

How Does Climate Change Make a State More Fragile?

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Abstract. This paper studies the degree of state fragility and the influence of climate change on fragility by the building of a state fragility assessment model. Firstly, based on the collected data, we constructed a three-level fragility assessment system. Five comprehensive indexes of the government, safety, society, climate and economy are obtained by PCA (Principal Component Analysis) from 16 representative primary indicators. The weights of five indexes are determined by the Entropy Method. Finally, we got the SFI (State Fragility Index) through the MADM (Multi-Attribute Decision Making) model. Secondly, we selected the Central African Republic and chose the year of 2014 as the sample which had the largest increasing rate to study how the variable of climate change impacted on a state's fragility. We found that there was a drought increasing its CSI and Economy Fragility Index (EFI) and consequently made the state more fragile. Then we use the TSM (Time Series Method) to predict the fragility index of Central Africa in 2014 without the impact of climate change. The improvements can be seen from the declines in its state fragility (from 1.75 to 1.68) and the results of the CSI and EFI.

1. Introduction

Under the circumstance of globalization, issues such as global security, development and poverty have aroused attention all over the world. The “fragility” of a state has been a cutting-edge domain under scholars' intensive study. [1] The effects of climate change including the raising temperature, decreasing arable land, and increased meteorological disasters like droughts and floods are important triggers of social conflicts, thus increase the fragility of a state especially in developing countries. [2] However, how climate change affects state fragility has not yet come to a unified view.

2. Symbol Definition

The symbols are defined as follows: (1) SFI: State Fragility Index; (2) GFI: Government Fragility Index; (3) SEFI: Security Fragility Index; (4) SOFI: Society Fragility Index; (5) EFI: Economy Fragility Index; (6) CSI: Climate Shock Index; (7) x_i : the i^{th} primary indicator.

3. The Establishment of State Fragility Assessment Model

After reading and analyzing a large number of documents, we initially selected 52 indicators that can reflect the fragility of a country. Then we followed the logical relationships between different concepts,



through systematizing the concept of state fragility that is using the smallest amount of components to describe the concept and avoiding redundancy. We adopted the correlation analysis and selected 16 indicators as primary indicators. Next, the 16 indicators are grouped into 5 comprehensive indexes as the second-layer indicators by PCA (Principal Component Analysis). Finally, the MAMD (Multi-Attribute Decision-Making model) is used to get the SFI (State Fragility Index).

The specific flow chart of how we assess the state fragility is shown as follows:

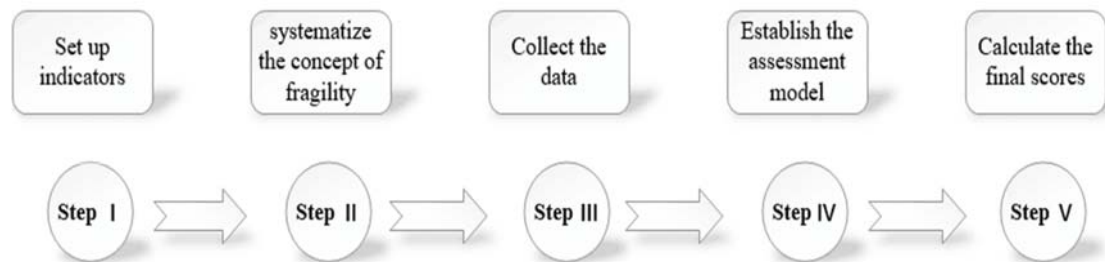


Figure 1. The flowchart of establishing a fragility assessment system

3.1. The Selection of Indicators

The fragility of a country has much to do with the economic development, distribution of resources, social justice and welfare system, and government management etc. With the expanding of climate shocks all over the world, climate has become a factor that we cannot ignore. In the end, we selected 16 primary indicators based on the principle of systemizing the concept and found the data of these indicators from 2005 to 2017 in the World Bank database. The indicators and explanations are as follows:

