Spatiotemporal analysis of global food system robustness

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Abstract: In the context of the rapid development of the world economy, world food security is still not guaranteed as it should be. Thus, a more rational model is urgently in need. We think that a robust food system should have better efficiency, profitability, sustainability, and fairness, so we selected 18 three-tier indicators and four secondary indicators closely related to the impact factors. Then, we use AHP and correlation analysis to put forward the FSRI model, which has the function of describing the composition of food system and evaluating the robustness of food system. We use spatial auto-correlation analysis to compare the differences in values, geospatial distribution, etc. of the food system before and after optimization. Then, through Grey-Verhulst M model, it is predicted that by 2027, FSRI will grow by 44.56 percent, and optimized systems will be implemented to help achieve the United Nations Millennium Goal of eliminating hungry people by 2030.

1. Introduction
The world developed rapidly in the past few decades. It is unacceptable that, in a world that produces enough food to feed its entire population, more than 1.5 billion people cannot afford a diet that meets the required levels of essential nutrients. The people of the poorest country Haiti even have to eat biscuits made of soil to sustain their lives. Besides, over 3 billion people cannot even afford the cheapest healthy diet. These trends in food insecurity contribute to increase the risk of child malnutrition, as food insecurity affects diet quality, including the quality of children’s and women’s diets, and people’s health in different ways. Seemingly, current food system works efficiently, creating significant economic value as a whole. However, what it generates “hidden costs” related to health costs and climate-change costs have made the cost unpayable for human beings. If current food system continues, diet-related health costs linked to mortality and diet related non-communicable diseases are projected to exceed USD 1.3 trillion per year by 2030. In order to solve this problem, we have to admit that we took the wrong way in the past. Thus, we need to analyze and optimize the current food system to save beautiful earth and precious lives of people down to earth.

2. The Establishment of FSRI Model
2.1. Selection of influence indicators
When describing the "food system", this paper proposed a food system robustness framework consisting of fairness, sustainability, efficiency, and profit. Therefore, this paper takes the FAO, the FSD and IBRD as
the data sources of food system constituent elements index, further refines and perfects the food system framework according to the available data, and forms the Food System Robustness Index (FSRI) with fairness, sustainability, efficiency and profit as secondary indicators, grain output and other 18 variables as three-level indicators.

According to the directivity of the indicators, we processed the indicators forward and used AHP (Analytic Hierarchy Process) to determine the weight of the 18 indicators.

2.2. Evaluation and relevance of secondary indicators

2.2.1. Establishment of evaluation function Based on the standardized data set and the three-level index, the second-level index evaluation model is established to evaluate the efficiency $Y_1$, fairness $Y_2$, sustainability $Y_3$ and profitability $Y_4$ of the food system:

$Y_1 = 0.3922X_1 + 0.0683X_2 + 0.1347X_3 + 0.0351X_4 + 0.2122X_5 + 0.0501X_6 + 0.1075X_7$  \hspace{1cm} (1)

$Y_2 = 0.1084X_8 + 0.232X_9 + 0.1084X_{10} + 0.3187X_{11} + 0.0312X_{12} + 0.205X_{13} + 0.0205X_{14}$  \hspace{1cm} (2)

$Y_3 = 0.3X_{15} + 0.6X_{16} + 0.1X_{17}$  \hspace{1cm} (3)

$Y_4 = X_{18}$  \hspace{1cm} (4)

($X_i$ is the positive index.)

2.2.2. Correlation analysis We use SPSS to analyze the relationship between efficiency system, profit system, SDG system and fairness system. As shown in the scatter plot below, the correlation of each system is very strong.

