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T1 ________________	**89226**	F1 ________________
T2 ________________		F2 ________________
T3 ________________	Problem Chosen	F3 ________________
T4 ________________	**E**	F4 ________________

2018
ICM
Summary Sheet

What controls the state fragility?

The degree of fragility in a country is tightly related to the climate change, which includes variation in temperature (T) and precipitation (P). In this article, a mathematical model is established to determine and predict the climate change effects on state fragility index based on Artificial neural network (ANN) and Monte Carlo simulation (MC).

In Task 1, the fragile index (F) is defined to assess the degree of fragility of a country. F is related with seven sub-indices from four categories – economy, demographics, environment and governance. According to ANN, F can be determined by learning the assessment of existing samples. Besides, a country is graded as fragile, vulnerable or stable based on the value of F. The influence of temperature and precipitation on fragility is defined as climate change index (C), which is determined based on differential equation theory.

In Task 2, Central Africa is investigated as one of the most fragile countries. By multiple linear regression, the expression between sub-indices and climate is determined. Consequently, C is calculated based on ANN. The fragility index is negatively correlated to temperature and precipitation, which decreases by 7.900 per 0.1 K increase in average temperature or 3.400 per 10 mm increase in total precipitation. Without the climate impact, the fragility reduces by 7.9% from 112.1 to 103.3, which indicates the climate variation may enhance the degree of fragility.

In Task 3, Philippines is selected as a country in vulnerable state. Temperature and precipitation controls all sub-indices except for the rate of government, thus influencing the fragility. The tipping point is defined by dynamic programming. MC is employed to solve the programming. According to the simulated P vs T expression, if the average temperature maintains 27 ℃, Philippines would turn fragile when the total precipitation is more than 4464 mm. Likewise, if the precipitation maintains 3000 mm, the fragile state comes when temperature reaches 30 ℃.

In Task 4, the effects of each sub-index on fragility index are determined. The most efficient state-driven interventions are to control the cereal production and to reduce the natural disaster cost. Based on MC and ANN, the relation between F, cereal production and natural disaster cost is measured. For Central Africa, if the cereal production keeps 0.25 Mt, the country will shift from fragile to vulnerable when the natural disaster cost decreases from 0.95 billion dollars to 0.90 billion dollars, and will turn stable when the cost further decreases to 0.37 billion dollars. The theoretical expression of predicted cost is also obtained.

In Task 5, the model is modified to fit smaller or larger states. For smaller states, the values of sub-indices would become less stable due to weaker robustness against external conditions for smaller states. In this way, additional momentum algorithm is introduced in ANN to enhance the stability of F. For larger states, the expression of F is revised considering the non-uniform distribution of temperature and precipitation, as well as the more complicated relation between sub-indices and climate.

1 Background

Fragility, according to Ministry of Foreign Affairs of Japan [1], means "lack of laws and functions of public institutions to provide basic services and to protect the citizens, or lack of governmental function, in whole or in part, with the nation being unable to fulfill its responsibilities (A New Climate for Peace)".

In the past decade, influences of climate change on national fragility has caught the attention of global scholars. Some countries have their homeland swallowed by sea due to melting ice in the Antarctic with rising temperature. Both fishing industry in Southeast Asia and droughts in Africa become abnormal compared to historical data. Human behavior disturbs nature, and vice versa.

Policy makers now bear a difficult task. They need to develop a model to conduct oriented evaluation. In other word, a concrete set of functions connecting measurable terms and data with overall national conditions is needed for detailed description.

The goal of our work is to find practical solutions through our model to improve citizens' well-being in some national states with their situations worsened by climate change.

2 Assumptions

We base our model on the following assumptions.

(1) The fragility of each country derived from our model should be consistent with Fragile State Index [2].

(2) The temperature and precipitation of each country have uniform influence on that area.

(3) The annual average temperature and annual total precipitation represent the climate of a country each year. The variation of temperature and precipitation within one year is not considered.

(4) The country is such a stable region that climate and other indices will not change drastically in a short time.

3 Model

3.1 Overview

To determine the fragility of a country, we firstly define the fragility index (F), and the sub-indices are selected as economy, demographics, environment and governance. Based on Artificial neural network (ANN), we are able to determine F by learning existing data results. With reference to theories of differential equation and linear regression, correlation between sub-indices and climate is determined. Then, in a fragile country (Central Africa), climate change index (C) is introduced to measure the change of national fragility under two conditions — with and without climate change. At the same time, in a vulnerable country (Philippines), we apply dynamic programming to determine the tipping point of its fragility transformation, and use Monte Carlo simulation (MC) to predict when the tipping point reaches. Thereafter, the state-driven interventions are determined according to the correspondence of F to different sub-indices. The cost is predicted by MC. Finally, the model is modified in smaller and larger states respectively by adding new algorithm or revising the existing formula of F. Fig. 1 is the flow shart.

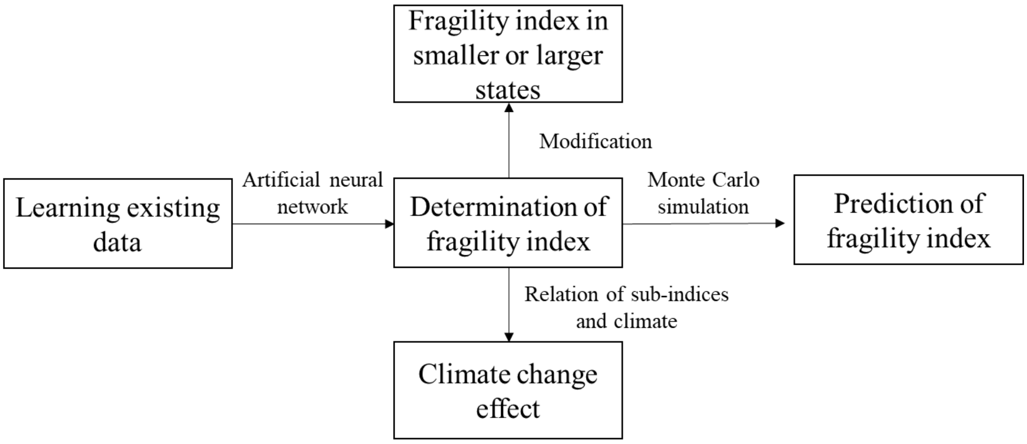

Fig. 1 Flow chat of this model.

3.2 Task 1: Determination of fragility and climate change effect

3.2.1 Categories and variants selected

As given in the background, fragility is both a political and a social-economic concept. To determine a state's overall situation, we need to break down the concept into several sub-fields with quantitative terms. We thus define the fragility index (F) and base our model on Artificial neural network. We conclude four factors for the fragility of a country, including economy, demographics, environment and governance [3]. Suppose $\boldsymbol{x} = (x_1, x_2, \ldots, x_n)^{\mathrm{T}}$ ($n \in \mathbf{N}_+$) are the sub-indices which influence the fragility, then

$$F = f(\boldsymbol{x}) \tag{1}$$

Table 1 shows the four general categories and seven detailed sub-indices picked to express the degree of fragility of a state.

Table 1 Categories and variants to measure fragility.

Category	Sub-indices	Symbol	Unit
Economy	Gross domestic production per capita	x_1	US dollar
Demographics	Population density	x_2	Person per km^2
	Percentage of urban population	x_3	
Environment	Cereal production	x_4	Million ton
	Water resources	x_5	Ton per capita
	Natural disaster cost	x_6	Billion US dollar
Governance	Rate of government	x_7	

A state's economy is a direct overall representation of its citizens' living standard. Gross domestic production (GDP) per capita acts as a major index for economy and can show level of economic life including personal consumption capability and varieties of products.

Demographics show both the pressure and possible labor force of a state. Here, population density is a fundamental index. Percentage of urban population change in response to how climate change affect agriculture and migration.

Environment provides us resources and its abnormal phenomenon can cause economic losses. For a country, we assume its primary produce is cereal. Hence, cereal production shows the ability of a state to feed its people. Water resources are crucial not only to agriculture, but also to industry and citizens' basic need. When disasters happen, their damage to a country can be mitigated through collective measures. Thus, we employ natural disaster cost to show the degree to which a country is harmed.

Finally, fragility is a political concept describing institutions' capability. Rate of government is a comprehensive factor to evaluate a state's governmental operation.

3.2.2Model based on Artificial neural network

ANN is employed to associate the sub-indices with fragility [4,5], which is composed of three layers – input, hidden and output layers. The expression between hidden and input layers can be regarded as linear.

$$net_i = \sum_{j=1}^{n} w_{ij}x_j - \theta_i \tag{2}$$

$$H_i = s(net_i) = s\left(\sum_{j=1}^{n} w_{ij}x_j - \theta_i\right) \tag{3}$$

Here net_i, w_{ij} and θ_i are the hidden layer intermittent, weight coefficient and bias. H_i is the hidden function and s is the stimulus function.

The correlation between output and hidden layer is

$$F = \sum_{i=1}^{n} a_i H_i - \theta = \sum_{i=1}^{n} a_i s\left(\sum_{j=1}^{n} w_{ij}x_j - \theta_i\right) - \theta \tag{4}$$

Where θ is the bias and a_i is the weight coefficient. Based on the assumption, the value of F should be in consistent with fragility state index (*fsi*). Let $F = fsi$. By learning the existing fragile index and sub-indices, the ANN determines F under new sub-indices according to back propagation algorithm (BP, details in 3.3.2) [6,7]. Table 2 indicates the classification of different degrees of fragility.