3.2. The Establishment of Second-layer Indicators

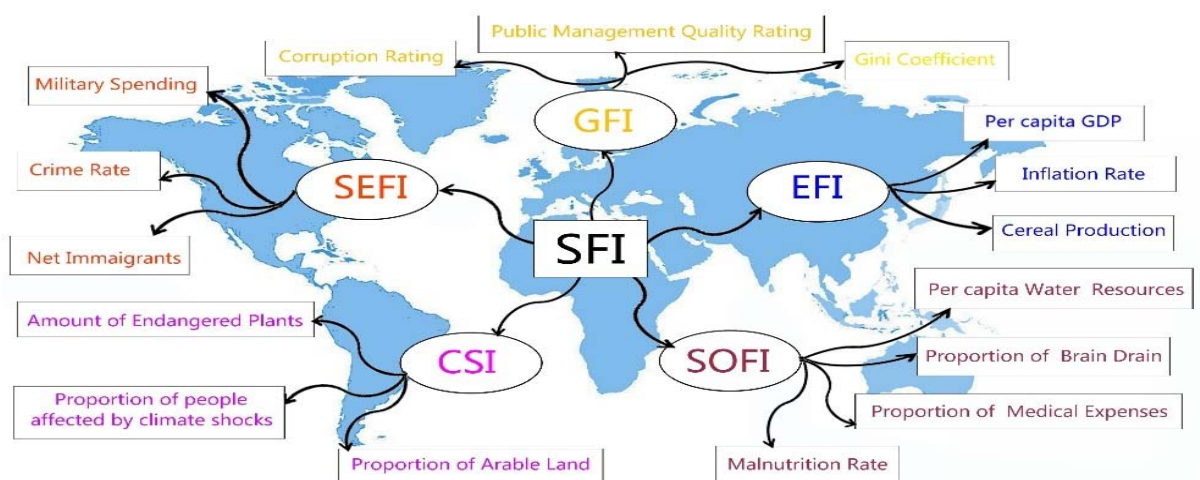


Figure 2. Three Layers of Indicators

If we directly adopted 16 primary indicators to measure a state's fragility, it would be messy and unfocused. Therefore, our team reduced the dimensions of primary indicators by the method of PCA. Meanwhile, to minimize the errors of our model and make our model applicable to countries of different fragility levels, we selected 15 countries from three scoring ranges of [0, 20], [20,60] and [60,120] according to the provided Fragile State Index. [2] Next, we built a model based on the data of these countries. Finally, we got 5 principal components of Government Fragility Index (GFI), Security Fragility Index (SEFI), Society Fragility Index (SOFI), Economy Fragility Index (EFI), and Climate Shock Index (CSI). The specific steps are as follows:

Table 1. Symbolic description

Indicator	Unit	Explanation
Crime Rate: x_1	per 10,000	It denotes the violence and conflicts within a state.
Proportion of Brain Drain: x_2	percent	It reflects the loss of well-educated talents.
Proportion of Arable Land: x_3	percent	It represents the agricultural development.
Public Management Quality Rating: x_4	-	It represents the efficiency and quality of government's policy-making and enforcement.
Cereal Production: x_5	Kg/Ha.	It represents the agricultural production.
Gini Coefficient: x_6	-	It reflects the fairness income distribution.
Net emigrants: x_7	person	It is the number of emigrates minus emigrants.
Military Spending Rate: x_8	percent	It reflects the degree of social stability.
Inflation Rate: x_9	percent	It reflects the prices of commodities.
Proportion of people affected by climate shocks: x_{10}	percent	It reflects the impact of climate change on people.
Per capita GDP: x_{11}	dollar	It reflects the economic development.
Per capita Water Resources: x_{12}	m ³	It shows the availability of water resources of each person.
Corruption Rating: x_{13}	-	It reflects the transparency and accountability of government.
Proportion of Medical Expenses: x_{14}	percent	It reflects the governmental investment in medical causes.
Malnutrition Rate: x_{15}	percent	It denotes the physical health of children.
Amount of Endangered Plants: x_{16}	type	It reflects changes in the biodiversity.

3.2.1. Data Normalization. Due to the different dimensions of the 16 indicators, the data cannot be directly compared. To normalize the data, we converted all the data to numbers between [0, 1]. [3].

Through analysis, these indicators can be categorized into three types: cost, benefit and moderate-type indexes. Among the three types of indexes, the smaller the cost index is, the more fragile the state is. Take medical cost as an example. Suppose other indicators remain unchanged, the less the medical cost, the more fragile of the state is. The benefit index is the opposite. Moderate-type index is better when it is closer to a certain value. Different methods of normalization were adopted to deal with the Cost Index, Benefit Index and Moderate-type Index. After the normalization of the index value, the values and second-layer indexes are of proportional relationship.

