Problem Chosen	2021 MCM/ICM Summary Sheet	Team Control Number
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Food system optimization analysis

Summary

With the continuous development of economy and society, the global food system that blindly pursues efficiency maximization has gradually exposed instability. In order to maintain the continuous and stable development of the food system, we have optimized the original food system, changed the priority of elements, and established a new model to improve the stability of the system.

In order to better reflect the stability, sustainability, fairness, and efficiency of the current food system, we have selected 17 indicators related to the food system from 8 perspectives and constructed a basic indicator system.

First, we used BWM and EWM to determine the subjective and objective weights of the traditional food system CFS, and constructed a CFS model.

Then we changed the priority of the variables in the CFS model and replaced it with a guaranteed result system

Fairness, the climate factor subsystem T is introduced into the sustainability variables, and the genetic algorithm (AG) is used to solve the objective programming equation to calculate the optimized weights, and the four main factors of supply, Stability, Sustainability, security result, and demand are constructed. The constituted 4SD Model.

After selecting representatives of two developed countries, Japan and the United States, and two developing countries, China and India, we found the data of each country and smoothed the data through SPSS's multiple imputation. Calculating the comprehensive scores of the food systems of the four countries in the CFS and 4SD models, it is found that system changes have a greater impact on developing countries. And through linear regression to predict the future food system trends in developed and developing countries and the time of system changes.

Next, we analyzed the impact of model changes on cost and income through the construction of cost function and income function in the food system. The basic model of cost-benefit analysis is obtained through cost-benefit curve construction, variable selection, and linear regression. And by bringing in data from developing countries and developed countries, it analyzes the impact of priority changes on the cost and benefit of food systems in developing and developed countries, predicts future trends, and infers the timing of the changes.

Finally, for the scalability and adaptability of the model, we introduce the impact of the epidemic, an exogenous variable that cannot be ignored. We analyze the impact of the epidemic impact on the world food system, and use the GM(1,1) model to evaluate the impact of the epidemic on the world food system in the future. The trend and time of impact were predicted, and it was concluded that the epidemic has greatly affected the stability of the system, and it will take at least 7 years to return to normal.

key words: Food system; linear regression;;; Ewm; genetic algorithm; GM(1,1);

context

1 Introduction

1.1 background

The food system refers to human energy sources and their supply process, including the production, processing, packaging, transportation, sales, distribution of food and related products. Social political, economic, environmental and many factors will affect its development.
Due to the advancement of science and technology and the expansion of trade, the food system has achieved a certain degree of efficiency today. However, food security and nutrition and health issues in the food system have not yet been resolved. The "State of Food Security and Nutrition in the World" report released by the United Nations in 2020 pointed out that in 2019, nearly 690 million people worldwide were hungry, and 750 million people faced severe food insecurity, accounting for 8.9% and 9.7% of the world's population respectively. The number of hungry people has increased by nearly 60 million in five years. Not only poor areas, but even some areas in developed countries are experiencing food shortages. Forecast data show that by 2030, the number of hungry people in the world will exceed 840 million.[1]
The environmental problems caused by the irrational development of the food system also greatly affect the sustainability and stability of people's lives and social development. Greenhouse gas emissions caused by the development of food systems accounted for 29% of total emissions, and also brought about 80% of biodiversity loss and 80% of deforestation. Almost one-third of food produced globally is wasted [2] and 14% of food have loss before the retail. These environmental issues, food security, nutrition and health issues continue to affect the optimization efficiency, profitability, sustainability and/or fairness of the food system.
Therefore, it is very necessary to build an optimized food system model worldwide to improve the sustainable, fair and efficient development of food systems in various countries.

1.2 Restatement of Problem

In order to build a more reasonable food system model, we need to formulate a plan to re-evaluate the priority and weight of different elements, taking into account the fairness and efficiency of food system development.
What we need to do is as follows:

- Reconsider the fairness and sustainability of the food system, re-evaluate the corresponding sub-variables, build a new food system model, and predict the time required to reach the new model.
- Compare the new model with the original model to find the differences between the two models. Explore the adaptability of the new model in different regions and systems of different sizes.
- Analyze the costs and benefits of changing the food system, and predict the time when the costs and benefits will be realized.
- Apply our model to at least one developed country and another developing country to illustrate the rationality of the model.

