Research on Food Security system and Optimization method based on multiple regression Analysis

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Abstract. Considering that the current model of the world food system puts efficiency and profit first, many people still go hungry and seriously pollute the environment. In this paper, the multiple nonlinear regression method is used to optimize the existing food system. Firstly, the food security evaluation system is established, and the global food security situation in recent years is obtained by calculating FSSI. Then, the model of influencing factors of food security is established, and the relationship between food system security index and various factors is obtained by multiple nonlinear regression, on this basis, fairness and sustainability index are obtained by the same method, and the existing food system is optimized. After analyzing the current situation of countries with different standards, we have formulated a series of intelligent optimization policies for them. Finally, by comparing the change trend of the index before and after optimization, it is found that the optimized index can reach the ideal value more quickly.

Keywords: Food system, Multiple nonlinear regression, Index system, Optimize

1. Introduction
As a basic necessity, food is the most important material basis for ensuring the sustainable development of mankind, and it has an irreplaceable basic position in supporting social and economic development. Food security issues are the focus of many United Nations framework documents and international scientific research programs [1].

The United Nations and the International Science Alliance are paying great attention to food security not only because food security plays a fundamental supporting role in promoting global sustainability, but also because of the huge gap between the sustainable development goals and the reality. Due to the impact of the food crisis triggered by several food price increases in 2008 and the severe drought in the Horn of Africa in 2011, in 2015, 57 out of 129 countries monitored by the Food and Agriculture Organization of the United Nations failed to achieve long-term The Millennium Development Goal of halving the proportion of hungry people. In 2016, the number of chronically undernourished people in the world was 815 million, an increase of 38 million people from 2015; the recent rebound in the number of chronically undernourished people after a long period of reduction may mean that the trend has reversed [2] [3], and the global food security situation is not optimism. In Maanpu’s article [4], he
systematically established a model of influencing factors affecting the world food system. In a McKinsey paper, it talked about the extremely uneven world food production and distribution [5]. In addition, Han Xiaorui’s research pointed out that the advantage condition index can be used to measure the strength of a country in market competition [6]. However, none of them have really studied how to prioritize the food system. This paper establishes a grain system model which can adjust different levels with different requirements such as efficiency, fairness, sustainability and so on.

2. Food safety appraisable index system (FSAIS)

FAOSTAT has made continuous statistics on 10 categories of indicators such as population, nutritional status, and food supply in various countries. Due to differences in per capita disposable income, food prices, and the circulation capacity of agricultural products such as transportation, storage, and trading, in a world with sufficient food supplies, the availability of food and people's ability to obtain food still differ greatly. At the same time, due to factors such as sanitary conditions, there are also major problems with food utilization. This shows that under the premise of sufficient food supply, food security must ultimately be achieved by obtaining food and effectively using its nutrients. Economic and political stability are used to measure the impact of political turbulence and other uncertain factors on food supply, food access and food utilization. The third-level indicators are shown in Table 1 below.

Table 1. Index Summary

| First-level index | Second-level index | Third-level index |
|-------------------|-------------------|------------------|
| Food System       | Economic and political stability | Political stability and absence of violence |
| Security          | Per capita food production variability |
|                   | Per capita food supply variability |
|                   | Food utilization | Proportion of population with access to clean water |
|                   | Percentage of children under 5 affected by waste |
|                   | Proportion of short children under 5 |
|                   | Food access | Food shortage |
|                   | GDP per capita |
|                   | Food supply | Adequacy of dietary energy supply |
|                   | Per capita animal source protein supply |
|                   | Per capita food protein supply |
|                   | Per capita food production |

3. Multi-index comprehensive evaluation

With the expansion of the connotation and extension of the concept of food security, single indicators such as grain output can no longer fully reflect the state of food security, which makes the multi-index comprehensive evaluation method an effective tool for food system security evaluation.

3.1. Data standardization processing

The paper used range standardization method to standardize index data. First, we classify the twelve indicators according to the index tropism.