3.2.2. The Establishment of the PCA Model. Based on the load factor of the principal components, we calculated the contributions of different primary indicators to the principal components. [4] The basic principle is to classify the variables for optimal scaling and linearize each variable. Then, do the principal component analysis of the continuous variables after transformation. According to the principles of eigenvalue and the contribution rate of principal components, the main steps of extracting principal components and figuring out their expressions are as follows:

1) Conversion to the optimal scale:

$$X = [x_1 \ x_2 \ \dots \ x_k] \xrightarrow{\text{iteration}} X' = [a_1 \ a_2 \ \dots \ a_k].$$

X Is the normalized variable value of the indicator, and the is the linear data vector of the transformed indicator.

2) Calculate the correlation coefficient between the normalized indicators and get the correlation coefficient matrix:

$$V_r = [R_{ij}].$$

Of which, $R_{ij} = \text{corr}(x_i \ x_j)$ ($i = 1, 2, \dots, n$, $j = 1, 2, \dots, m$).

Then, we work on the correlation coefficient matrix and get the corresponding eigenvalues and eigenvector. After substituting into the index value of countries, we get the following eigenvectors:

$$K = [1.03 \ 0.01 \ 0.02 \ 0.00 \ 0.00 \ 2.05 \ 0.48 \ 3.12 \ 0.05 \ 2.69 \ 0.77 \ 3.47 \ 0.36 \ 0.79 \ 0.03 \ 0.00]$$

According to the principle that the eigenvalue should be greater than 1, five principal components are extracted.

3) Calculate the load matrix D of the principal components of each index according to matrix R and determine their loads.

The expressions of principal components are as follows:

$$\begin{aligned} y_1 &= 0.178x_1 + 0.155x_2 + 0.192x_3 + 0.522x_4 - 0.146x_5 + 0.686x_6 + 0.114x_7 - 0.125x_8 \\ &\quad + 0.136x_9 + 0.107x_{10} - 0.166x_{11} - 0.188x_{12} + 0.677x_{13} + 0.123x_{14} + 0.132x_{15} + 0.145x_{16} \\ y_2 &= 0.671x_1 + 0.177x_2 - 0.282x_3 - 0.108x_4 - 0.205x_5 + 0.185x_6 + 0.723x_7 + 0.546x_8 \\ &\quad + 0.168x_9 + 0.232x_{10} + 0.193x_{11} - 0.161x_{12} + 0.294x_{13} - 0.272x_{14} + 0.266x_{15} + 0.162x_{16} \\ y_3 &= 0.113x_1 + 0.539x_2 + 0.112x_3 - 0.143x_4 - 0.198x_5 + 0.084x_6 + 0.134x_7 - 0.057x_8 \\ &\quad + 0.081x_9 + 0.162x_{10} - 0.074x_{11} + 0.613x_{12} - 0.108x_{13} + 0.789x_{14} + 0.592x_{15} + 0.154x_{16} \\ y_4 &= 0.246x_1 + 0.126x_2 + 0.531x_3 + 0.221x_4 - 0.141x_5 + 0.205x_6 + 0.103x_7 - 0.137x_8 \\ &\quad + 0.239x_9 + 0.665x_{10} - 0.104x_{11} + 0.132x_{12} + 0.146x_{13} + 0.144x_{14} + 0.138x_{15} + 0.692x_{16} \\ y_5 &= 0.218x_1 + 0.136x_2 - 0.155x_3 - 0.143x_4 + 0.597x_5 + 0.242x_6 + 0.122x_7 + 0.265x_8 \\ &\quad + 0.654x_9 + 0.162x_{10} + 0.782x_{11} + 0.149x_{12} + 0.139x_{13} - 0.228x_{14} + 0.166x_{15} + 0.212x_{16} \end{aligned}$$

From the expression of the first principal component y_1 , it has relatively larger positive loads on the Public Management Quality Index (x_4), Corruption Rating Index (x_{13}) and Gini coefficient (x_6). The Public Management Quality Index and the Corruption Index are related to the government's management level. The Gini coefficient reflects the life quality of residents. The smaller the Gini coefficient, the more satisfied the residents should be. Thus, y_1 is a comprehensive index representing the government authority, legitimacy, and service, known as the Government Fragility Index (GFI).