Table 2 Classification of different degrees of fragility

Identification	Range of F
Fragile	> 100
Vulnerable	[60, 100]
Stable	< 60

Larger F means larger fragility of a country, which is more sensitive to external parameters, such as climate change and international conflicts.

When F is larger than 100, a state is determined as fragile. When the index is between 60 and 100, a state is viewed as vulnerable. A country can basically ensure the survival of its citizens, yet it lacks the ability to deal with risky situations such as natural disasters. If lower than 60, then the state is in a stable condition with its government fulfilling responsibilities.

3.2.3 Climate change index

The climate condition consists of annual average temperature (T) and annual total precipitation (P). The relation between each sub-index and climate is defined as

$$x_i = h_i(T,\ P) \tag{5}$$

Define climate change index (C) to quantify the influence of climate change to the fragility.

$$C_T = \frac{\partial F}{\partial T} = \sum_{i=1}^{n} a_i \left(\frac{\mathrm{d}s}{\mathrm{d}net_i} \sum_{j=1}^{n} w_j \frac{\partial x_j}{\partial T} \right) \tag{6}$$

$$C_P = \frac{\partial F}{\partial P} = \sum_{i=1}^{n} a_i \left(\frac{\mathrm{d}s}{\mathrm{d}net_i} \sum_{j=1}^{n} w_j \frac{\partial x_j}{\partial P} \right) \tag{7}$$

$$C = \sqrt{{C_T}^2 + {C_P}^2} \tag{8}$$

Assume that the sub-index is linearly related to its change rate to climate.

$$\begin{cases} x_i = \dfrac{1}{\alpha_i} \dfrac{\partial x_i}{\partial T} \\ x_i = \dfrac{1}{\beta_i} \dfrac{\partial x_i}{\partial P} \end{cases} \tag{9}$$

Where α_i, β_i ($\alpha_i\beta_i \neq 0$) are the coefficients. Solve the equation, then

$$x_i = k_i \mathrm{e}^{\alpha_i T + \beta_i P} \tag{10}$$

In this way, Eq. (8) can be simplified as

$$C = \sqrt{\left[\sum_{i=1}^{n} a_i \left(\frac{\mathrm{d}s}{\mathrm{d}net_i} \sum_{j=1}^{n} \alpha_i w_j x_i \right) \right]^2 + \left[\sum_{i=1}^{n} a_i \left(\frac{\mathrm{d}s}{\mathrm{d}net_i} \sum_{j=1}^{n} \beta_i w_j x_i \right) \right]^2} \tag{11}$$

Notably, when x_i is unrelated with climate, α_i and β_i can be regarded as 0. Overall, C means the effect of climate change to fragility. The absolute value of C_T or C_P shows effect of temperature or precipitation on F. While the positive C_T (C_P) indicates that the rising temperature (rainfall) increase the fragility, the negative C_T (C_P) shows the opposite effect.

3.3 Task 2: Fragility of Central Africa

3.3.1 Relation between sub-index and climate

Central Africa is selected as a typical top 10 most fragile country. The values of each sub-index and fragility (*fsi*) from 2006 to 2016 are listed in Table S1. In order to figure out the climate change effect based on Eq. (11), the relation between variants (x_i) and climate (T, P) should be determined. Based on Eq. (10)

$$\ln x_i = \alpha_i T + \beta_i P + \ln k_i \tag{12}$$

Parameters α_i and β_i can be calculated by multiple linear regression[8]. Table 3 shows the parameters for different sub-indices[9].

Table 3 Parameters for different sub-indices. R^2 is goodness of fit.

Sub-index	α	β	ln$k$	R^2
x_1	0.06755	-0.0005472	5.016	0.05730
x_2	0.01342	0.0002189	1.281	0.7752
x_3	0.004933	0.0001500	3.312	0.8276
x_4	-0.05946	0.0007387	-0.8802	0.9490
x_5	0.001119	0.0001620	3.940	0.8101
x_6	0.03955	0.0005551	-2.000	0.8133
x_7	0.09702	-0.0004508	-1.095	0.2025

For x_1, x_2 and x_7, the goodness of fit is less than 0.8, which means climate change exerts negligible effects on fragility. The α_i and β_i are regarded as 0 in Eq. (11). For other four indices, the goodness of fit is larger than 0.8, so the regression is accepted. Overall, climate change may have no significant influence on GDP per capita, population density and rate of government in Central Africa. However, it affects urban population percentage, cereal production, water resources and natural disaster cost. For urban population percentage, water resources and natural disaster cost, they all increase with rising temperature and precipitation. The coefficient $\alpha >> \beta$, which indicates the temperature change is the dominant change in climate variation in Central Africa. Cereal production has the most significant dependence on climate, which decreases with temperature and increases with rainfall. This is because the climate in this country is hot but dry all year round, where the crops yielding would increase with reduced heat or increased rainfall.

3.3.2 Determination of climate change index

The C can be redefined in difference equation form (ΔT and ΔP approximate to 0).

$$C_T = \frac{\Delta F}{\Delta T} \tag{13}$$

$$C_P = \frac{\Delta F}{\Delta P} \tag{14}$$

$$C = \sqrt{(C_T \cdot 0.1\ \mathrm{K})^2 + (C_P \cdot 10\ \mathrm{mm})^2} \tag{15}$$

In reality, let $\Delta T = 0.1$ K and $\Delta P = 10$ mm. The climate change causes variation in x_i, thus influencing F. Back propagation algorithm is applied to determine the new fragility ($F + \Delta F$) when T (P) changes to $T + \Delta T$ ($P + \Delta P$).

The data in Table S1 are used for the study of the algorithm. As for the stimulus function, sigmoid function is selected.

$$H = s(net_i) = \frac{1}{1 + \mathrm{e}^{-net_i}} \tag{16}$$

The *fsi* values are regarded as the expected output Y. The error (e) is defined as

$$e = F - Y \tag{17}$$

The weight coefficients are modified based on the feedback of error.

$$w_{ij}^{'} = w_{ij} + \eta H_i(1 - H_i)x_j + a_i e \tag{18}$$

$$a_i^{'} = a_i + \eta H_i e \tag{19}$$

$$\theta_i^{'} = \theta_i + \eta H_i(1 - H_i) + a_i e \tag{20}$$

$$\theta^{'} = \theta + e \tag{21}$$

Where the plum means modified values and η is the study efficiency. The algorithm will keep iteration until the error is acceptable. Thereafter, the new fragility is predicted according to ANN algorithm. Table 4 shows the fragility corresponding to climate change in Central Africa in 2016.

Table 4 Fragility corresponding to climate change in 2016.

F	F ($T + \Delta T$)	F ($P + \Delta P$)	C_T (K^{-1})	C_P (mm^{-1})	C
112.1	104.2	108.7	-79.00	-0.3400	8.600

From Table 4, the fragility of Central Africa will decrease by 7.9 if the annual average temperature increases by 0.1 K, or decrease by 3.4 if the annual total precipitation increases by 10 mm. The climate change index is 8.600, which shows the combined effects of temperature and precipitation variation.

3.3.3 Effect without climate change

Suppose the climate change exerts no effects on sub-indices. Therefore, $\alpha = \beta = 0$. For those variants irrelevant with climate, the values are unchanged. For those variants which are previously dependent on climate, $x_i = k_i$. Based on ANN, the fragility on this condition is determined as 103.3. Compared with 112.1 with climate change, the fragility decreases by 7.9%. Because Central Africa is a country in the torrid zone, the climate change may have a strong effect on its water resources, crop production and etc. When temperature and precipitation have no direct or indirect connection with those sub-indices, Central Africa could get less fragile, though the fragility index is still higher than 100. The poor economic and low rate of government may be the answers.

3.4 Task 3: Investigation of Philippines

3.4.1 Determination of fragility factor

Philippines is selected as a country not in the list of top 10 most fragile countries. The values of each sub-index and fragility (*fsi*) from 2006 to 2016 are listed in Table S2. Similar to the investigation of Central Africa, the relation between sub-index and climate is determined as shown in Table 5. Based on ANN and BP algorithm, the climate change index can be measured as seen in Table 6.

Table 5 Parameters for different sub-indices.

Sub-index	α	β	ln$k$	R^2
x_1	0.2543	0.0006080	-0.6080	0.8796
x_2	0.04327	0.0001520	4.217	0.8986
x_3	0.01267	0.0000546	3.341	0.8860
x_4	0.04039	0.0003300	1.270	0.8402
x_5	0.009482	0.00003420	4.161	0.8970
x_6	0.02380	0.0001410	0.4366	0.9006
x_7	-0.03098	0.00007370	1.801	0.1505

Table 6 Fragility corresponding to climate change in 2016.

F	$F\,(T+\Delta T)$	$F\,(P+\Delta P)$	C_T	C_P	C
84.70	83.01	86.15	-16.90	0.1450	2.227

The goodness of fit for x_7 is much smaller than 0.8. That is to say, the climate change may have no strong effects on the governance, where α_7 and β_7 are regarded as 0. For other indices, they are positively related with both temperature and precipitation. Notably, compared with that in Central Africa, the climate in Philippines also influences GDP per capita and population density. This is because the economy and population in this country relies heavily on agriculture. The increase of temperature or precipitation is good for crop-yielding, thus increasing GDP and population. From Table 6, the fragility of Philippines decreases by 1.69 with 0.1 K of temperature increasing and increases by 1.45 if the precipitation increases by 10 mm. The climate change index of Philippines is 2.227.