For positive indicators:

\[ X'_{yj} = \frac{(X_{yj} - \min X_{yj})}{\max X_{yj} - \min X_{yj}} \quad (1) \]

For negative indicators:

\[ X'_{yj} = \frac{(\max X_{yj} - X_{yj})}{\max X_{yj} - \min X_{yj}} \quad (2) \]
Where \( X'_j(i=1,2,...,165, j=1,2,...,12) \) is the raw data for the \( j = \text{th} \) indicator of the \( i = \text{th} \) country, \( X'_{ij} \) is the corresponding standardized variable, \( X'_j \in [0,1] \) and \( \max X'_j, \min X'_j \) are the maximum and minimum values of the \( j = \text{th} \) index.

3.2. Mean square deviation index weight

Since the purpose of food system safety evaluation in this article is to analyze the pattern of differences in food system safety at the national level, the determined indicator weights should reflect the relative dispersion of the sample values of each indicator. For this reason, the mean square deviation method is used to determine the weight of each indicator.

(1) Based on the standardized data set, we can calculate the mean square deviation of each evaluation index from 2010 to 2020.

\[
\hat{\sigma} = \sqrt{\frac{\sum_{i=1}^{n} (X'_{ij} - \bar{X}'_j)^2}{n}}, i=1,2,...,165, j=1,2,...,12
\]  

Where \( \hat{\sigma} \) is the mean square deviation of index, \( \bar{X}'_j \) is the average of standardized variable and \( n \) is the number of participating countries.

(2) Based on the mean square error, we can calculate the weight coefficients of the three-level indicators of food supply, food access, food utilization, and economic and political stability from 2010 to 2020.

\[
\omega_{mkj} = \frac{\hat{\sigma}_{mkj}}{\sum_{k=1}^{K} \hat{\sigma}_{mkj}}
\]  

Where \( m \) is the year number, \( m = 2010,...,2020 \), \( k \) is the number of three-level indicators included in the four second-level indicators, \( k = 4,2,3,3 \), \( j \) is the serial number of the three-level indicator, \( j = 1,2,...,12 \) and \( \omega_{mkj} \) is the weight of the \( j = \text{th} \) indicator at \( m \).

(3) Calculating the average value of the weight coefficients of each three-level indicator from 2010 to 2020, and using this as the unified weight of each three-level indicator during the study period.

\[
\omega_j = \frac{\sum_{m=2010}^{2020} \omega_{mkj}}{15}, k = 4,2,3,3, j=1,2,...,12
\]  

Where \( \omega_j \) is the weight of each three-level indicator, the results are shown in the table below.

Table 2. Weight of the third indicators

| Second level indicators | Food supply | Food access | Food utilization | Economic and political stability |
|-------------------------|-------------|-------------|------------------|----------------------------------|
| Code of Third level indicators | \( X_1 \) | \( X_2 \) | \( X_3 \) | \( X_4 \) | \( X_5 \) | \( X_6 \) | \( X_7 \) | \( X_8 \) | \( X_9 \) | \( X_{10} \) | \( X_{11} \) | \( X_{12} \) |
| Weight                   | 0.15        | 0.27        | 0.30            | 0.28                             | 0.60 | 0.40 | 0.31 | 0.31 | 0.38 | 0.27 | 0.33 | 0.40 |
Firstly, based on standardized data sets and three-level indicator weights, a second-level indicator evaluation model was established to evaluate the food supply ($Y_1$), food access ($Y_2$), food utilization ($Y_3$) and economic and political stability of countries ($Y_4$) from 2010 to 2020.

$$\begin{align*}
Y_1 &= 0.15X_1 + 0.27X_2 + 0.30X_3 + 0.28X_4 \\
Y_2 &= 0.60X_5 + 0.40X_6 \\
Y_3 &= 0.31X_7 + 0.31X_8 + 0.38X_9 \\
Y_4 &= 0.27X_{10} + 0.33X_{11} + 0.40X_{12}
\end{align*}$$

Then, substituting the standardized index data, the evaluation results of food supply, food access, food utilization, economic and political stability in various countries from 2010 to 2020 were obtained.