From the expression of the second principal component y_2 , it accounts for a large proportion of the crime rate (x_1), the number of emigrants (x_7) and the military expenditures (x_8). Therefore, y_2 should be related to social security and state investment in it and reflects the society fragility. Following this idea, we find that the principal component y_3 is mainly related to the loss of well-educated intellectuals (x_2), per capita water resources (x_{12}), the proportion of health care expenditure (x_{14}) and malnourished children (x_{15}), so y_3 is defined as the Society Fragility Index (SFI). Principal component y_4 occupies a relatively large proportion of people affected by frequent droughts (x_{10}) and the plant diversity (x_{16}) and, etc. Thus, y_4 is considered as the Climate Shock Index (CSI). Finally, from the expression of principal component y_5 , we could see that y_5 is mainly related to per capita GDP (x_{11}), cereal production (x_5) and inflation (x_9). As a result, y_5 is the Economy Fragility Index (EFI).

3.3. Determining the State Fragility Index

3.3.1. Determining the Weights. The state fragility is closely connected with factors such as the government, security, society, economy and climate of a country. Therefore, we selected 5 second-layer indexes to denote these aspects of a country. Weights of five second-level indexes are determined by the entropy method. The model is as follows:

If n countries and m indicators are selected, the value of the j^{th} indicator of the i^{th} country is x_{ij} . ($i = 1, 2, L, n, j = 1, 2, L, m$)

$$X_{ij} = \begin{bmatrix} X_{11} & X_{12} & L & X_{1m} \\ X_{21} & X_{22} & L & X_{2m} \\ M & M & O & M \\ X_{n1} & X_{n2} & L & X_{nm} \end{bmatrix}$$

Through the Entropy Weight Method [5], the weights of the 5 second-layer indexes can be obtained as follows:

$$w_1=0.376, w_2=0.223, w_3=0.154, w_4=0.137, w_5=0.110.$$

3.3.2. Calculating the State Fragility Index. Establish the Multi-Attribute Decision Making (MADM) model and use the weighted arithmetic average operator to obtain the State Fragility Index.

$$SFI = w_1 \times GFI + w_2 \times SEFI + w_3 \times CSI + w_4 \times SOFI + w_5 \times EFI.$$

By the SFI value, we can know the current fragility degree of a country. In addition, the values of second-layer indexes can exhibit which aspect has a greater impact on the SFI .

Climate change influences a state's fragility directly and indirectly. The Climate Shock Index (CSI) indicates the direct influence of climate change on state fragility. Firstly, climate change will lead to changes in temperature, soil and the distribution of water resources. The eco-system will consequently be altered and species with strong adaptability may survive, but species which are sensitive to environment cannot escape. We selected the amount of endanger plants as an indicator to show the great impact of climate change. Specifically speaking, the rising temperature will lead to the desiccation of soil and deterioration in hydrological conditions, and a lot of plants cannot adapt to these changes will go extinct.

Climate change also has an indirect effect on the SFI . On the one hand, a decrease in rainfall will lead to the reduction in the per capita water resources; the drought will result in lower cereal production in the framework of Economy Fragility Index (EFI) and an increase in the proportion of malnutrition, which in turn will lead to an increase in the crime rate and the country's fragility. On the other hand, the extreme weather caused by climate change will impair people's interests, reduce per capita GDP, destroy the livable environment, and lead to the sharp increase of net emigrants. All these changes will increase the fragility of a country. Finally, if the government fails to take proactive measures to address conflicts when the climate shocks occur, its authority will be weakened. Consequently, people's trust in the government will be affected and the stability in the region will be threatened.

4. The Fragility Analysis of CAR

In the ranking of fragile states in 2017, we selected the third rank, Central African Republic (CAR), to analyze how climate change can increase its fragility. From the given Fragile State Index, we could see that the fragility of CAR has been on the rise since 2012. In addition, we learned from literature that the climate shocks have been rampant over the year in CAR such as anomalous rainfall and changes in soil conditions, which is suitable for studying SFI and the impact of climate change on fragility.

4.1. Changes in the SFI of CAR

First of all, we select the data of 16 indicators in the CAR from 2012 to 2015.