3.4.2 Indicators to push fragility

The indicators to push fragility are divided into two different types, the direct and indirect ones.

a. Direct indicators. Six of the sub-indices chosen are the direct indicators, which are GDP per capita, population density, percentage of urban population, water resource, natural disaster cost and cereal production. For population density and cereal production in Philippines, the increasing temperature and precipitation may cause the increasing of population density and cereal production. This is because high temperature and enough rainfall are necessary for the growth of crops. Besides, the increasing crop production could feed more people, which causes the increasing of population. For Philippines, the agriculture makes great contribution to its economic, so the GDP per capita will increase with cereal production increasing. On the other hand, too much rainfall and too high temperature are usually the reasons for natural disasters like flood, so the natural disaster cost rises.

b. Direct indicators – temperature and precipitation. The average temperature and total precipitation per year directly influences the sub-indices and exert an indirect effect on the fragility index.

3.4.3 Definition of tipping point

Tipping point is such a condition of climate (T, P) that fragility of a country reaches the transition point from vulnerable to fragile state. It is not a single point, but a series of combination of temperature and precipitation. In the P vs T plot, tipping point is a curve which separates the area into two parts – vulnerable state and fragile state. According to the dynamic programming, the (T, P) for fragile state should follow

$$\begin{gathered} F = \sum_{i=1}^{n} a_i s\left(\sum_{j=1}^{n} w_{ij} h_j(T,\ P) - \theta_i\right) - \theta > F_0 \\ T_{\min} \le T \le T_{\max} \\ P_{\min} \le P \le P_{\max} \end{gathered} \tag{22}$$

where $F_0 = 100$ is the transition point from vulnerable to fragile state. $T_{\min}$, $T_{\max}$, $P_{\min}$ and $P_{\max}$ are the lower and upper limits for T and P in Philippines. In this question, the average temperature ranges from 15 ℃ to 35 ℃ and the annual total precipitation ranges from 2000 mm to 8000 mm.

On this case of Philippines, the Monte Carlo simulation [10,11] is employed to detect the tipping point. Fig. 2a shows the results of MC and 2b illustrates the pseudo-color P vs T plot for Philippines in 2016.

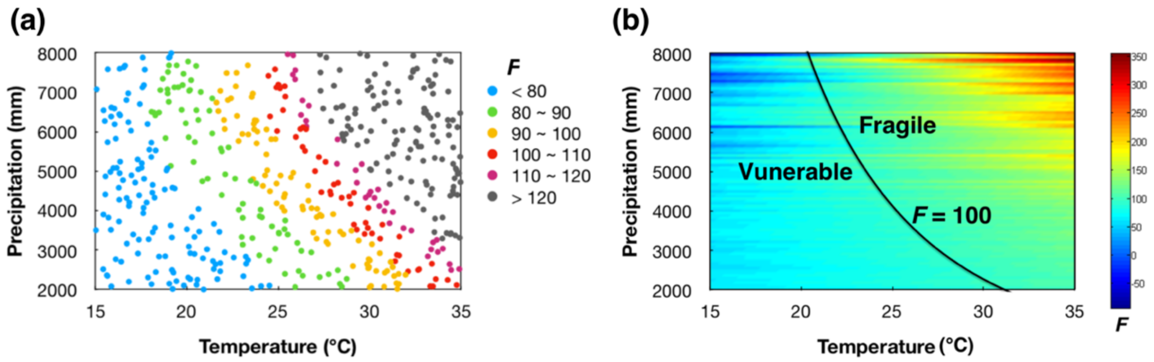

Fig. 2 (a) the results of Monte Carlo simulation (b) the pseudo-color P vs T plot for Philippines in 2016.

From the results of simulation, with T and P increasing, the fragility rises to reach the fragile state. At the tipping point, the relation between T and P can be simulated as

$$P = -1.203T^3 + 128.9T^2 - 4877T + 6.596 \times 10^4 \tag{23}$$

Therefore

$$\begin{cases} P \leq -1.203T^3 + 128.9T^2 - 4877T + 6.596 \times 10^4 & \text{Vulnerable} \\ P > -1.203T^3 + 128.9T^2 - 4877T + 6.596 \times 10^4 & \text{Fragile} \end{cases} \tag{24}$$

The fragility grade for Philippines is 'vulnerable' in 2016 with $T = 27$ ℃ and $P = 3000$ mm. If the average temperature maintains 27 ℃, this country would transform to fragile state when the annual precipitation is 4464 mm. Likewise, if the annual precipitation maintains 3000 mm, the fragile state comes when temperature reaches 30 ℃. Usually, the climate variation is not so drastic. In this way, Philippines may stay in the 'vulnerable' state without unexpected natural disaster or external intervention.

3.5 Task 4: Effects of state-driven interventions

3.5.1 Intervention of sub-indices

The state-driven intervention influences F by tuning x_i. The fragility of a country is tightly correlated to the sub-indices on economy, population, environment and governance. The F may exhibit different correspondence to slight change of different variants. Define the correspondence (δ_i)

$$\delta_i = \frac{\partial F}{\partial x_i} = \frac{\Delta F}{\Delta x_i} \tag{25}$$

Let Δx_i be the 1% of the original x_i value. Table 7 lists the correspondence of fragility to different sub-indices in Central Africa and Philippines in 2016 respectively.

Table 7 Correspondence of fragility in Central Africa and Philippines in 2016.

Sub-index	δ_i in Central Africa	δ_i in Philippines
x_1	1.259	0.006091
x_2	72.18	0.04750
x_3	10.69	0.5301
x_4	2274	0.5913
x_5	9.414	0.2783
x_6	582.4	3.540
x_7	285.2	6.387

According to Table 7, Central Africa is much more sensitive to sub-indices than Philippines. The correspondence for x_1 and x_5 is much smaller compared with that of other indices, which means the variation of GDP per capita and water resources may not increase the degree of fragility significantly according to the data. Besides, although demographic indices (x_2 and x_3) and governance have great effects on F, it may be difficult to take effective actions by the state government to manipulate the population density or urban people percent, or to improve the rate of the government in a short term. Accordingly, cereal production (x_4) and natural disaster cost (x_6) are the only two variants which not only have significant impact on fragility index, but also can be controlled by the government in an efficient way.

Therefore, the state driven intervention includes –

a. Control the cereal production. The cereal production should be restricted under a certain level according to the agriculture situation of a country. The excessive farming will decrease the sustainability of farmland, or even destroy the whole eco-system. By planning the crop yielding, the farmland can be utilized sufficiently without deterioration.

b. Reduce the natural disaster cost. Although the natural disasters are usually unavoidable, the cost can be reduced by building public construction like dams and reservoirs, improving transport systems and settling the residents from disaster-prone areas to safe areas.

c. Other long-term measurements, such as increase the rate of government.

3.5.2 Total cost of intervention

The two major intervention is to control x_4 and x_6, such that $F < F_0$ and reaches the vulnerable state.

$$F = \sum_{i=1}^{n} a_i s\left(\sum_{j=1}^{n} w_{ij}x_j - \theta_i\right) - \theta \le F_0$$
$$x_{4\min} \le x_4 \le x_{4\max} \tag{26}$$
$$x_{6\min} \le x_6 \le x_{6\max}$$

where x_{4min}, x_{4max}, x_{6min} and x_{6max} are the lower and upper limits for x_4 and x_6 in Central Africa. In this question, the cereal production per year ranges from 0.15 Mt to 0.35 Mt and the annual natural disaster cost ranges from 0 billion dollars to 1.5 billion dollars.

Monte Carlo simulation is employed to solve the dynamic programming problem. Fig. 3a shows the results of MC and 3b illustrates the pseudo-color x_6 vs x_4 plot for Central Africa in 2016.

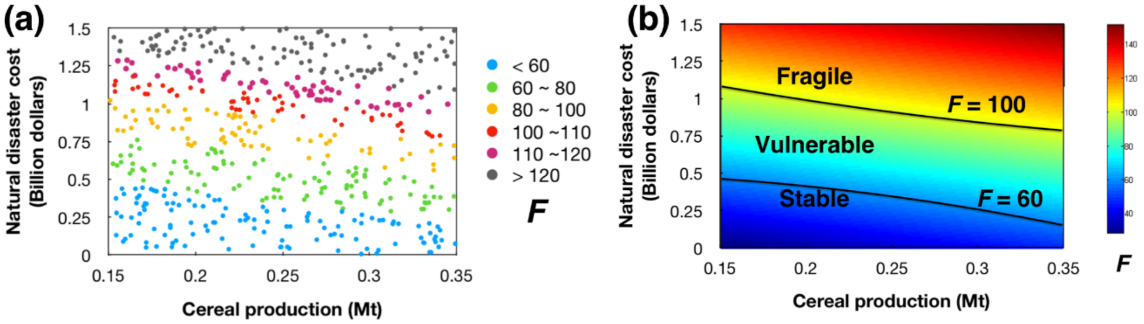

Fig. 3 (a) the results of Monte Carlo simulation (b) the pseudo-color x_6 vs x_4 plot for Central Africa in 2016.