1.3 our work

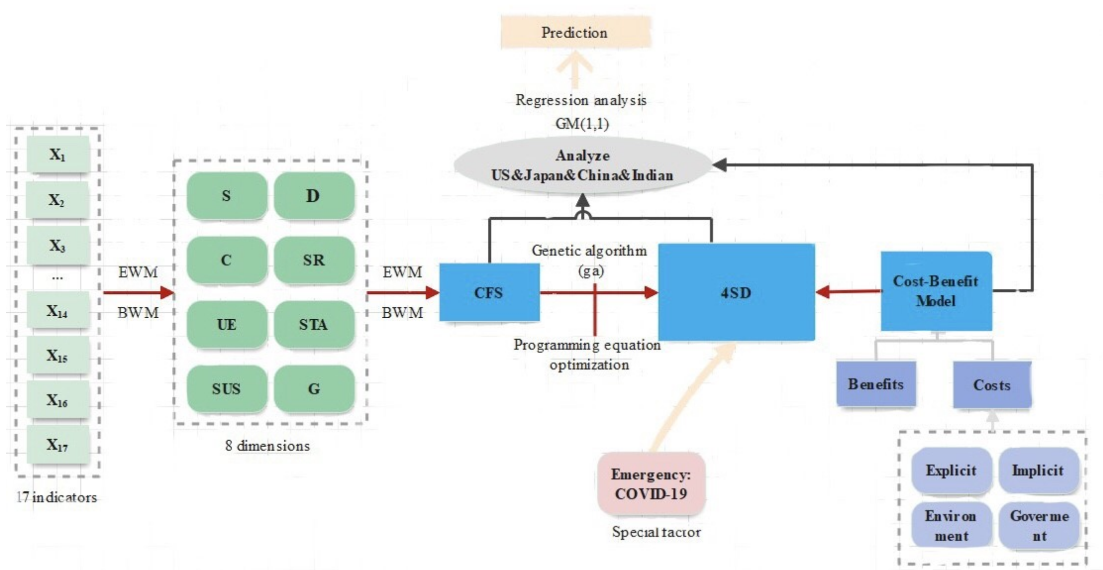


Figure 1: whole modeling process of the paper

We set up an evaluation index system of food system now, and on this basis through the optimization model of fairness and sustainable system optimization, change the forecast at the same time, the introduction of test case, then after cost-benefit model analysis was used to optimize the costs and benefits, through the case the time of the forecast, finally, the epidemic factor is introduced to further improve the model.

2 Assumptions and Justifications

To simplify the model, we have made following basic assumptions, each of which is properly justified.

- We assume that all the countries are regular and react positively to handle food scarcity.
- We assume that sudden change in the environment can be ignored, unless we analyze the influence of COVID-19 to food system.
- We assume that food loss rate in all countries remain the same.
- We assume that developing countries are a whole, while developed countries are a whole. Because they always have similarities in many ways.

3 Notations

Table1: Symbol table

Symbol	Description
S	supply
S_1	Food
S_2	calories

D	Distribution
D_1	Income
D_2	price
D_3	Availability
C	consumption
C_1	Nutrition structure
SR	Security result
SR_1	General security
UE	usage efficiency
UE_1	Whole process loss
STA	Stability
STA_1	Self-sufficiency
STA_2	Volatility
SUS	Sustainability
SUS_1	Environmental discharge pressure
SUS_2	Cultivated land resources
G	Government control
G_1	Financial support for agriculture
K_i	Weight of 4SD
x_i	The *i*-th indicator

