加，这将增加参数 k 和 A.通过与叙利亚的情况类似的分析，我们可以预期 r 和 s 都会略微增加，并且这将有助于古巴进入稳定状态。从下图可以看出，我们看到曲线略微向上移动，这表明如果降雨量正常并且没有遭遇异常的自然灾害，古巴将变得稍微稳定一些。 r - s 情节进一步证实了这一点。

至于引爆点，古巴将达到一个临界点，当 r 或 s 增加时它将变为稳定状态。由于 r = Am1 / B，s = km / A2，为了增加 r 或 s，我们将增加 k，A 或减少 B.由于 B 相对稳健，我们将只考虑如何增加 k 和 A.因为 k 是与气候，政策和人口结构密切相关的是，如果能够实现更好的政治环境，我们可以预期古巴将达到临界点。由于古巴的结构和自然资源，很难改变气候和人口，因此我们不会进一步讨论这两个变量的变化。至于 A，由于它与经济地位，气候，政策和人口结构正相关，如果经济地位和政治环境得到改善，古巴将达到临界点。



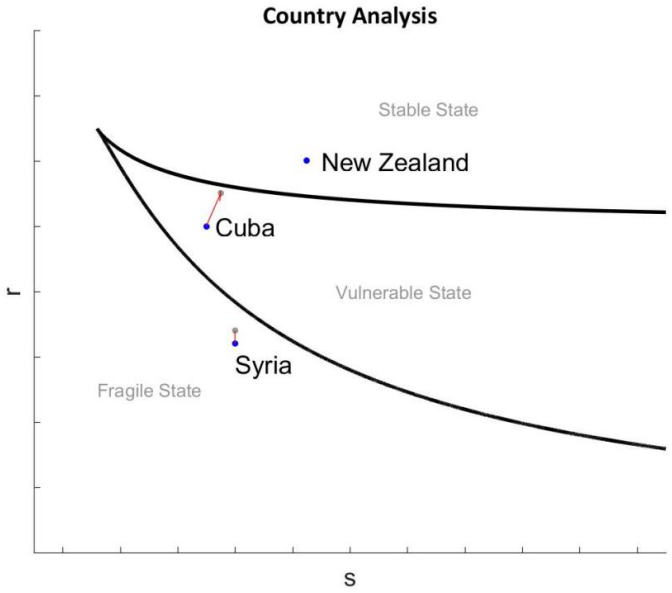


Figure 6: This bifurcation plot positioned three countries at their current states and shows the potential change of position.

图 6：这个分叉图将三个国家置于当前状态，并显示了位置的潜在变化。

6.3 New Zealand

New Zealand's fragile state index ranks 169th out of 178 countries. FSI categorizes New Zealand in the list of "sustainable" countries. Sustainable development has been the central focus for Ministry (The Heritage Foundation, 2018). Access to natural resources, water quality, urban issues and climate change are major sustainable development issues for New Zealand in the early years of the 21st century.

6.3 新西兰

新西兰脆弱指数在 178 个国家中排名第 169 位。FSI 将新西兰列为“可持续”国家名单。可持续发展一直是该部的重点（传统基金会，2018 年）。 获取自然资源，水质，城市问题和气候变化是 21 世纪初新西兰的主要可持续发展问题。

In 1991, the Resource Management Act was enacted to allows public participation communities are making decisions on resource consents. This legislation let New Zealand become the first to adopt sustainability principles. Since the last decade, environmental policies have started to integrate with social, economic and cultural aims, which results a sustainable development framework.

Initiatives such as new air quality standards, improvements in sewage systems, closure of sub-standard landfills, and clean-up of priority contaminated sites are leading to measurable improvements in the quality of air, water and land resources (Bebbington et al., 2009). So government pays considerable efforts to address immediate threats to key natural resources.

New Zealand has an open and export-driven economy with exports accounting for 30% of GDP. Its economy has been growing steadily recent years. The OECD (2015) commented that New Zealand has strong fiscal monetary policy frameworks and a healthy financial sector, which have yielded macroeconomic stability. Although New Zealand's economy slowed down during the 2008 financial crisis, the economy quickly recovered in 2010 and increased the growth rate by 3.7 percentage points, unlike most OECD countries.