From the results of simulation, with x_4 and x_6 declining, the fragility index change from fragile state to vulnerable state, and then to stable state. The boundary between fragile and vulnerable states is

$$x_6 = 2.571x_4^2 - 2.772x_4 + 1.441 \tag{27}$$

The boundary between vulnerable and stable state is

$$x_6 = -3.816x_4^2 + 0.3492x_4 + 0.4955 \tag{28}$$

In 2016 for Central Africa, the cereal production is 0.25 Mt and the cost from natural disaster is 0.95 billion dollars. Suppose the controlled cereal production is still 0.25 Mt, the country will become less fragile with the reduced natural disaster cost. When the cost decreases to 0.90 billion dollars, the country turns to vulnerable state. When the cost further decreases to 0.37 billion dollars, the state will be stable.

In terms of the total cost of intervention, the cost coefficient should be introduced. Let u and v be the cost for the reduce of every 1 Mt cereal and every 1-billion-dollar natural cost, respectively. The total cost (U) to improve Central Africa to vulnerable state is

$$\begin{aligned} U &= u\Delta x_4 + v\Delta x_6 = u\Delta x_4 + v\left(-7.632x_4\Delta x_4 - 3.816\Delta x_4^2 + 0.3492\Delta x_4\right) \\ &= -3.816v\Delta x_4^2 + (u + 0.3492v - 7.632vx_4)\Delta x_4 \end{aligned} \tag{29}$$

3.6 Task 5: Modification of models

3.6.1 Modification for smaller states

According to the assumption, the country which applies to this model should be relatively stable and robust against the external change. However, in smaller states, considering the limited resources and government manipulation, the sub-indices will be more discrete.

Consequently, the learning mechanism should be modified to fit the more unstable data. One way is to improve the BP algorithm with additional momentum algorithm. Eq. (18) is modified as

$$\Delta w_{ij}(t+1) = \gamma \Delta w_{ij}(t) + (1-\gamma)\eta e x_j \tag{30}$$

where $\Delta w_{ij}(t)$ is the change in weight at time t and $\gamma \in [0, 1]$ is the influence of the inertial term. With the addition of momentum, the F is calculated more stable in smaller states.

3.6.2 Modification for larger states

The model built above does not work on larger states perfectly either. When the states get larger, the temperature and precipitation are not uniformly distributed in the states, but may vary greatly among different areas in the states. So, it is not suitable to assume that the state average annual temperature or precipitation could work well in different areas. Accordingly, we can divide the states into n smaller areas and figure out their own fragility index F_k ($k \in \mathbf{N}_+$). The fragility index for this state is

$$F = \frac{\sum_{k=1}^{n} F_k}{n} \tag{31}$$

Besides, for larger states, the relation between sub-indices and climate is more complicated considering the interconnection within the state. Therefore, the Eq. (12) in 3.3.1 is no longer correct under such circumstance and a new function should be derived

$$x_i = h_{li}(T, P) \tag{32}$$

Overall, the improved model is

$$F = \frac{1}{n}\sum_{k=1}^{n}\left[\sum_{i=1}^{n} a_{ik} s\left(\sum_{j=1}^{n} w_{ijk} h_{ljk}(T,\ P)\ - \theta_{ik}\right) - \theta_k\right] \tag{33}$$

4 Conclusion

4.1 Achievements and innovation

(1) ANN algorithm is employed to determine the fragility index. Through learning data from 2006 to 2016, the F of the country can be calculated on condition with or without climate change effect.

(2) The effect of climate change on the degree of fragility is quantified according to differential theory.

(3) Monte Carlo simulation is used to solve the programming of tipping point for the transformation between fragile and vulnerable states. It is also used to predict the cost of state-driven intervention to avoid fragile situation.

4.2 Weakness

(1) This model works only for a medium state where the sub-indices are relatively stable

and the temperature and precipitation is uniformly distributed. The model need modification in smaller or larger states.

(2) A series of historical or existing data is needed to train the BP algorithm in order to figure out the fragile index for each country.

(3) Only two variants are considered in the intervention of state fragility, while multiple ways of intervention may be taken in the real world.

5 Reference

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6 Appendices

Table S1 The values of each sub-index and fragility (*fsi*) from 2006 to 2016 in Central Africa.

	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006
Gross domestic production per capita	382	333	365	332	484	500	458	465	475	418	373
Population density	7.31458	7.297345	7.248053	7.222789	7.207962	7.185067	7.140719	7.069617	6.975161	6.863463	6.744611
Percentage of urben population	39.332	40.037	39.759	39.4	39.258	39.334	38.928	38.74	38.47	38.118	38.11
Cereal production	0.250013	0.270941	0.266452	0.258764	0.257978	0.25167	0.250667	0.235527	0.24657	0.227	0.231741
Water resources	67.9	68.5	68.4	68	67.8	67.7	67.2	66.7	66.2	65.7	65.2
Natural disaster cost	0.95	0.94	0.9	0.88	0.91	0.93	0.9	0.85	0.9	0.8	0.77
Rate of government	2.3	2.2	2.2	2.2	2.2	2.4	2.6	2.5	2.4	2.3	2.3
Temperature	27	27.2	27	26.8	26.6	27	26.6	27	26.9	26.4	26.3
Precipitation	1500	1600	1550	1520	1500	1500	1460	1400	1500	1320	1310
Fragility index	112.1	111.9	110.6	105.3	103.8	105	106.4	105.4	103.7	101	97.5

Table S2 The values of each sub-index and fragility (*fsi*) from 2006 to 2016 in Philippines.

	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006
Gross domestic production per capita	2960	2870	2840	2760	2580	2350	2130	1830	1920	1670	1390
Population density	343	339	334	328	323	317	312	307	303	298	293
Percentage of urben population	46.872	46.603	46.333	46.063	45.793	45.524	45.255	45.017	44.81	44.633	44.488
Cereal production	28.73459	27.6921	26.73912	25.81744	25.44014	23.65565	22.14937	23.3007	23.74401	22.9773	21.40902
Water resources	91.8	91.5	91.1	90.8	90.5	90.1	89.8	89.5	89.2	88.9	88.6
Natural disaster cost	4.5	4.4	4.3	4.3	4.2	4.3	4.2	4.1	4.1	4	3.9
Rate of government	3.3	3.3	3.3	3.2	3.2	3.1	3.2	3.2	3.3	3.1	3.4
Temperature	27	26.8	26.8	26.4	27.2	26.6	26.4	26.4	26	25.9	25.6
Precipitation	3000	2875	2800	2600	2600	2700	2500	2400	2600	2400	2300
Fragility index	84.7	86.2	85.3	82.8	83.2	85	87.1	85.8	83.4	83.2	79.2

Table S3 MC simulation DATA in defining tipping point

T	*P*	*F*	*T*	*P*	*F*
15.869029	2078.3937	66.931874	30.01123	2738.513	95.29512
15.658988	2344.2338	67.349338	30.83119	2425.7	95.30432

15.626831	2361.4846	67.360183	29.95401	2768.423	95.36243
15.426147	2513.3336	67.526148	31.60799	2143.335	95.37276
16.828607	2197.1686	68.061767	27.28441	3893.349	95.44904
16.110525	2767.3718	68.786334	23.68525	6057.474	95.45425
16.410475	2704.3822	68.93333	27.36944	3861.374	95.499
18.06885	2136.578	69.12004	23.66339	6192.81	95.88858
17.87885	2305.122	69.39191	26.65382	4248.841	95.8897
15.02913	3501.674	69.42628	23.85956	5997.463	95.89052
19.22425	2014.724	69.99369	28.55821	3395.617	95.90743
19.04316	2148.894	70.20021	28.38982	3468.569	95.92289
18.30611	2442.566	70.25301	27.13261	4043.149	96.05496
15.84584	3511.29	70.37251	30.9583	2471.119	96.16572
16.72026	3163.043	70.48243	31.34305	2342.148	96.31789
17.32695	2911.862	70.49174	23.7141	6285.675	96.43908
19.43086	2210.031	70.83382	25.69903	4839.231	96.53428
15.43823	3898.976	70.83508	23.80984	6276.552	96.80279
19.83823	2100.957	70.96309	23.55123	6875.468	97.54891
15.71318	3821.201	70.98426	23.33717	7675.521	97.58316
19.26801	2428.342	71.33664	29.40151	3240.707	97.59324
16.2915	3722.332	71.45496	31.58723	2394.439	97.71111
19.18993	2494.845	71.45497	25.82349	4957.176	97.78018
17.06795	3393.138	71.54035	23.60712	6959.071	98.02012
17.37771	3263.453	71.55957	24.62209	5805.023	98.05618
18.48193	2834.322	71.65312	24.36098	6052.421	98.17777
20.53623	2119.865	71.87616	28.00989	3908.067	98.18204
20.07598	2303.456	71.92548	31.2631	2570.223	98.22667
20.18787	2262.276	71.9265	29.01069	3490.244	98.36117
20.92136	2001.899	71.94988	26.63546	4628.132	98.60182
18.81975	2841.239	72.10395	26.65977	4632.218	98.72682
15.54208	4406.468	72.14255	31.96831	2373.176	98.94275
15.67596	7574.455	72.21552	30.55822	2919.948	98.95652
17.91388	3272.95	72.27634	24.84892	5807.83	99.01981
20.57905	2248.094	72.37811	31.15629	2697.85	99.08129
15.06717	7071.963	72.80249	31.16487	2695.539	99.09149
16.30507	4272.327	72.8759	30.13035	3148.249	99.49992
15.55154	4863.866	73.11395	29.29911	3516.074	99.706