4 Conventional Food System Model (CFS)

4.1 Identify indicators

Table2: Introduction to indicators

Target Layer	Dimension layer	Theme layer	Indicator layer	Direction
Food system Model	supply	Food	Per capita grain output (x_1)	+
		calories	Average dietary energy supply adequacy (percent) (x_2)	+
			Dietary energy supply used in the estimation of prevalence of undernourishment (x_3)	+
	Distribution	Income	GDP per capita (x_4)	+
			Incidence of poverty (x_5)	−
		price	consumer price index (x_6)	/
		Availability	Rail lines density (total route in km per 100 square km of land area) (x_7)	+
	consumption	Nutrition structure	Average supply of protein of animal origin (g/cap/day) (x_8)	/
	Security result	General security	Incidence of malnutrition (x_9)	−
			Prevalence of severe food insecurity in the total population (x_{10})	−
	usage efficiency	Whole process loss	Attrition rate (x_{11})	/
	Stability	Self-sufficiency	Value of food imports in total merchandise exports (percent) (x_{12})	−
		Volatility	Per capita food production volatility (x_{13})	−
			Per capita food supply volatility (x_{14})	−
	Sustainability	Environmental discharge pressure	Fertilizer usage (x_{15})	/
		Cultivated land resources	Percentage of arable land equipped with irrigation facilities (x_{16})	+
	Government control	Financial support for agriculture	Fiscal expenditure (x_{17})	+

Supply

- **Per capita grain output（x_1）:** It refers to the average grain output owned by each person around the world. It reflects the availability of food for people in the whole world.
- **Average dietary energy supply adequacy (percent)（x_2）:** It reflects whether the calories food system supplied in the world is adequate.
- **Dietary energy supply used in the estimation of prevalence of undernourishment（x_3）:** It refers to the calories that food system supplied to people.

The expressions as follow:

$$Dietary\ energy\ supply\ (x_3) = \frac{(Total\ grain\ output + Net\ food\ import)}{Combined\ calories\ of\ grain}$$

$$Combined\ calories\ of\ grain = \sum_i ((P_i/\sum_j P_j) \times c_i)$$

（c_i refers to the average calorific value of rice, wheat, corn, soybean and potato; P_i refers to a kind of food; P_j refers to all food.）

Distribution

- **GDP per capita（x_4）:** It refers to the average of Gross Domestic Product of each country. It reflects economic strength and food market size in the world.
- **Incidence of poverty（x_5）**: It refers to the proportion of the world's poor in the population. It reflects current poverty situation. And by comparing consecutive years of data, we can find the characteristics of changes of poverty population in recent years.

$$Incidence\ of\ poverty\ (x_5) = \frac{the\ population\ of\ poor\ \text{people}}{annual\ population}$$

- **consumer price index (x_6)**: It refers to the price level change of consumer goods and services purchased by households. It mainly reflects the inflation in the world.
- **Rail lines density (total route in km per 100 square km of land area) (x_7)** : It mainly reflects availability of food for people in the world.

Consumption
Nutrition structure

- **Average supply of protein of animal origin (g/cap/day) (x_8) :** It mainly reflects the nutrition structure in the world.

Security result

- **Incidence of malnutrition (x_9) :**

We assume that calorie gain follows a lognormal distribution. Thus, the density function follows:

$$\mathrm{F}(x) = \frac{1}{\sqrt{2\pi}\sigma x} e^{(\frac{-\ln(x)-\mu^2}{2\sigma^2})}$$

μ refers to the mean, σ refers to the variance.

We assume that $E(X)$ refers to the mean of calories which calculated for food consumption, $var(X)$ refers to the variance of calories which calculated for food consumption. Thus,

$$\mu = ln\big(E(X)\big) - \frac{1}{2}\ln\left(1 + \frac{var(X)}{E(X)^2}\right)$$

$$\sigma = ln\left(1 + \frac{var(X)}{E(X)^2}\right)$$

- **Prevalence of severe food insecurity in the total population (x_{10}) :** It reflects the security of food and can be calculated in the similar way of *incidence of malnutrition*.

