Research on evaluation and optimization of food Systems based on FSI Model

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Abstract: In this paper, an FSI model has been proposed, which uses the multi-index comprehensive evaluation method to evaluate the food security level of 172 countries from 2000 to 2014 based on the establishment of the data set of food security evaluation factors and influencing factors. The FSI model takes FAOSTAT as the data source of food security evaluation factors, further refines and improves the food security framework according to the available data, and forms a perfect food security evaluation index system. By interfering with the indicators in the FSI model, we propose that the global food system can achieve the minimum goal of fair distribution and sustainable food development by 2030. Specifically, we use the grey Verhulst model to predict and compare the FSI curve with the perturbed FSI curve to evaluate the effectiveness of perturbed FSI. Finally, the improved food system is applied to Japan and China. According to the result analysis, the model proposed in this paper can evaluate the actual situation scientifically and reasonably, and the model is relatively stable and scalable.

1. Introduction

There are still many loopholes in the current food system in the global implementation process,[1] resulting in hundreds of millions of people being unable to get food security.[2] Moreover, even in rich countries, there are poor food areas.[3] In addition, the current food system has also left a huge environmental impact, accounting for 29% of greenhouse gas emissions.[4] It causes up to 80% biodiversity loss, 80% deforestation, and 70% freshwater use.[5] With the continuous growth of our global population, the unscrupulous use of the environment in recent decades has greatly harmed human beings.[6] Therefore, while maintaining or even improving our environmental health, the need to produce more food has never been more urgent, and a more comprehensive food system is also urgently needed. We all want to find and implement actions that change how food systems work, so a model needs to be redeveloped to conceive and prioritize food systems.

This paper aims to establish a perfect food security evaluation indicator system. In this paper, we propose the FSI model for evaluating the level of food security using a comprehensive multi-index comprehensive evaluation method [7]. The FSI model uses FAOSTAT as the data source for food security evaluation factors and further refines and improves the food security framework based on existing data to form a perfect food security evaluation indicator system.

2. Establishment Of Models

2.1. Data set of food security evaluation factors

In the evaluation index system of food security, food supply is a necessary but not sufficient condition for food security. Due to the uneven distribution of economic level, the difference of food price, and the ability of production, supply, distribution, and consumption, there are still great differences in the availability of food and people's ability to obtain food in a world with sufficient food supply. At the same time, affected by various factors such as health conditions and storage methods, food utilization is significantly inadequate, unscientific and unbalanced, and food waste, food health, obesity, and emaciation are still prominent. It shows that under the premise of sufficient food supply, food security should be realized by obtaining food and making full, reasonable, and effective use of its nutrients. Therefore, food access and food use is the ultimate way to achieve food security. Economic and political stability is used to measure the impact of uncertain factors such as output fluctuation, price fluctuation, and political turbulence on food supply, access, and utilization, which is an important factor in determining whether a country can achieve long-term food security. According to this, the corresponding variables from FAOSTAT are selected as three-level indicators to form the food security evaluation index system. The incomplete and discontinuous evaluation units are continuously eliminated through screening, and finally the food security evaluation factor data sets of 172 countries from 2000 to 2014 are obtained. The composition and measurement method of the index system is shown in Figures 1 and 2.

First level indicators	Secondary indicators	Third level indicators	Index tropism
food safety	Food supply	X1: grain output per capita (kg / person)	+
		X2: protein supply per capita (g / person · day)	+
		X3: animal protein supply per capita (g / person · day)	+
		X4: dietary energy supply adequacy ratio (%)	+
	Food acquisition	X5: degree of food shortage (kcal / person · day)	-
		X6: per capita GDP (fixed value in US dollars in 2011)	+
	Food utilization	X7: proportion of short children under 5 years old (%)	-
		X8: proportion of children under 5 years old affected by waste (%)	-
		X9: proportion of population with access to clean water (%)	+
	Economic and political stability	X10: variability of grain yield per capita	-
		X11: variability of grain supply per capita (kcal / person · day)	-
		X12: political stability and Non Violence	+