18.13959	3451.065	73.12788	27.36037	4464.282	100.2124
16.83249	4114.112	73.21349	31.39426	2718.516	100.2271
16.32775	7588.122	73.46199	29.14334	3643.447	100.2637
16.8551	4204.284	73.48434	29.72729	3405.814	100.3714
16.70969	4315.532	73.56177	32.10646	2460.016	100.3933
16.28103	4576.967	73.57033	24.93701	6011.519	100.5028
18.25948	3559.976	73.63667	24.55131	6382.288	100.5493
16.61706	7668.937	73.70543	33.31892	2082.468	101.2498
15.81927	4977.867	73.72925	33.46244	2079.293	101.8183
16.55094	7625.899	73.76342	27.87725	4408.173	101.8939
17.61564	3932.907	73.83587	30.13295	3420.075	102.1839
21.67062	2264.243	73.92306	31.49375	2877.39	102.3082
15.9787	5075.501	74.156	27.83841	4482.533	102.3714
19.18253	3318.35	74.18377	29.90708	3557.567	102.6032
17.63389	4068.587	74.25603	31.61833	2862.404	102.6798
20.19026	2920.865	74.25921	30.57778	3287.748	102.7286
15.44555	6535.853	74.32642	27.01842	4996.437	103.0472
16.50801	4768.585	74.34784	32.65179	2494.686	103.0675
16.32535	4946.404	74.44467	29.78491	3690.666	103.4126
16.17059	5080.024	74.46433	32.71368	2514.615	103.5691
20.4179	2900.975	74.52145	28.47356	4322.812	103.7367
15.51361	6265.011	74.56549	24.46365	7409.024	104.0141
15.6648	5729.419	74.58522	26.46492	5509.894	104.4546
21.47573	2517.493	74.62741	28.95608	4170.326	104.4673
20.1127	3085.798	74.74579	25.97056	5862.092	104.5386
17.39189	4385.513	74.77158	26.33688	5611.436	104.5829
20.88625	2789.862	74.80235	33.62309	2264.947	104.7208
17.79895	4202.509	74.89414	28.04931	4658.472	104.8901
17.58805	7871.847	74.90855	25.26247	6540.883	105.0051
21.82792	2462.239	74.93536	24.89599	7115.494	105.6782
15.87388	6609.412	75.03469	28.8815	4355.209	105.9398
16.35331	5235.176	75.04058	28.27493	4701.056	106.3698
19.11719	3622.18	75.11678	25.00319	7185.448	106.6788
15.86074	6379.742	75.15225	25.04142	7167.658	106.849
21.57311	2637.417	75.24991	25.09926	7091.474	106.8677
17.1744	4707.297	75.25577	27.22774	5352.914	107.0201

16.97277	4890.41	75.35895	24.8273	7574.302	107.0708
16.03587	6581.385	75.35911	30.70065	3641.982	107.1383
21.42754	2721.682	75.36193	26.21624	6065.082	107.2681
16.11205	5819.369	75.42251	34.27296	2242.052	107.5505
16.04999	6184.64	75.50783	25.38873	6884.107	107.6491
21.83116	2668.669	75.77892	27.58729	5231.482	107.8215
23.56127	2029.264	75.78373	29.93412	4068.821	108.1102
16.30652	6437.264	75.95259	29.14112	4449.656	108.1879
18.2362	4325.576	75.95297	31.62861	3339.875	108.2018
21.10567	3020.242	76.04144	34.76889	2112.735	108.3289
16.35161	6409.57	76.0472	26.35973	6104.658	108.3724
18.11401	4453.045	76.12124	33.40796	2651.471	108.5533
20.41763	3331.913	76.13865	25.35578	7145.702	108.8588
20.00449	3523.788	76.18139	26.5239	6060.467	108.9842
17.66284	4803.691	76.30341	31.0922	3677.126	109.5268
17.34819	5044.207	76.33168	26.54143	6127.088	109.61
16.7938	6966.464	76.34388	33.18573	2839.922	109.8812
23.09744	2337.209	76.39906	26.24875	6419.045	110.0515
16.69515	6796.514	76.41089	29.78284	4327.152	110.2133
17.70051	7566.171	76.64853	26.52222	6269.997	110.6206
18.13217	4649.4	76.70257	28.21695	5183.358	110.7931
17.52716	5082.385	76.7276	30.52968	4113.092	111.7824
17.31218	5292.51	76.78301	30.80994	3987.17	111.7957
24.06475	2084.712	76.84926	29.30376	4702.356	111.8099
16.80157	6236.088	76.91432	34.46372	2494.488	112.0454
17.53801	5196.639	76.9934	29.9693	4396.9	112.0486
20.67719	3467.13	77.08918	31.85696	3552.117	112.0803
16.94422	6020.512	77.09087	30.2666	4320.263	112.8214
22.07305	2943.547	77.33031	33.37002	3017.207	113.3369
18.78949	4532.533	77.51884	26.32864	6787.465	113.3751
22.56794	2809.381	77.59799	30.05161	4478.227	113.4999
24.51953	2098.423	77.68633	34.37715	2641.377	113.7043
17.57224	7115.404	77.73836	32.28417	3493.305	113.7235
17.65351	7174.196	77.79001	25.80096	7440.048	113.9847
20.28288	3832.43	77.79851	31.27538	3961.211	114.1293
17.43028	6694.525	78.05697	25.9245	7320.739	114.197

23.24729	2651.548	78.07315	33.73079	2951.067	114.4877
18.05783	5353.921	78.28232	25.52055	7955.018	114.6908
17.95083	5541.225	78.4341	26.67769	6652.469	114.81
19.21844	4579.414	78.44424	34.91027	2518.232	115.0025
19.34135	4556.905	78.60301	30.92173	4193.119	115.0759
19.14864	7985.143	78.63588	29.24147	5020.139	115.1066
23.34456	2746.225	78.689	25.93595	7551.219	115.9132
19.0265	7868.756	78.87503	33.46999	3193.855	116.5344
23.22935	2833.125	78.88632	30.46255	4531.639	116.6924
19.0659	7886.734	78.904	34.00905	3035.573	117.4891
18.06175	5719.387	78.94787	25.82171	7928.172	117.5042
17.85302	6190.414	79.01773	28.24869	5799.94	117.5561
21.78165	3460.88	79.03108	33.67533	3255.978	118.8155
18.2978	5521.651	79.08371	29.57335	5175.798	119.23
18.88983	5015.539	79.08721	28.59679	5770.773	119.7201
20.63896	4039.265	79.23459	27.46024	6581.1	120.1774
21.48536	3660.94	79.3221	27.90405	6259.136	120.1845
18.94439	5069.813	79.33855	28.53057	5859.248	120.299
18.06898	6499.608	79.55606	30.07371	5023.775	120.7216
19.02677	7676.02	79.75142	30.03023	5046.885	120.7296
18.19276	6481.865	79.8365	28.50743	5938.816	121.0942
19.12015	5128.433	79.84464	33.54425	3452.921	121.1223
18.68621	7335.045	79.95033	33.9824	3292.026	121.4912
23.05865	3135.619	79.98962	28.70816	5940.987	122.6988
18.27693	6408.409	80.02286	31.10716	4666.13	123.0338
25.92662	2061.721	80.07796	27.3165	7030.453	123.8327
18.97117	7508.542	80.21094	29.34088	5658.146	123.9766
18.55215	7049.742	80.22685	32.044	4313.722	124.4534
23.9624	2865.093	80.43634	30.3777	5191.367	125.4593
18.48085	6482.329	80.49807	34.2152	3429.233	125.6059
18.83633	5833.081	80.75529	28.803	6137.832	126.1191
25.37107	2395.359	80.78618	28.98102	6046.536	126.403
23.00396	3329.113	80.79941	32.58917	4181.204	126.4153
24.50327	2733.906	80.84145	32.94761	4023.661	126.4675
19.44595	7674.769	81.02501	34.41308	3400.041	126.5992
18.94561	7069.664	81.21487	28.18085	6601.751	126.7458