4. Food system security index (FSSI)

For the sake of measuring the safety of the food system, the FSSI is used to express its index and quantify it. The FSSI calculation formula is as follows.

$$FSSI = (Y_1 * Y_2 + Y_2 * Y_3 + Y_3 * Y_4 + Y_4 * Y_1) / 2$$

Based on the comprehensive evaluation, the average value of the FSSI natural break point value is used as the unified grading standard, and the evaluation results over the years are divided into five levels.

When $0 \leq FSSI \leq 0.47$, it is extremely insecure. When $0.48 \leq FSSI \leq 0.68$, it is insecure. When $0.69 \leq FSSI \leq 0.86$, it is general. When $0.87 \leq FSSI \leq 1.10$, it is safer. When $1.11 \leq FSSI \leq 2$, it is safe.

Then we can get the geographic distribution map of the FSSI value based on the known data.

![Figure 1. FSSI values of countries in 2005](image1)

![Figure 2. FSSI values of countries in 2008](image2)

![Figure 3. FSSI values of countries in 2012](image3)

![Figure 4. FSSI values of countries in 2015](image4)
5. Fair and sustainable food system

In order to study how to optimize a food system towards fairness and sustainability, we first establish a multivariate nonlinear regression model to study the factors that affect food system safety, and divide it into fairness factors and sustainability factors. Then we establish indexes forecast models and give corresponding adjustment policies to finally achieve a fair and sustainable food system.

5.1. Factors affecting food system safety

This paper gradually screens the indicators according to the availability of data. From the 22 initial indicators drawn up at the beginning of the study, 10 indicators with no data records, discontinuous recording time, or incomplete coverage space are excluded, and finally 12 indicators are included.

Table 3. Methods of measuring factors affecting food system security

| Influencing factors       | Measurement method                                      |
|---------------------------|--------------------------------------------------------|
| globalization             | \( Z_1 = \text{Trade to GDP ratio} \)                  |
| revenue growth            | \( Z_2 = \text{Gini index annual growth rate} \)        |
|                           | \( Z_3 = \text{Gini Index} \)                           |
| population growth         | \( Z_4 = \text{Population growth rate} \)              |
|                           | \( Z_5 = \text{Total stock of international migrants} \) |
| climate change            | \( Z_6 = \text{Total agricultural greenhouse gas emissions} \) |
| urbanization              | \( Z_7 = \text{Proportion of urban population} \)       |
| agricultural policy       | \( Z_8 = \text{High-tech industry growth value} \)      |
|                           | \( Z_9 = \text{Grain yield} \)                          |
|                           | \( Z_{10} = \text{Government effectiveness} \)         |
| agricultural policy       | \( Z_{11} = \text{Available clean fuel and cooking technology account for the total population} \) |
|                           | \( Z_{12} = \text{Instability and Chaos Index} \)      |

5.2. Multiple nonlinear regression analysis

Considering FSSI as the dependent variable, and food security influencing factors as the independent variable, a stepwise regression analysis was performed. Assume that significant test probability \( F \leq 0.05 \) is entry criteria and \( F > 0.10 \) is delete criteria, therefore, influencing factors are screened. Simultaneously establish multiple linear regression equations as comparison. For multiple linear regression equations and non-linear regression equations, the best choice is used for influencing factor analysis according to the goodness of fit and significance test results.