Figure 1 Index system and method for evaluation of food security

Three-level index	Measurement method
X_1	X_1 = Total grain output/Total population
X_2	X_2 = Food protein supply /(Total population × Days in current year)
X_3	X_3 = Supply chain of animal - derived protein /(Total population × Days in current year)
X_4	X_4 = The numberof peoplewhosedailydietaryenergysupplyis more than 2320kcal/Totalpopulation
X_5	X_5 = 2320 - Daily per capita dietary energy intake of malnourished people
X_6	X_6 = Gross domestic product converted by purchasing power parity/Total population
X_7	X_7 = number of short children under 5 years old/total number of children under 5 years old
X_8	X_8 = Number of children under 5 years old affected by waste/u nder 5 years old Total children
X_9	X_9 = Population with access to clean water/total population
X_{10}	X_{10} = Standard deviation/average value of per capita grain output
X_{11}	X_{11} = Standard deviation of per capita food supply
X_{12}	X_{12}World governance indicators developed by the World Bank(WGI)

Figure 2 Measurement method of food security evaluation index

2.2. Multi index comprehensive evaluation

With the development of the connotation and extension of the concept of food security, a single index such as grain yield can no longer fully reflect the situation of food security, making the multi-index comprehensive evaluation method an effective tool for food security evaluation. In this paper, the multi-index comprehensive evaluation of food security is carried out according to the following steps.

2.2.1.Data standardization processing

The range standardization method was used to standardize the index data. For positive indicators:

$$X'_{ij} = (X_{ij} - minX_{ij})/(maxX_{ij} - minX_{ij}) \tag{1}$$

For negative indicators:

$$X'_{ij} = \left(maxX_{ij} - X_{ij}\right)/\left(maxX_{ij} - minX_{ij}\right), i = 1,2,\cdots,172; j = 1,2,\cdots,12 \tag{2}$$

Where, X'_{ij} is the original data of index j of the i-th country (in alphabetical order); X'_{ij} is the corresponding standardized variable value, X'_{ij} ∈[0, 1]; max (X_{ij}) and min (X_{ij}) are the maximum and minimum values of index j, respectively.

2.2.2. Weight determination based on mean square error

Because the purpose of food security evaluation in this paper is to analyze the difference pattern of food security at the national level, the index weight should reflect the relative discrete degree of each index sample value. Therefore, the mean square error method is used to determine the weight of each index.

Based on the standardized data set, the mean square error (standard deviation) of each evaluation index from 2000 to 2014 is calculated:

$$\partial = \sqrt{\frac{\sum_{i=1}^{n}\left(X'_{ij}-\bar{X}_{ij}\right)^2}{n}}, i = 1,2,\cdots,172; j = 1,\cdots,12 \tag{3}$$

Where ∂denotes the mean square deviation of indicators; X'_{ij} is the standardized variable value of j indicators in the ith country; $\bar{X}_{ij}$ is the mean value of standardized variable value. n is the number of participating countries.

Based on the mean square deviation, the weight coefficients of the three indicators of food supply, food access, food use, economical and political stability from 2000 to 2014 were calculated:

$$\omega_{mkj} = \frac{\partial_{mkj}}{\sum_{k=1}^{K}\partial_{mkj}} \tag{4}$$

Where m is the year serial number, M = 2000, 2001,..., 2014; K is the number of three-level indicators including food supply, food acquisition, food utilization, economic and political stability, K is 4, 2, 3, 3; J is the serial number of three-level indicators, j = 1, 2 ,..., 12; ω_{mkj} is the weight of the j-th index in M year under the corresponding upper index.

The average weight coefficient of each three-level index from 2000 to 2014 is calculated as the unified weight of each three-level index in the study period:

$$\omega_j = \frac{\sum_{m=2000}^{2014}\omega_{mkj}}{15}, k = 4,2,3,3; j = 1,\cdots,12 \tag{5}$$

Where: ω_j is the weight of each three-level index, and the calculation results are shown in Figure 3.