18.95703	6965.111	81.39454	33.58173	3794.889	127.357
19.01252	6752.406	81.72798	34.44917	3425.291	127.3595
23.58592	3302.094	81.8619	31.04179	4989.627	127.6619
19.31833	7118.131	82.15266	34.69133	3369.261	128.2287
20.85386	4742.019	82.30188	28.80854	6334.387	128.9604
26.34225	2349.853	82.54492	34.92897	3312.115	129.0496
20.07079	7771.68	82.70083	27.31186	7495.647	129.3462
19.53375	7120.559	82.75991	29.84681	5757.32	129.7768
26.12765	2468.844	82.77333	28.46187	6631.962	129.8944
20.37309	5228.148	82.82695	31.70846	4824.978	130.4976
19.81721	7459.872	82.89502	28.53441	6650.599	130.9031
24.83807	3033.577	83.14666	33.9924	3823.168	131.3058
21.13953	4806.313	83.17672	29.5211	6116.987	132.5061
23.05845	3815.117	83.25043	28.04941	7158.861	133.1813
21.91151	4392.31	83.29527	30.97198	5350.685	133.2855
19.76787	7176.542	83.35684	32.2791	4733.378	133.9211
19.71659	6547.629	83.59523	29.21026	6452.61	134.8722
22.84859	4015.965	83.73868	27.29098	7948.393	135.3024
20.10223	5855.41	83.7584	30.07108	6009.49	136.2657
19.94449	6207.892	83.92924	29.22774	6569.669	137.0753
20.43793	5733.021	84.33549	33.34194	4405.73	137.3597
27.26958	2316.026	84.41319	31.279	5431.656	137.8576
20.23715	7299.706	84.60399	27.63368	7871.619	138.9846
20.13237	7030.459	84.64484	33.12593	4651.048	140.5436
20.51081	7661.141	84.65208	33.41547	4549.007	141.2764
20.17466	7053.53	84.75223	33.07454	4728.771	141.752
23.06474	4171.964	84.99117	28.36215	7556.833	143.9996
23.98169	3857.174	85.62255	31.37231	5676.37	144.0012
28.48072	2072.35	85.70704	32.11338	5330.253	144.8192
24.10738	3828.412	85.7778	31.48104	5776.557	147.5896
25.04359	3418.873	85.796	34.41479	4374.543	148.1442
20.52402	6538.949	85.85282	30.25082	6573.377	150.0167
25.03355	3436.101	85.87076	30.80339	6260.294	150.2283
24.65758	3599.624	85.87642	32.23267	5542.694	151.4305
20.63116	6291.723	85.90214	34.59105	4421.551	151.5349
22.1028	4915.587	85.92422	31.39055	5995.919	151.7155

28.37337	2145.497	85.93984	32.93431	5259.113	153.1753
27.7587	2387.043	86.0458	34.55603	4497.216	153.2003
26.26631	2978.505	86.16639	34.8082	4395.408	153.5397
24.03593	4021.5	86.6326	30.47433	6657.539	155.313
20.76259	6999.402	86.66196	29.90378	7044.683	156.2849
25.51842	3391.381	86.82065	34.59665	4602.584	156.773
22.64279	4806.563	86.8649	30.19985	6907.494	157.4986
26.04963	3181.141	86.88529	31.80409	6032.46	158.5466
25.34555	3526.605	87.18936	32.67878	5619.589	159.7
26.81003	2941.469	87.30831	32.53928	5716.021	160.4522
21.3888	5952.524	87.42718	30.06922	7117.445	160.9728
21.91782	5497.008	87.60132	32.54199	5742.752	161.282
21.86172	5570.847	87.68886	32.82008	5618.254	161.7674
28.74796	2270.67	87.77134	30.83012	6721.94	162.743
21.23737	6525.596	88.01721	29.92546	7275.072	162.8478
28.26236	2488.275	88.0346	30.88504	6716.853	163.5227
25.38513	3747.494	88.62823	34.65212	4814.837	164.1529
21.3905	6839.347	88.77875	33.56507	5329.124	164.1817
23.49951	4752.619	88.95379	34.97387	4717.336	165.8114
22.28326	5598.433	89.00525	33.97098	5297.159	169.5767
23.80762	4684.325	89.49199	30.81268	6989.801	170.6288
21.62254	6733.243	89.51164	34.82416	4928.055	170.7056
23.621	4797.46	89.52251	34.89406	4944.42	172.4526
21.72419	6517.419	89.59927	32.5604	6083.189	172.468
30.00883	2058.902	89.63788	32.67665	6038.124	172.9869
22.07448	6063.899	89.79624	34.76234	5029.384	173.3208
24.91334	4183.689	89.91923	34.71131	5066.69	173.816
25.34026	3989.008	89.97846	30.28567	7447.674	175.2916
30.07636	2087.461	90.05584	29.47599	7971.551	175.3552
25.21184	4082.578	90.17815	34.57225	5181.609	175.6598
24.16367	4623.299	90.20974	31.6254	6741.651	178.0223
22.0338	6291.187	90.21657	33.70332	5742.304	181.1219
27.10132	3288.39	90.45532	29.87333	7915.16	182.7499
21.83565	7029.176	90.46028	31.01988	7214.202	182.7932
24.547	4488.472	90.60337	33.44766	5915.374	182.9514
26.91951	3442.105	90.99681	31.53316	7017.565	186.5935

29.08819	2594.459	91.15159	34.95576	5361.412	190.319
22.83272	5758.831	91.28871	34.57759	5596.485	192.8084
27.72387	3156.362	91.34289	33.49612	6127.164	192.8631
27.63816	3207.029	91.45783	32.98633	6478.558	197.0133
22.18117	7480.251	91.76622	33.32085	6342.693	198.6613
22.24824	6797.025	91.8647	33.19655	6412.685	198.9737
24.28294	4888.534	91.99628	30.87415	7707.91	200.0499
25.31631	4336.799	92.0483	33.08149	6519.569	201.2498
30.79457	2070.553	92.06191	34.33879	5908.659	202.0974
22.41622	6841.01	92.57537	32.99537	6583.2	202.1759
23.03858	5938.461	92.62862	33.72157	6421.383	212.8361
25.36663	4415.432	92.69437	34.33639	6143.87	214.3058
24.9057	4683.905	92.83954	34.28239	6292.942	221.2797
22.74801	6394.596	92.98219	32.25756	7369.644	223.3417
24.40201	5019.154	93.08464	34.80851	6109.144	225.5995
29.93349	2537.765	93.30525	34.55593	6289.624	229.1939
26.36032	4026.816	93.33094	32.98299	7094.797	230.036
27.7372	3458.795	93.65072	32.37424	7512.342	236.1482
29.96619	2572.432	93.70503	33.46746	6957.218	237.2711
23.3634	5925.267	93.7338	32.39368	7556.525	239.7927
26.32293	4103.215	93.73598	33.34981	7151.761	246.5177
31.5157	2016.302	93.89062	32.58983	7591.485	249.6164
29.8686	2641.465	93.97515	33.22273	7296.396	252.2876
22.68095	7143.112	93.99949	33.46479	7199.731	254.3555
30.35854	2470.365	94.11041	34.95711	6466.284	254.8788
22.71985	7486.546	94.29252	32.39078	7919.438	266.8319
27.11091	3834.769	94.42102	34.30521	7010.74	273.1173
23.81971	5701.185	94.45686	33.59921	7432.429	279.0405
25.12954	4885.426	94.78872	33.57308	7792.388	313.0185
24.35225	5420.123	95.03215	33.80393	7954.634	345.5556
31.46633	2159.522	95.03633	34.18388	7810.322	351.3025
26.82669	4060.306	95.11886	34.43534	7772.132	362.6586

Table S4 MC simulation DATA in estimating intervention cost

x_4	x_6	F	x_4	x_6	F

0.171589	0.050018	31.13002	0.159762	0.914096	90.40835
0.177538	0.056138	32.19948	0.259076	0.764304	90.60652
0.158386	0.089325	32.46277	0.26606	0.754108	90.64411
0.186388	0.052593	32.90417	0.17436	0.896569	90.75221
0.171671	0.082882	33.44188	0.323125	0.668079	90.7608
0.159599	0.106161	33.77317	0.300067	0.703605	90.76723
0.193895	0.059396	34.18942	0.234233	0.807438	90.9539
0.186812	0.078624	34.77405	0.230469	0.819653	91.40449
0.154391	0.131	34.95292	0.34855	0.641138	91.6109
0.219046	0.038442	35.42944	0.27717	0.753994	91.83257
0.162788	0.130254	35.80496	0.225091	0.840306	92.2727
0.188822	0.094442	36.09898	0.194979	0.897784	93.05777
0.182346	0.131834	38.02185	0.196469	0.899709	93.35313
0.232874	0.061506	38.53482	0.335682	0.687204	93.45339
0.24878	0.051726	39.56244	0.164071	0.953191	93.61204
0.253898	0.044214	39.58722	0.153755	0.970135	93.68845
0.249184	0.053077	39.70059	0.271908	0.789929	93.78415
0.21527	0.108432	39.92755	0.237107	0.848097	94.11266
0.252738	0.053439	40.10877	0.228601	0.868075	94.59667
0.198478	0.137396	40.14891	0.279894	0.793069	94.8642
0.17619	0.172536	40.21117	0.172915	0.961275	95.13097
0.2952	0.006472	41.39013	0.177826	0.954645	95.19524
0.281906	0.028457	41.49919	0.184441	0.949869	95.57291
0.185485	0.180569	41.77512	0.221513	0.907605	96.60354
0.167374	0.20969	41.86546	0.340677	0.730078	96.99576
0.304085	0.009911	42.58797	0.150912	1.022151	97.02748
0.206854	0.160715	42.68507	0.317865	0.766733	97.10783
0.249706	0.096121	42.77318	0.348435	0.723377	97.36163
0.185448	0.196762	42.90591	0.193924	0.960872	97.36528
0.157319	0.253594	43.85932	0.211757	0.934546	97.44078
0.163137	0.247255	44.04167	0.222999	0.917859	97.48209
0.29846	0.040621	44.13427	0.219055	0.92483	97.54589
0.305031	0.032107	44.24532	0.22574	0.914779	97.56145
0.205814	0.192889	44.82773	0.181808	0.984811	97.73799
0.269595	0.10094	45.25272	0.244472	0.890964	97.90979
0.154578	0.278035	45.27686	0.222357	0.928347	98.1479