New Zealands political system is based on the British model and is considered to be relatively stable. There is a single house of Parliament and the role of head of state is held by Queen of New Zealand. Democratic engagement is strong and typically between 75-80% of New Zealanders turn out to vote in general elections.

1991 年，颁布了“资源管理法”，允许公众参与社区就资源
作出决定。这项立法让新西兰成为第一个采用可持续性原则的人。
自上个十年以来，环境政策已开始与社会，经济和文化目标相结合，从而形成可持续发展框架。

诸如新的空气质量标准，污水系统的改进，关闭不合标准的垃圾填埋场以及清理优先污染场地等举措正在导致空气，水和土地资源质量的显着改善（Bebbington 等，2009） ）。因此，政府付出了相当大的努力来应对对关键自然资源的直接威胁。

新西兰拥有开放和出口导向型经济，出口占国内生产总值的 30％。近年来，中国经济稳步增长。经合组织（2015 年）评论说，新西兰拥有强大的财政货币政策框架和健康的金融部门，这些部门已经产生了宏观经济稳定性。尽管新西兰经济在 2008 年金融危机期间经济放缓，但与大多数经合组织国家不同，2010 年经济迅速复苏，增长率提高了 3.7 个百分点。

新西兰政治体系以英国模式为基础，被认为相对稳定。国会有一个议院，新西兰女王担任国家元首。民主党的参与度很强，通常有 75-80％的新西兰人参加大选投票。

The following graph of the fragility assessment of New Zealand shows that New Zealand is currently in the stable state and is slowing approaching to the fixed point. This finding confirms our expectation based on our research and suggests the robustness and validity of our framework.

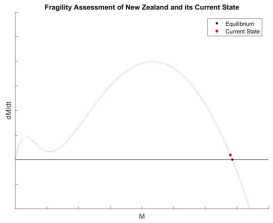


Figure 7: This figure shows the fragility assessment of New Zealand and its current status in *M* - *dM / dt* plot. The model shows that New Zealand is slowly approaching its equilibrium.

7 Human Intervention

We think human intervention can be reflected by the politica indicators because human can enact policies and enforce legislations to affect dynamics of a society, in our case, a country. The impacts of human intervention can be both positive and negative. For example, when a country prioritizes its economic growth and manufacturing sector, it is sometimes possible that this country overlooks the environmental policies and the sustainable growth. Therefore, it would take more human efforts than expected on mitigating the risk of climate change, not only including those targeted on unexpected natural disasters but also on longterm sustainable developments.

新西兰脆弱性评估的以下图表显示，新西兰目前处于稳定状态，正在放慢接近稳定点。这一发现证实了我们对我们研究的期望，并提出了我们框架的稳健性和有效性。

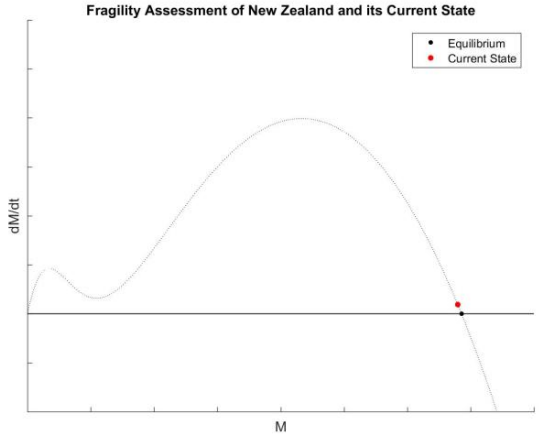


图 7：该图显示了新西兰的脆弱性评估及其在 M - dM / dt 图中的现状。该模型显示新西兰正在慢慢接近其均衡。

7 人类干预

我们认为人为干预可以通过政治指标来反映，因为人类可以制定政策并执行立法来影响社会的动态，在我们的案例中，是一个国家。 人为干预的影响既可以是积极的，也可以是消极的。 例如，当一个国家优先考虑其经济增长和制造业时，该国有时可能会忽视环境政策和可持续增长。 因此，在减轻气候变化风险方面需要做出比预期更多的人力工作，不仅包括针对意外自然灾害的目标，还包括长期可持续发展。

Since Cuba is in the range of vulnerable countries, our team chooses to examine the impacts and costs of human intervention in Cuba and use both of our empirical framework and research to show that interventions alleviate the negative market impacts of climate change and preventing Cuba from becoming a fragile state.