Secondary indicators	Food supply				Food acquisition		Food utilization			Economy and policy stability		
Level 3 index code	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	0.21	0.28	0.33	0.18	0.51	0.49	0.39	0.31	0.30	0.27	0.31	0.42

Figure 3 Weight of the third tier indicators

2.2.3. Secondary index evaluation

Based on the standardized data set and three-level index weight, a two-level index evaluation model was established to evaluate the food supply (Y_1), food access (Y_2), food use (Y_3), and economic and political stability (Y_4) of countries from 2000 to 2014:

$$Y_1 = 0.21X_1 + 0.28X_2 + 0.33X_3 + 0.18X_4 \tag{6}$$

$$Y_2 = 0.51X_5 + 0.49X_6 \quad (7)$$

$$Y_3 = 0.39X_7 + 0.31X_8 + 0.30X_9 \quad (8)$$

$$Y_4 = 0.27X_{10} + 0.31X_{11} + 0.42X_{12} \quad (9)$$

By substituting the standardized index data, the evaluation results of food supply, food access, food use, economic and political stability of various countries from 2000 to 2014 are obtained used as the input of the radar area model.

2.2.4. Building radar area model

When the system security depends on the States and interactions of subsystems, the radar area model can integrate the state information of subsystems. As far as food security is concerned, sufficient food supply is the first premise of food security. On this basis, food security needs to be realized through food acquisition and food utilization. Supply, acquire and use food stably and reliably needs economic and political stability as a guarantee. It can be seen that food supply, food acquisition, food utilization, economic and political stability constitute a closed transitive relationship to food security, and the radar area model can better reflect this relationship. Therefore, the FSI is used to represent the food security index, and the radar area model FSI = $(Y_1 \times Y_2 + Y_2 \times Y_3 + Y_3 \times Y_4 + Y_4 \times Y_1)/2$ is established to evaluate the food security.

2.3. Optimization of model

Food security is the basis of achieving the overall goal of sustainable development. Since the millennium development goal of "halving the proportion of hungry people by 2015" has not been achieved as scheduled, the realization of zero hunger by 2030 faces greater challenges. We calculate FSItarget = 1.628 according to the 2030 goal of zero hunger, so we need to intervene to a certain extent to ensure that the goal can be achieved by 2030. Meanwhile, according to the interference index to determine the order of priority supply, in order to measure the difference of equity, sustainable development, efficiency and profitability brought by changing the order of priority supply. In order to assess the ability of the global goal of equitable distribution of food, we should set the optimal goal of equitable distribution of food and sustainable development of food on a global scale.

According to the food and Agriculture Organization of the United Nations, we analyzed 12 indicators in the FSI model of 172 regions on average and calculated the growth rate of corresponding indicators shown in Figure 4.

index	X_1	X_2	X_3	X_4	X_5	X_6
annual rate of increase	0.92%	0.66%	0.82%	0.38%	1.07%	1.82%
index	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
annual rate of increase	-1.24%	-0.79%	0.53%	-0.53%	-2.50%	-12.19%

Figure 4 Growth rate without intervention for 12 indicators

In order to measure the equitable distribution of food and the sustainable development of food, we plan to intervene in many aspects. From the four aspects of food supply, access, utilization, and economic and political stability, we assume that these 12 indicators will increase or decrease with different growth rates as the change of supply order. According to the fsitarge in 2030, we have carried out political, economic, and environmental interventions. The growth rate of specific intervention indicators is shown in Figure 5. According to fairness and sustainability, the growth rate of X_1, X_2, X_3, and other indicators will increase, and the cost of increasing these indicators will sacrifice the economy, so the growth rate of X_6 will decrease. Because of the complexity of global politics and the epidemic in 2020, the growth rate of X_{12} will decrease.

index	X_1	X_2	X_3	X_4	X_5	X_6
annual rate of increase	1.40%	0.70%	0.90%	0.40%	1.20%	1.75%
index	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
annual rate of increase	−1.00%	−0.70%	0.52%	−0.50%	−2.00%	−21.00%