0.197379	0.213533	45.36606	0.206684	0.959781	98.6629
0.239312	0.151729	45.55077	0.234128	0.917851	98.68004
0.167897	0.272213	46.30316	0.28392	0.860994	100.0577
0.334407	0.018465	46.45282	0.335905	0.784311	100.2823
0.335254	0.01773	46.49251	0.232948	0.944278	100.4048
0.233732	0.175901	46.64378	0.22327	0.961382	100.5613
0.210249	0.215444	46.88586	0.225315	0.959558	100.6536
0.211157	0.214809	46.93921	0.318705	0.820236	100.9475
0.292205	0.104322	47.92468	0.333957	0.798476	101.0651
0.314711	0.073412	48.18223	0.220812	0.972663	101.0871
0.277576	0.131728	48.26987	0.340361	0.789157	101.1018
0.170647	0.298586	48.44751	0.153708	1.080444	101.4136
0.283915	0.1285	48.72622	0.261685	0.916267	101.5367
0.279835	0.138702	49.00177	0.332768	0.809589	101.7158
0.225568	0.228127	49.42435	0.280081	0.891277	101.7665
0.339642	0.053231	49.45288	0.171005	1.06484	102.1828
0.252291	0.188043	49.4933	0.17252	1.063419	102.2463
0.254391	0.187929	49.71138	0.247362	0.951688	102.4764
0.228588	0.231023	49.95256	0.316158	0.85649	103.2139
0.186106	0.297132	50.01039	0.189315	1.053833	103.3833
0.170187	0.322408	50.06736	0.249568	0.963666	103.5533
0.331309	0.079848	50.42076	0.163892	1.098114	103.7485
0.241341	0.219468	50.51618	0.220662	1.012223	103.8431
0.33089	0.082171	50.5384	0.221782	1.014221	104.1039
0.215691	0.259529	50.5613	0.301234	0.892259	104.1133
0.233666	0.233189	50.65113	0.317818	0.870257	104.3574
0.166018	0.34319	51.07475	0.153465	1.123173	104.3817
0.230068	0.245016	51.0926	0.230293	1.008249	104.6019
0.273961	0.178904	51.18646	0.166971	1.108718	104.8233
0.171785	0.338446	51.36331	0.18509	1.083307	104.9937
0.170999	0.341166	51.46926	0.301165	0.906474	105.102
0.337818	0.086744	51.60488	0.186366	1.092649	105.7858
0.349143	0.074327	51.95435	0.255911	0.989846	106.071
0.154247	0.373895	51.95882	0.227406	1.035106	106.173
0.22871	0.265627	52.39063	0.154046	1.149643	106.2991
0.329552	0.113283	52.57448	0.235385	1.024727	106.3049

0.190454	0.329503	52.74709	0.229867	1.034379	106.3871
0.281887	0.189028	52.74944	0.249858	1.004767	106.4648
0.183612	0.340208	52.76037	0.173498	1.125079	106.6727
0.337266	0.104093	52.76123	0.203963	1.081096	106.8713
0.341396	0.098101	52.78617	0.181197	1.120145	107.156
0.187086	0.342835	53.31864	0.307428	0.927478	107.2484
0.264254	0.22582	53.42887	0.296524	0.945066	107.3066
0.199495	0.326542	53.51315	0.2039	1.087414	107.3072
0.166455	0.377822	53.54871	0.311635	0.923658	107.4336
0.204316	0.321874	53.70531	0.286599	0.966432	107.735
0.337858	0.121433	54.04018	0.197109	1.105115	107.8164
0.271533	0.224336	54.10865	0.245457	1.033552	108.008
0.217259	0.308846	54.18614	0.22781	1.071089	108.7381
0.158837	0.403129	54.50168	0.248287	1.048662	109.3716
0.167698	0.392071	54.68109	0.164037	1.180409	109.5312
0.264062	0.252209	55.25744	0.304109	0.971914	110.0049
0.334787	0.144923	55.35548	0.165165	1.185797	110.0302
0.240948	0.289283	55.36635	0.271474	1.023203	110.0846
0.196246	0.36158	55.61873	0.269829	1.025993	110.1029
0.295216	0.210033	55.6568	0.300875	0.983158	110.4445
0.181885	0.392003	56.20408	0.318193	0.960058	110.6907
0.291273	0.230043	56.63453	0.242169	1.076903	110.6918
0.157704	0.438732	56.87463	0.274716	1.027495	110.7344
0.264948	0.275464	56.98245	0.258446	1.052653	110.7453
0.250666	0.297547	56.99189	0.277518	1.02412	110.7997
0.238707	0.317808	57.12391	0.178116	1.183701	111.278
0.210935	0.362049	57.23338	0.333849	0.946729	111.4427
0.3404	0.163792	57.28233	0.293004	1.010479	111.5115
0.313293	0.205563	57.29034	0.231223	1.107093	111.6287
0.188238	0.40245	57.62036	0.265403	1.056581	111.7698
0.165441	0.437722	57.63707	0.202686	1.154109	111.8503
0.213677	0.364408	57.69403	0.257655	1.073716	112.1361
0.316576	0.206795	57.73019	0.266946	1.060207	112.19
0.177545	0.421066	57.77337	0.314724	0.991205	112.4998
0.328136	0.191024	57.86989	0.160044	1.23118	112.6591
0.176063	0.42652	57.99603	0.198309	1.173569	112.7427

0.305621	0.229072	58.11151	0.316524	0.994179	112.9021
0.313737	0.220556	58.38881	0.225768	1.135565	113.0365
0.17449	0.435075	58.42602	0.310331	1.00593	113.0586
0.307692	0.230913	58.46356	0.32284	0.993225	113.5154
0.169482	0.444469	58.54513	0.323054	0.995142	113.6728
0.301331	0.243686	58.6737	0.265928	1.083976	113.7461
0.339089	0.187136	58.77704	0.23268	1.136874	113.8726
0.207436	0.392115	58.96354	0.216106	1.164363	114.014
0.18241	0.434613	59.24662	0.262679	1.094292	114.1191
0.29553	0.265498	59.57748	0.272274	1.079959	114.1481
0.334213	0.209316	59.80619	0.255424	1.105908	114.1519
0.284104	0.286446	59.81504	0.197346	1.20196	114.6285
0.238362	0.36118	60.12614	0.282253	1.072768	114.7187
0.200823	0.419658	60.1815	0.240184	1.14085	114.9593
0.195831	0.438414	60.9583	0.195353	1.217244	115.4849
0.284601	0.307366	61.33455	0.238569	1.151175	115.5089
0.240751	0.375849	61.4113	0.27811	1.090736	115.5317
0.170046	0.493412	62.0356	0.252486	1.13027	115.5426
0.245094	0.382082	62.31585	0.188138	1.230615	115.6449
0.248904	0.379087	62.51621	0.201521	1.210684	115.6895
0.184122	0.484381	62.91862	0.16345	1.269874	115.7374
0.312173	0.288975	63.01492	0.216926	1.188609	115.8014
0.262432	0.365745	63.03816	0.155318	1.283408	115.8101
0.205111	0.463174	63.69279	0.184106	1.239499	115.8332
0.222011	0.438855	63.80853	0.275596	1.101804	116.0366
0.283152	0.345702	63.86496	0.344842	0.996774	116.1335
0.281183	0.350328	63.9771	0.267596	1.117985	116.309
0.162282	0.539386	64.42124	0.160648	1.288005	116.7062
0.263953	0.390922	64.96622	0.218599	1.206354	117.2251
0.225051	0.458859	65.53772	0.191322	1.25209	117.4927
0.30587	0.33814	65.78152	0.329619	1.044714	117.8537
0.247529	0.42821	65.8106	0.273507	1.140659	118.5345
0.245124	0.433541	65.92525	0.293112	1.116921	118.9822
0.32987	0.30384	65.96241	0.258636	1.173571	119.2394
0.331072	0.3039	66.09613	0.201506	1.266785	119.6192
0.163802	0.561891	66.16205	0.310983	1.100672	119.7681

0.170622	0.558688	66.67191	0.156363	1.349216	120.5343
0.18597	0.540852	67.07486	0.333666	1.077579	120.5925
0.154936	0.591826	67.30492	0.178711	1.317273	120.7024
0.272203	0.411626	67.30561	0.237118	1.227611	120.709
0.306954	0.359356	67.38508	0.31398	1.115788	121.1501
0.34559	0.300377	67.41267	0.283884	1.163966	121.2852
0.169407	0.571399	67.43185	0.208531	1.283384	121.5389
0.28972	0.389035	67.60889	0.221383	1.269342	121.9389
0.152595	0.603059	67.84002	0.172456	1.349494	122.2868
0.297632	0.384324	68.13085	0.18375	1.334537	122.4549
0.201643	0.532578	68.1829	0.18455	1.338902	122.847
0.197442	0.545766	68.65468	0.229906	1.270924	122.9677
0.33239	0.343456	69.00998	0.272618	1.207269	123.1065
0.311989	0.37546	69.05572	0.179018	1.35169	123.1473
0.163903	0.603318	69.07588	0.266124	1.220251	123.317
0.157211	0.613783	69.08867	0.348695	1.09352	123.3281
0.331622	0.34683	69.1637	0.340194	1.106926	123.352
0.272652	0.439791	69.32766	0.297052	1.1737	123.3855
0.334067	0.346737	69.42049	0.175576	1.360525	123.3958
0.230633	0.510196	69.7364	0.289756	1.189848	123.7313
0.297216	0.409227	69.83111	0.281112	1.209842	124.2016
0.274348	0.446848	70.00481	0.318309	1.154707	124.3436
0.176252	0.598307	70.05464	0.228048	1.293653	124.3603
0.194681	0.580401	70.78448	0.246761	1.268571	124.6179
0.286685	0.441119	70.93194	0.174691	1.381539	124.7731
0.262579	0.478246	70.93769	0.273708	1.229949	124.8133
0.250507	0.502653	71.34802	0.187301	1.364138	124.9117
0.331789	0.386206	71.94106	0.156931	1.412148	125.0054
0.323404	0.399315	71.95677	0.193205	1.358799	125.1733
0.211955	0.570675	71.96314	0.17721	1.384609	125.2595
0.157014	0.656964	72.09341	0.237574	1.301094	125.9076
0.289537	0.455344	72.23593	0.16941	1.406117	125.9267
0.21057	0.577025	72.25903	0.221076	1.329576	126.1269
0.286917	0.460501	72.31508	0.211849	1.344555	126.1829
0.33692	0.383948	72.33539	0.301238	1.208013	126.2408
0.187611	0.615845	72.50689	0.293498	1.220052	126.2509