According to the multiple non-linear regression model established above, the multiple non-linear regression equation established every year to identify factors affecting food security is obtained, and the regression equation obtained based on the 2014 data has the smallest error.

\[
FSSI = -0.12 - 0.02z_1^{0.593} + 0.032z_2^{-0.711} - 0.8*10^{-15}z_3^{7.563} + 0.24z_4^{0.118} \\
+ 0.12z_5^{0.28} + 2.64*10^{-12}z_6^{5.316} + 1.979*10^{-5}z_7 + 0.12z_8^{0.208}
\]  

5.3. Fairness and sustainability index

Analyzing the indicators in Table 2, we can divide them into fairness indicators and sustainability indicators according to the objects they affect, as shown in the following figures respectively.
First use formula (1), (2) to standardize the data, and then determine its weight, and then get its regression expression.

Based on the comprehensive evaluation, the average value of the \( FI \) and \( SI \) natural break point value is used as the unified grading standard, and the evaluation results over the years are divided into four levels. When \( 0 \leq FI \leq 0.39 \), it is extremely unfair. When \( 0.40 \leq FI \leq 0.54 \), it is unfair. When \( 0.55 \leq FI \leq 0.69 \), it is general. When \( 0.70 \leq FI \leq 1.50 \), it is fairer. Besides, we assume that \( 0.70 \) is the ideal value of \( FI \) which is \( FI_0 \).

And when \( 0.4 \leq SI \leq 0.89 \), it is extremely unsustainable. When \( 0.90 \leq SI \leq 1.09 \), it is unsustainable. When \( 1.10 \leq SI \leq 1.29 \), it is general. When \( 1.30 \leq SI \leq 2.00 \), it is sustainable. Besides, we assume that \( 1.20 \) is the ideal value of \( SI \) which is \( SI_0 \).
5.4. Adjustment and optimization

Based on the above analysis, different countries have different food systems and make some adjustments and optimizations.

(a) Improve food self-sufficiency rate
(b) Improve the availability of food and residents' ability to access things.
(c) Designate a regional health food plan.
(d) Rejuvenate rural areas and promote food security.
(e) Protect arable land resources and cultivate emerging professional farmers.

In order to reflect the extensiveness of the study and the robustness of the model, we selected four countries: central Africa, Thailand, France and Australia as the object of study. According to the time series prediction model shown in the following figure, the time-varying curves of FI and SI under normal conditions are obtained.

Figure 11. SI values of countries and regions in 2008  
Figure 12. SI values of countries and regions in 2012  
Figure 13. SI values of countries and regions in 2015  
Figure 14. SI values of countries and regions in 2018  
Figure 15. The predicted FI value
Figure 16. The predicted FI value

By analysing the figures, we can see that France and Australia have performed well in the fairness index and sustainability index in a predictable time frame, so we will not adjust them. Then, adjust the two countries of Central Africa and Thailand, and obtained the following two graphs of changes in SI and FI.

Figure 17. The adjusted predicted FI value

Figure 18. The adjusted predicted FI value
By analysing the figures, we can see that the two indexes of the two countries have their own advantages. For $SI$, Central Africa has always been ahead of Thailand and is the first to complete a sustainable food system. The reason should be that Thailand has a large population and is difficult to manage. For $FI$, contrary to the situation of $SI$, Thailand has always been ahead of Central Africa. Considering that Central Africa is located in Africa, the development is backward, the environment is relatively harsh, and the biodiversity is low, which is basically in line with the actual situation.

6. Conclusion

According to the selected three-level evaluation index, this paper establishes a food safety evaluation model to evaluate the food system of a certain country and region. It is concluded that under the premise of adequate food supply, food security must ultimately be achieved through the acquisition of food and the effective use of its nutrients. At the same time, the impact of economic and political stability on food supply, access and utilization needs to be taken into account. The multi-index comprehensive evaluation method is selected to evaluate the safety of the grain system.

Then a multiple nonlinear regression model is established to study the factors affecting food system safety, which are divided into fairness factors and sustainability factors. Establish the index prediction model, and give the corresponding adjustment policies, and finally achieve the fair and sustainable development of the grain system. Finally, targeted optimization is made and four countries are selected to view the results.

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