Figure 5 Growth rate of interventions for 12 indicators

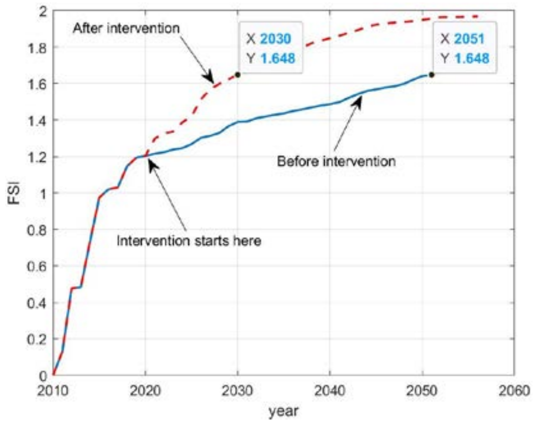

Figure 6 Global FSI curves before and after intervention

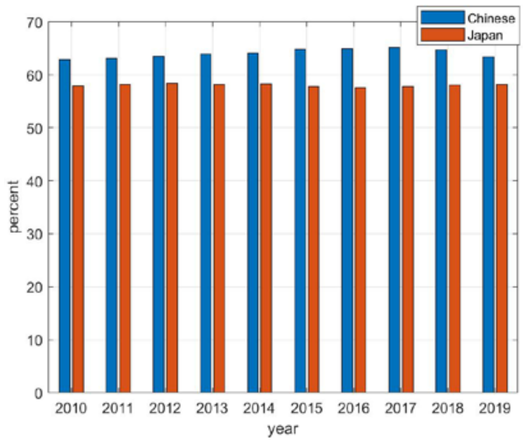

Figure 7 Global FSI curves before and after intervention

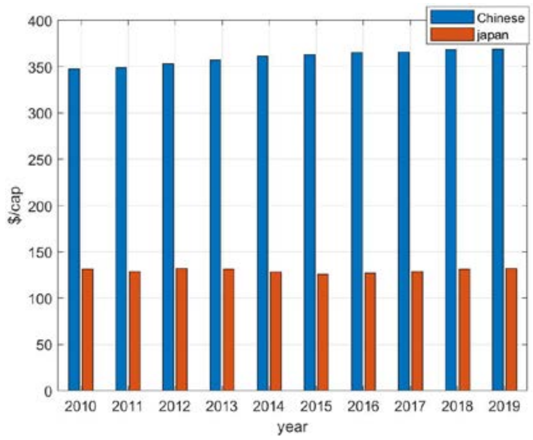

Figure 8 Average value of food production

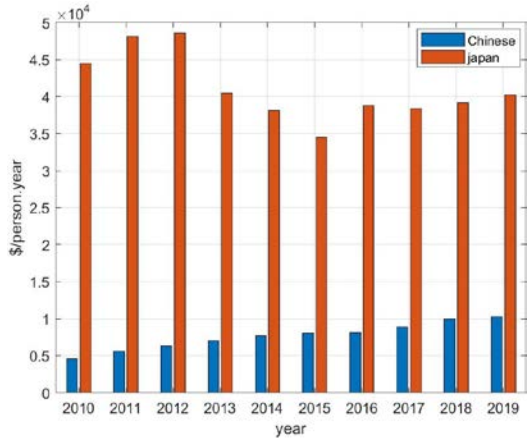

Figure 9 Per capita GDP

3. Analysis Of Results

In order to show the change of FSI before and after the intervention, we used the grey Verhulst model to predict the FSI curve without intervention. The grey Verhulst model can better reflect the saturation state of indexes than the commonly used grey GM (1,1).

It can be seen from Figure 6 that the curve of FSI without intervention is relatively flat, and the curve without intervention does not reach the goal of zero hunger in 2030. In the case of intervention, FSItarget=1.628 in 2030, while the curve without intervention equals 1.628 in 2051. When the intervention index is implemented during the implementation period of the system experiment, the changing size of the index and the changing size before and after the intervention are analyzed to judge whether the best goal of fairness and sustainable development is achieved. Finally, the 2030 index will reach the best target index after calculation, and the predicted implementation time of the system is initially set at 2030.

Based on the comprehensive evaluation, taking the mean value of FSI natural discontinuities as the unified grading standard, the evaluation results over the years were divided into five grades: extremely unsafe (0 FSI 0.47), unsafe (0.48 FSI 0.68), general (0.69 FSI 0.86), relatively safe (0.87 FSI 1.10) and safe (1.11 FSI 2), and the contour coefficient (silhouette) was used The clustering validity of FSI is tested by coefficient, and the contour coefficient of all years is greater than 0.60, which indicates that the unified classification standard is scientific and reasonable.