![Figure 1 Scatter diagram of four secondary indexes](image)

Therefore, we performed Spearman test \cite{1} on the sample data, with the specific calculation formula as follows:
The correlation coefficients calculated by SPSS software are shown in the following table:

|          | Efficiency | Profit | SDG       | Fairness |
|----------|------------|--------|-----------|----------|
| Efficiency | 1.000      | 1.000**| 1.000**   | 1.000**  |
| Profit    | 1.000**    | 1.000  | 1.000**   | 1.000**  |
| SDG       | -1.000**   | 1.000**| 1.000     | 1.000**  |
| Fairness  | -1.000**   | 1.000**| 1.000     | 1.000    |

We can see from the chart above, efficiency, profit, SDG, and fairness are all linear functions. Therefore, the four secondary indicators are significantly correlated with each other and have a one-to-one corresponding relationship. For example, efficiency is linearly positively correlated to profitability and linearly negatively correlated to SDG, which is consistent with reality, and thus verifies the rationality of our third-level indicator selection.

### 2.3. Establishment of FSRI model

When the system depends on the state of each subsystem and its interaction, the radar map area model can be used to integrate the state information of the subsystems. As far as the food system is concerned, efficiency is obviously the first element of the food system. And on this basis, the food system will also be affected by fairness, sustainability, and profitability. Efficiency, fairness, sustainability, and profitability constitute a closed transfer relationship to the food system, which can be better reflected by using the radar map area model. Therefore, the robust index of food system is represented by FSRI \(^{[2]}\), and the radar map area model is established to describe and evaluate the robust index of food system.

\[
Y_i = 0.3922X_1 + 0.0683X_2 + 0.1347X_3 + 0.0351X_4 + 0.2122X_5 + 0.0501X_6 + 0.1075X_7
\]
\[
Y_2 = 0.1084X_8 + 0.232X_9 + 0.1084X_{10} + 0.3187X_{11} + 0.0312X_{12} + 0.205X_{13} + 0.0205X_{14}
\]
\[
Y_3 = 0.3X_{15} + 0.6X_{16} + 0.1X_{17}
\]
\[
Y_4 = X_{18}
\]

\[
FSRI = \frac{Y_1Y_2 + Y_2Y_3 + Y_3Y_4 + Y_4Y_1}{2}
\]

Among them, \(Y_i(i = 1, 2, 3, 4)\) is the result after normalization and standardization.

FSRI model can not only describe the composition of a food system, but also reflect the robustness of a food system, so as to evaluate the food system.

### 3. Present situation and improvement

#### 3.1. Analysis of calculation results (existing food system)

Based on the available data, we calculated and analyzed the data of 82 countries to obtain the FSRI of them. Moreover, the normalized results show that in 2017, the average efficiency index of the global food system
is 0.98, the profitability index is 0.89, the sustainability index is 0.03, and the fairness index is 0.24. Through further processing of the four indicators, the national average FSRI in 2017 was 0.57 based on the FSRI model.

![Radar chart of various indicators in 2017](image)

By analyzing the figure above, today's global food system pays more attention to efficiency and profitability, but is unbalanced in terms of SDG and fairness. So, there is a large space for optimization.

3.2. How to optimize

In order to improve the robustness of the food system to a large extent, we plan to intervene in several areas to improve the sustainability and fairness of the food system, as well as conform to the law of social development [3].

In the production process of the food system, people use a large amount of pesticides, fertilizers. The overdevelopment and overuse of water resources in the basin, inadequate environmental awareness and management, the unreasonable mode of production growth and other reasons will lead to the deterioration of water quality of rivers and lakes and groundwater. Especially, the continuous decline of surface drinking water quality will endanger human health. Soil pollution harms aquatic plants and crops and reduces the sustainability of local food systems.

Through the implementation of centralized sewage treatment and the formulation of comprehensive water pollution prevention and control plan, the pollution damage caused by fertilizers can be effectively reduced during production, and the pollution risk can be reduced from 0.12% to -0.1%. At the same time, by developing water-saving agriculture and building water conservancy projects, per capita renewable water resources can be significantly increased, raising the per capita renewable water resources growth rate from -1.2% to 0.6%.

Hunger is still a huge crisis the world facing today. Due to the influence of the "Matthew Effect", it is much more difficult for people in developing countries to obtain energy supplied from the food system than in developed countries, which seriously damages the fairness of the food system.