Extreme weather conditions has always been the primary concern for Cuba. In 2008, four hurricanes Fay, Gustav, Ike and Paloma damaged 647 thousand dwellings, resulted an estimated amount of 9.76 billion pesos economic losses. The country has also suffered extreme drought which severely affected croplands and availability of water, and increased danger from fires. In 2013, 388 forest fire were reported and lost 4279 hectares of forest. Despite those direct economic losses, loss of human life has been fairly low due to government's warning and the effective Civil Defense system.

Some research suggests that climate changes in Cuba are associated with ecological and socio-economic changes that promote epidemiological shifts affecting the health system (ElSobki et al., 2009). Cuba's First National Communication to the United Nations Framework Convention on Climate Change identifies the sectors of water, forestry and agriculture as the most vulnerable to the effects of climate change.

由于古巴属于脆弱国家，我们的团队选择审查人类干预在[illegible]影响和成本，并利用我们的经验框架和研究表明干预措施减轻了气候变化的负面市场影响，并阻止古巴成为一个脆弱的国家。

极端天气条件一直是古巴最关心的问题。2008 年，四次飓风 Fay，Gustav，Ike 和 Paloma 损坏了 647,000 套住房，估计造成 97.6 亿比索的经济损失。该国还遭受了极端干旱，严重影响了农田和水的供应，并增加了火灾的危险。 2013 年，报告了 388 起森林火灾，并损失了 4279 公顷的森林。尽管有这些直接的经济损失，但由于政府的警告和有效的民防系统，人命损失相当低。

一些研究表明，古巴的气候变化与促进影响卫生系统的流行病学变化的生态和社会经济变化有关（ElSobki 等，2009）。古巴第一次向联合国气候变化框架公约提交的国家信息通报将水，林业和农业部门确定为最易受气候变化影响的部门。

Cuba has a long history of policy initiatives to address climate change. In 1991, National Commission on Climate Change was created with a mandate to study the impacts of the phenomenon on its population, food production, water supplies and health. In recent years, Cuba has taken many measures on environmental issues and climate change (Alonso and Clark, 2015). In 2007, Cuba launched the Cuban Society Program to Face Climate Change which analyzes all sectors of the Cuban economy in terms of vulnerability to climate change and required adaptation measures. In addition to those efforts, Cuba has established a sophisticated national disaster risk reduction framework through the creation of a comprehensive Civil Defense System that protects lives in the case of extreme climatic events and acts as an early warning system. From 1998 to 2008, environmental protection spending increased from 41.9 million pesos about 1.8% of total public spending to 335.6 million pesos about 6.4% of total spending (ElSobki et al., 2009). And based on our model, we project that if the Cuban government is going to alleviate or even eliminate the negative effects of climate change, the total cost, which is also the magnitude of political indicators in the function, would be more than $12 billion dollars by 2025.

There is moderate number of current discrete adaptation projects in Cuba. Those adaptation projects are addressing needs related to each of its identified priority sectors of agriculture and, to a less extent, freshwater resources and forestry. Our group think that future initiatives could expand upon its current adaptation efforts related to agriculture, disaster risk management, government, coastal zone management and water. They could also close observed gaps related to human health, the differential impacts of climate change by gender.

古巴在应对气候变化方面的政策举措历史悠久。 1991 年，气候变化委员会成立，其任务是研究这一现象对其人口，粮食生产，供水和健康的影响。近年来，古巴在环境问题和气候变化方面采取了许多措施（Alonso 和 Clark，2015 年）。 2007 年，古巴启动了古巴社会应对气候变化计划，该计划分析了古巴经济在气候变化脆弱性和所需适应措施方面的所有部门。除了这些努力之外，古巴还通过建立一个全面的民防系统建立了一个复杂的国家减少灾害风险框架，该系统在极端气候事件中保护生命，并作为预警系统。从 1998 年到 2008 年，环境保护支出从 4190 万比索增加到公共支出总额的 1.8％，达到 3.356 亿比索，约占总支出的 6.4％（ElSobki 等，2009）。根据我们的模型，我们预计如果古巴政府要减轻甚至消除气候变化的负面影响，那么总成本，也就是该职能中政治指标的大小，将超过 120 亿美元到 2025 年。