After normalization, we use different methods of normalization to get the SFI of CAR. From the figure we can see that the overall changing trend of the given Fragile State Index and the SFI calculated using our model are consistent. The fragility of CAR has been on the rise, especially there has been a significant increase from 2013 to 2014. Therefore, we use 2013-2014 as an example to discuss the

impact of climate change on the SFI. The values of second-layer indexes of these two years are shown in the figure 4-2.

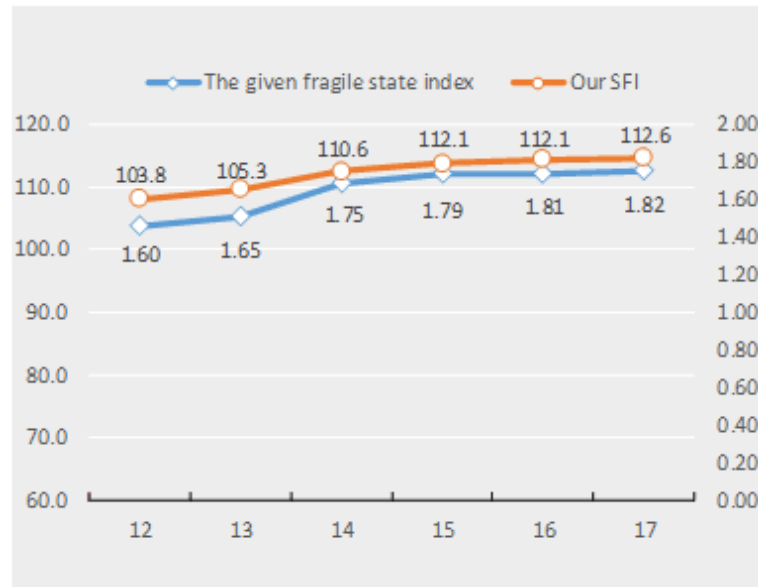


Figure 3. The given FSI and our SFI

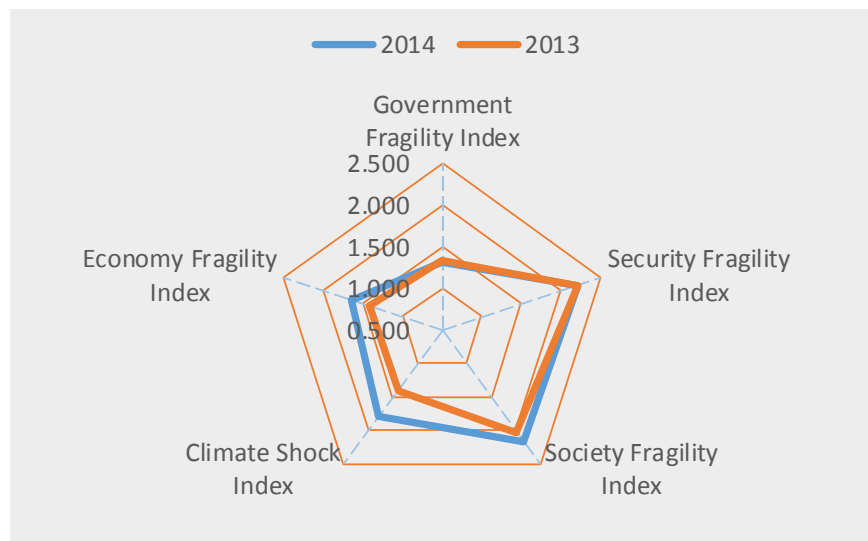


Figure 4. The Changes of the Second-layer Indicators (2014-2015)

From the above figure, we can see that the SFI of Central Africa changed from 1.65 in 2013 to 1.75 in 2014. The most obvious changes in the second-layer indexes are the EFI and CSI. During this period, the Climate Shock Index and Economy Fragility Index are the critical factors of state fragility, and the climate change would also influence the Economy Fragility Index indirectly.

The change in the Climate Fragility Index (CFI) can be directly attributed to the dramatic increase in the proportion of the population affected by the drought and the number of threatened plants in the area. According to data provided by the World Bank, the precipitation of CAR in 2014 decreased by 91 mm compared to 2013, and the annual average temperature increased by 0.36 °C. These changes have exacerbated the drought in the region and reduced the grain production, resulting in an increase in the number of people being affected. Meanwhile, Changes in soil and hydrological conditions caused by

climate change have led to an increase in the number of endangered species of plants from 15 to 23. Both of which increase the CSI and directly lead to an increase in state fragility.