In order to verify the applicability of the FSI model, we combined two cases for analysis. In order to make the analysis results more universal, we selected a developed country and a developing country based on the original data of 2010-2019 corresponding to the above six factors affecting the food security index to our model. The FSI of Japan is 1.1856, and that of China is 0.9874. Through the above evaluation criteria, we can know that the food security level of Japan is better than that of China. Next, we can analyze the reliability and authenticity of this result by comparing some data from these two countries.

It can be seen from Figure 7 that the proportion of arable land available for irrigation in China is higher than that in Japan over the years from 2010 to 2019, which is also determined by geographical location, and indirectly leads to the fact that China's average grain production is much higher than that in Japan as shown in Figure 8. However, why is China's average grain output so much higher than Japan's and its food security factor lower than Japan's? There is also a great connection between the two countries' agricultural policies and treatment methods.

One of the keys to the success of Japanese agriculture lies in dealing well with the relationship between the market and the government. The government does not directly intervene in agricultural production activities but guides producers through policies and regulations. The government formulates and implements targeted and operable policies and constantly improves the legal system so that the healthy development of agriculture is supported and guaranteed by strong policies and regulations. Although China's agricultural policy is scientific enough, it is still not perfect. We need to learn some good methods from other countries. Therefore, China's agricultural policy needs to be perfect compared with Japan.

It can be seen from Figure 9 that there is a considerable difference between China's per capita GDP and Japan's per capita GDP, which is also an important factor affecting the agricultural safety factor. Therefore, comprehensive analysis shows that Japan's psi value is larger than China's is reasonable and scientific, which also verifies the feasibility of our model.

In order to verify the scalability of our model, we use the local sensitivity analysis method to analyze the model. Among the 12 indexes mentioned in this paper, we choose the most influential index X1 to change according to the influence degree of index change on the evaluation index of grain system to verify the sensitivity of our model judge the scalability. According to $X_1 = 0.3333$, FSI = 0.4771, the sensitivity of the model is 0.0873, that is, if X_1 increases by 2%, FSI increases by 0.17%. Therefore, the model in this paper is relatively stable and scalable.

4. Conclusion

In this paper, an FSI model has been established to evaluate the food security level of 172 countries from 2000 to 2014 based on the data set of food security evaluation factors and influencing factors. The FSI model sets more comprehensive global achievable goals for achieving negative growth of the Global Hunger Index and optimizing equitable and sustainable development. The model uses accurate and latest databases to guarantee the reliability of results. Through comprehensive evaluation, our model can output the compellent results. The model is stable in the evaluation progress, with subjective factors excluded. According to the result analysis, the evaluation model proposed in this paper can evaluate the actual situation scientifically and reasonably, and the model is relatively stable and scalable.

References

[1] Xiaoxi Zhu, Xiuqi Fang, Gao Yong. Assessment of the food security in China based on system science. Chinese Journal of Agricultural Resources and Regional Planning, 2012, 33(6): 11-17.

[2] Liu Yue, Wenwu Zhao, Zhang Xiao. Promoting the delivering on the Environmental Dimen- sion of the 2030 Agenda for Sustainable Development: Summary of the Second Session of the United Nations Environment Assembly. Acta Ecologica Sinica, 2016, 36(12): 3843-3846.

[3] Wenbin Wu, Huajun Tang, Yang Peng, et al. Model- based assessment of food security at a global scale. Acta Geographica Sinica, 2010, 65(8): 907-918.

[4] Jiang Li, Feibiao Xu. Review on climate change and food security. International Information, 2011(5): 37-42.

[5] Yiming An, Wenwu Zhao. Global climate change and food security: Review of the 2012 Planet under Pressure International Conference. Acta Ecologica Sinica, 2012, 32(15): 4940-4942.

[6] Enpu Ma, Jianming Cai, Lin Jing, et al. Spatiotemporal evolution and influencing factors of global food security pattern from 2000 to 2014 [J]. Acta geographica Sinica, 2020, v.75 (02): 126-141.

[7] Shen Yue, XIE Yong, Tian Yuan. An empirical analysis of China's financial security based on FSI [J]. Financial Forum, 2007 (10): 14-18.