0.247021	0.524685	72.51655	0.260782	1.270651	126.2735
0.3406	0.380989	72.52438	0.295072	1.220505	126.4521
0.27101	0.488914	72.59319	0.153125	1.439183	126.4901
0.162545	0.659292	72.85215	0.215554	1.345327	126.6359
0.24755	0.533543	73.19427	0.298714	1.217953	126.6655
0.254272	0.523769	73.23331	0.287181	1.242357	127.1337
0.194166	0.617982	73.3626	0.265507	1.281049	127.5111
0.268355	0.50867	73.69177	0.302543	1.224914	127.5657
0.34844	0.387929	73.85494	0.250795	1.306584	127.7161
0.216232	0.602856	74.6789	0.193727	1.394795	127.752
0.292324	0.487386	74.78145	0.204153	1.381214	127.9231
0.220999	0.603782	75.25719	0.188675	1.407866	128.1239
0.309196	0.475002	75.7306	0.17423	1.430295	128.1401
0.216058	0.620619	75.90495	0.306312	1.227561	128.157
0.233946	0.601927	76.52143	0.214703	1.370853	128.3331
0.167803	0.704396	76.57911	0.326347	1.203837	128.6521
0.234054	0.605702	76.79759	0.177473	1.446321	129.6124
0.335765	0.450658	76.88587	0.208656	1.400147	129.7348
0.276495	0.542918	76.96838	0.192009	1.436166	130.4661
0.162948	0.719869	77.1406	0.305889	1.261175	130.4671
0.290463	0.524966	77.21453	0.178896	1.4565	130.4789
0.297267	0.518712	77.50897	0.233029	1.374631	130.5714
0.311311	0.498728	77.62094	0.258254	1.337233	130.6672
0.325529	0.485344	78.21416	0.255109	1.345944	130.9389
0.207005	0.66751	78.21598	0.244975	1.366978	131.3215
0.297194	0.529371	78.24811	0.250919	1.357853	131.3222
0.292223	0.541448	78.55905	0.274542	1.321922	131.3483
0.287755	0.551273	78.76641	0.320468	1.254439	131.565
0.238798	0.629592	78.98261	0.218581	1.41851	132.0904
0.211592	0.676382	79.33169	0.196969	1.453794	132.2356
0.319854	0.51327	79.56002	0.202839	1.445159	132.2627
0.214881	0.679854	79.92916	0.183473	1.481197	132.7025
0.166531	0.760871	80.3998	0.266459	1.369729	133.828
0.210877	0.694272	80.50836	0.313679	1.30583	134.4353
0.297886	0.562088	80.61535	0.329203	1.282819	134.4945
0.27361	0.603492	80.90244	0.1938	1.493751	134.6944

0.209204	0.702478	80.90323	0.206818	1.473976	134.7105
0.292071	0.575544	80.93207	0.201506	1.486275	135.0004
0.197657	0.723136	81.10742	0.348819	1.263972	135.2862
0.195824	0.731622	81.50461	0.311296	1.321913	135.3057
0.19941	0.740291	82.49838	0.262743	1.399284	135.4989
0.265105	0.640378	82.57144	0.266378	1.395685	135.6382
0.308759	0.578065	82.9059	0.20792	1.486689	135.7201
0.15516	0.825138	83.67883	0.326736	1.308815	136.0505
0.158501	0.820779	83.73317	0.338221	1.292767	136.1627
0.195468	0.770329	84.17876	0.279133	1.391377	136.7098
0.241747	0.702582	84.41505	0.210958	1.496476	136.7331
0.231821	0.718272	84.44569	0.257762	1.43529	137.4857
0.216881	0.742759	84.55271	0.326392	1.329859	137.4883
0.227772	0.726784	84.60609	0.299717	1.373859	137.699
0.336827	0.561228	84.74859	0.261333	1.434419	137.8093
0.27592	0.656895	84.89353	0.330016	1.335301	138.2598
0.163068	0.838812	85.48878	0.344382	1.314203	138.3284
0.238596	0.723455	85.53844	0.226977	1.49583	138.413
0.214736	0.763715	85.79029	0.285028	1.411004	138.7202
0.226342	0.757976	86.6379	0.28498	1.418108	139.2128
0.215952	0.777797	86.90805	0.248342	1.483649	139.8601
0.336706	0.598289	87.33264	0.275495	1.449733	140.4075
0.178216	0.845964	87.62121	0.343145	1.346788	140.4787
0.187098	0.833249	87.68662	0.316131	1.390507	140.6332
0.318648	0.631949	87.74676	0.252172	1.495958	141.1351
0.192219	0.835845	88.42005	0.270546	1.473025	141.5067
0.300021	0.673013	88.6186	0.334329	1.382126	142.0057
0.222756	0.792824	88.69386	0.272051	1.480296	142.1783
0.175111	0.872789	89.1666	0.297609	1.448873	142.7287
0.295522	0.690998	89.39439	0.347015	1.408377	145.2114
0.165529	0.891336	89.43452	0.341746	1.431827	146.2873
0.221128	0.806005	89.44212	0.312197	1.496646	147.6475
0.214991	0.827361	90.27784	0.329534	1.496534	149.5067
0.275091	0.73608	90.35333	0.348581	1.482895	150.602

Code 1 BP nerual

```
clc;
close all;
clear all;
x1=[382 333 365 332 484 500 458 465 475 418 373];
x2=[7.31458 7.29734502  7.248052907 7.222788854 7.207961732 7.185066936
7.140718803 7.069617002 6.975161321 6.863462711 6.744611384];
x3=[39.332  40.037  39.759  39.4    39.258  39.334  38.928  38.74   38.47   38.118  38.11];
x4=[0.250013    0.270941    0.266452    0.258764    0.257978    0.25167 0.250667
0.235527    0.24657 0.227   0.231741];
x5=[67.9    68.5    68.4    68  67.8    67.7    67.2    66.7    66.2    65.7    65.2];
x6=[0.95    0.94    0.9 0.88    0.91    0.93    0.9 0.85    0.9 0.8 0.77];
x7=[2.3 2.2 2.2 2.2 2.2 2.4 2.6 2.5 2.4 2.3 2.3];
y=[112.1    111.9   110.6   105.3   103.8   105 106.4   105.4   103.7   101 97.5];
p=[x1;x2;x3;x4;x5;x6;x7];
t=y;
[pn,input_str]=mapminmax(p);
[tn,output_str]=mapminmax(t);
net=newff(pn,tn,[]),{'purelin','purelin','purelin'};
net.trainParam.show=10;
net.trainParam.lr=0.05;
net.trainParam.epochs=5000;
net.trainParam.goal=0.65*10^(-3);
%net.divideFen='';
net=train(net,pn,tn);
an=sim(net,pn);
a=mapminmax('reverse',an,output_str);
pnew=xlsread('C:\Users \Documents\Tencent Files\FileRecv\MC
2.xlsx','A1:SF7')%current path
%pnew=xlsread('C:\Users\ Documents\Tencent Files\FileRecv\MC.xlsx','A1:CV7');
pnew=mapminmax('apply',pnew,input_str);
anewn=sim(net,pnew);
anew=mapminmax('reverse',anewn,output_str);
```

Code 2 Multiple linear regression

```
clc;
clear all;
```

```
y1=[5.837730447 5.826000107 5.811140993 5.793013608 5.777652323 5.758901774
5.743003188 5.726847748 5.713732806 5.697093487 5.680172609];
y=y1';
x1=[27  26.8    26.8    26.4    27.2    26.6    26.4    26.4    26  25.9    25.6];
x2=[3000    2875    2800    2600    2600    2700    2500    2400    2600    2400    2300];
x3=[1 1 1 1 1 1 1 1 1 1 1  ];
x0=[x3;x1;x2];
x=x0';
[b,bint,r,rint,stats] = regress(y,x);
```

Code 3 Pseudo-color plot

```
A=xlsread('C:\Users\Desktop\Book1.xlsx','A1:C500');
x=A(:,1);y=A(:,2);z=A(:,3);
scatter(x,y,10,z)
figure
[X,Y,Z]=griddata(x,y,z,linspace(min(x),max(x))',linspace(min(y),max(y)),'v4');
pcolor(X,Y,Z);shading interp
figure,contourf(X,Y,Z)
```