古巴目前的离散适应项目数量适中。这些适应项目正在解决与其确定的每个农业优先部门有关的需求，以及较少程度上的淡水资源和林业。我们小组认为，未来的举措可以扩展其目前与农业，灾害风险管理，政府，沿海地区管理和水有关的适应工作。他们还可以关闭与人类健康有关的观察到的差距，以及按性别划分的气候变化的不同影响。

8 Discussion & Conclusion

One strength of our model is its flexibility. All the parameters are relatively independent from each other. Hence, it is easy to change metrics without making major changes to our model. Besides, this helps us to use our model to predict what happens if we change one or some of the parameters, and thereby making predictions for future. Another strength is that it fits the result from Fragile State Index, which shows the accuracy of our model. However, there are also limitations. One limitation is that the weight of each parameter may be revised to make this model more accurate. Also, we did not account for the interaction between countries, which may play an important role in evaluating fragility of some countries.

Our model can be used to evaluate fragility of small \states", such as cities. To do so, we can find data for the city and plug into our model to see where the city locates on the graph. However, it may be difficult to use our model to evaluate fragility of larger \states" because we have to change our definition of some data we are using. For example, we may need to define carefully on corruption for a continent. We may use the GDP or population, etc as weights to calculate a mean for the continent. Besides, some data may not be defined over a continent, like devaluation of currency. After carefully define new metrics for assessing fragility of a continent, we may plug in our equation to make it work on larger \states".

8 讨论与结论

我们模型的一个优点是它的灵活性。所有参数彼此相对独立。因此，在不对我们的模型进行重大更改的情况下，很容易更改指标。此外，这有助于我们使用我们的模型来预测如果我们改变一个或一些参数会发生什么，从而对未来做出预测。另一个优势是它符合脆弱状态指数的结果，该指数显示了我们模型的准确性。但是，也存在局限性。一个限制是可以修改每个参数的权重以使该模型更准确。此外，我们没有考虑到各国之间的互动，这可能在评估一些国家的脆弱性方面发挥重要作用。

我们的模型可用于评估小城市的脆弱性，例如城市。为此，我们可以找到城市的数据并插入我们的模型，以查看城市在图表中的位置。但是，可能很难使用我们的模型来评估较大地区的脆弱性“因为我们必须改变我们正在使用的一些数据的定义。例如，我们可能需要仔细定义一个国家的腐败。我们可以使用 GDP 或人口等作为权重来计算非洲大陆的平均值。此外，某些数据可能无法在一个大陆上定义，如货币贬值。在仔细定义用于评估大陆脆弱性的新指标之后，我们可以插入我们的等式，使其适用于较大的“地区”。

In our paper, we have developed a framework that measures the fragility of a state, taking account of economic, political, demographical factors and climate change. Our framework accounts for a composite measure of major metrics and uses logistic equations to represent the positive and negative market impacts of those factors with carrying capacities. To check the robustness and validity of our model's results, we selected three representative countries, Syria, Cuba and New Zealand. Our results follow the latest ranking by Fragile State Index, where Syria, Cuba and New Zealand are considered to be fragile, vulnerable and stable respectively. Moreover, we further analyze the impacts of climate change by calibrating our meta-metrics and evaluating the potential level of selected countries.

在我们的论文中，我们已经建立了一个衡量一个国家脆弱性的框架，同时考虑到经济，政治，人口因素和气候变化。 我们的框架考虑了主要指标的综合衡量指标，并使用逻辑方程来表示具有承载能力的那些因素的正面和负面市场影响。 为了检查我们模型结果的稳健性和有效性，我们选择了三个代表性国家，叙利亚，古巴和新西兰。 我们的结果遵循脆弱国家指数的最新排名，其中叙利亚，古巴和新西兰分别被认为是脆弱，脆弱和稳定的。 此外，我们通过校准我们的元指标和评估所选国家的潜在水平，进一步分析气候变化的影响。