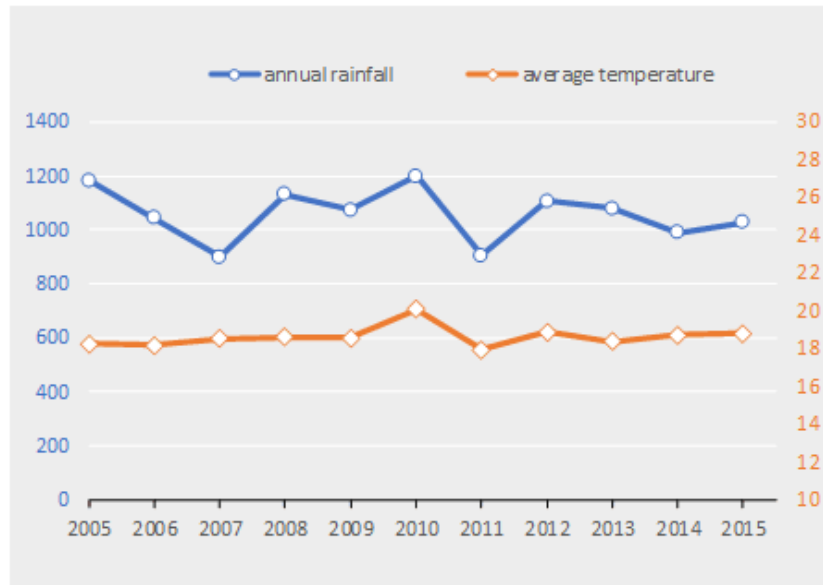


Figure 5. Weather statistics of CAR (annual rainfall/mm; average temperature/°C)

On the other hand, the frequent droughts have led to a decrease in cereal production and per capita GDP and an increasing inflation rate, which indicates that the impact of climate shocks is affecting the EFI. In order to cope with climate change, the local government has stepped up its investment in medical care and security. Therefore, the management and authority of the government have not been questioned so much that the GFI has only slightly declined. The indirect impact of climate change on other indexes, to a certain extent, also increases the SFI. To estimate the impact of climate change, we establish the Time Series Model (TSM) to observe the changes in various indicators without sudden climate shocks of CAR in 2014 based on historical data. The values of the five indexes were calculated by the TSM:

$$\begin{cases} a_1 = 0.482 \\ b_1 = 0.847 \end{cases} \begin{cases} a_2 = 0.482 \\ b_2 = 0.847 \end{cases} \begin{cases} a_3 = 0.672 \\ b_3 = 0.753 \end{cases} \begin{cases} a_4 = 1.579 \\ b_4 = 0.523 \end{cases} \begin{cases} a_5 = 0.678 \\ b_5 = 1.547 \end{cases}$$

By substituting the second-layer index data from 2002 to 2013 into the above formula, we can get the predictive values of the five indexes in the CAR without the impact of climate change as follows:

Table 2. The values of five second-layer indexes and the SFI

	GFI	SEFI	SOFI	CSI	EFI	SFI
2013	1.321	2.224	2.028	1.399	1.409	1.650
2014	1.331	2.226	2.170	1.749	1.652	1.750
prediction	1.329	2.225	2.102	1.425	1.437	1.670

As can be seen from the above table, after excluding the impact of climate change, the SFI increased by only 0.02, where the changing rate of the CFI dropped from 20.01% to 1.86%. Under the circumstance of no dramatic decline in rainfall and sharp rise in temperature, the drought would be mitigated, the cereal production would not drop significantly, and the number of affected people would be within a stable range. The stability of soil conditions would reduce the number of endangered plant species and the fluctuations in CSI. In addition, the cereal production and GDP per capita would remain relatively stable with the exclusion of the drought. The predicted inflation rate is also within the

acceptable range. The changing rate of EFI has also decreased to 1.98%, thus reduced the SFI. The sustained investment in medical care and security of CAR Government led to no serious decrease in its government and the GFI has declined to some degree. In sum, without these effects of climate change, there would be no significant change in the climate and economic aspects of CAR. The CSI and EFI would not increase so dramatically.

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