Cultivating good seeds, developing production, the surplus energy supply in developed regions could help the energy be accessible to poor ones, thereby increase per capita energy supply by 1% a year.

Sustainability also increases the cost of the food system by investing in infrastructure, science and technology. At the same time, the profitability of the food system suffered as a result of falling from an annual growth rate of 2.2% to 1.2%, in order to provide adequate energy for people in poor areas.
3.3. **Outcome after optimization**

(1) **In terms of numerical value**

Based on the optimized model determined above, we find by calculation that, in terms of second-level indicators, the sustainability will rise from 0.03 to 0.86 in 2025. Fairness also increased to 0.70. However, efficiency and profitability declined to a certain extent, which is also consistent with the correlation analysis in 1.3. The indicators are shown in the figure below:

![Figure 3: Data comparison chart of 2017 and 2027](image)

Based on the analysis above, we found that by 2027, the world's food system sustainability and impartiality, which once focused on efficiency and profitability, also withdrew from the historical arena gradually. In spite of this, the food system robustness index FSRI instead with ascension, also suggests that when the food system has been in some people’s interests and realize the balance between the interests of all mankind, and more stable as a whole.

(2) **In terms of geographical distribution**

Based on obtaining the FSIR of each country, this paper uses the GIS analysis model tool to make the spatial autocorrelation analysis. The spatial pattern of the global food system is determined by calculating the *Moran’s I* index[^4], z-score, and P-score for 2017. The mathematical formula is as follows:

\[
I = \frac{n}{S_0} \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij} z_i z_j
\]

\[
S_0 = \sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}
\]

In the formula: \(z_i\) is the deviation between the national food security index and its average value, namely \(z_i = \overline{FSRI}_i - \overline{FSRI}\). \(w_{ij}\) is the spatial weight between country \(i\) and country \(j\). \(n\) is the number of participating countries, \(n = 172\).
By using GeoDa, the calculation results are as follows:

| Year | Moran’s I | z value | P value |
|------|-----------|---------|---------|
| 2017 | 0.27      | 17.04   | 0       |
| 2027 | 0.29      | 1.59    | 0.06    |

In 2017, Moran’s I > 0 and P-score is 0, it indicates that the null hypothesis of "FSRI" is randomly distributed among countries" can be rejected. Namely, the difference of global food system robustness is statistically significant, as shown in the figure below, and the overall spatial distribution pattern presents "high-high agglomeration, low-low agglomeration". At a 99% confidence level, Europe and sub-Saharan Africa are the hot and cold spots in the global food security landscape, respectively.

However, after nearly a decade of optimization, we found that the null hypothesis that FSRI is randomly distributed among countries could not be rejected. Therefore, FSRI presents a trend of random distribution among regions, which indicates that the food system of all countries in the world is more stable and the international distribution of food is more equitable. Besides, the number of children without food will be less and less.

![Figure 4 Spatial autocorrelation analysis](image)

4. Conclusion (Time required for optimization)

In 2.4, we have optimized the sustainability and fairness of the food system. In order to show the changes of FSRI before and after intervention, we used Grey-Verhulst model [5] to predict the FSRI curve without intervention. Grey-Verhulst model can better reflect the saturation state of the index than the Grey GM(1,1) commonly used. After calculation, the whitened differential equation is finally obtained:

\[
\frac{dx^{(1)}}{dt} = 0.5787x^1 - 0.9714(x^1)^2
\]  

(10)
As can be seen from Figure 5, before the optimization, the FSRI curve was relatively flat, reaching 0.7142 in 2027. Compared with 0.602 in 2019, it increases by 18.7%. The steeper the FSRI curve is, the faster the FSRI growth rate will be, which will reach 0.8702 in 2027 after optimization, an increase of 44.56% compared with 2018. In 2027, FSRI s after intervention were 1.21 times higher than those before the intervention. The results show that the optimized food system is having a positive impact on improving the World Food Pattern, making the global food system more sustainable and equitable. It will also help to achieve the United Nations Centennial goal of eradicating hunger by 2030.

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