Usage efficiency

- **Attrition rate** (x_{11}) : Based on the loss coefficient and food balance table issued by the International Food and Agriculture Organization, we consider the five processes of food production, storage, processing, circulation, and consumption to calculate the world average loss rate, and assume the same loss rate in all countries.

Stability

- **Value of food imports in total merchandise exports (3-year average) (x_{12}) :** It refers to how food imports and out ports reflect to stability of food system.
- **Per capita food production volatility (x_{13}) :** We use the coefficient of variation of the divergence between the actual and trend values over the past three years. Through ARIMA trend fitting, the trend value and deviation of per capita output in each year are obtained according to the autocorrelation graph, partial correlation graph and unit root test. After excluding the effect of outliers in caloric intake, the standard deviation of the absolute deviation over the past three years was calculated to obtain the coefficient of variation. [3]

- **Per capita food supply volatility（x_{14}）:** We use the same calculation as *per capita food production volatility* to reflect the stability of food supply.

Sustainability

- **Fertilizer usage（x_{15}）:** It refers to the mean global fertilizer use, which reflects on the sustainability of food system.
- Percentage of arable land equipped with irrigation facilities（x_{16}）: It reflects the global irrigation which have an impact on food system sustainability.

Government control

- **Fiscal expenditure（x_{17}）:** It refers to the proportion of agricultural expenditure in total fiscal expenditure which show the government control in food system.

4.2 Data processing

We searched World Bank [4], Food and Agriculture Organization of the United Nations [5], United Nations [6] for statistics. But some statistics of indicators are missing so we use SPSS's multiple imputation to fill the blank.
Then we normalization the data. We divide them into three parts: who have positive, negative or specific impact on food system. We use following equation to normalization them：$t_i = \frac{t_i t_{min}}{t_{max} t_{min}}$；$t_i = \frac{t_{max} t_i}{t_{max} t_{min}}$; $t_{ta} = 1 - \frac{|ta|}{|ta|_{max}}$.[7]

4.3 Weight determination

Determining weights is very important for food system models. Thus, we use Best-worst multi-criteria decision-making method（BWM [8]） to compare the best and worst indicators with other indicators to calculate the subjective weight of each indicator. Next, use Entropy weight method (EWM) to calculate objective weights to obtain a more balanced comprehensive weight. [9]

4.3.1 Use BWM to determine the subjective weight

Firstly, the steps of Best-worst multi-criteria decision-making method are as followed:
1）Select the best index X_B and the worst index X_W based on expert opinions in index set $X = \{x_1, x_2, \dots, x_n\}$
2）Determine the importance of other indicators relative to the best indicators by scoring 1-9 points.
3）Determine the insignificance of other indicators relative to the worst indicator, and construct a comparison vector $C_W = \left(C_{1W}, C_{2W}, \dots, C_{jW}\right)^T$.
4）Establish a mathematical programming formula and solve it to determine the best index weight: $w_j^* = (w_1^*, w_2^*, \dots, w_n^*)$

$$\min \max_{j}\left\{\left|\frac{w_B}{w_j}-a_{Bj}\right|,\left|\frac{w_j}{w_W}-a_{jW}\right|\right\}$$
$$s.t.\begin{cases} \sum_{j=1}^{n} w_j = 1 \\ w_j \geq 0,\ \ j = 1,2,\dots,n \end{cases}$$

where: w_B is the weight of C_B; C_j is the criterion vector; w_j is Weight of C_j , which is actually, the actual weight of the indicator; w_W the weight of C_W; a_{Bj} means the importance value of C_B to C_j ; a_{jW}represents the importance value of C_j to C_B.

Thus, the subjective weight is:

$$\overline{w}_j^* = \frac{\sum_{a=1}^{p} w_j^a}{p}$$

4.3.2 Use EWM to determine the objective weight

First, we use the Min-max standardized processing method [10]to standardize all evaluation indicators in matrix $X = [x_{ij}]_{m\times n}$. And we get matrix $B = [b_{ij}]_{m\times n}$, $0 \leq b_{ij} \leq 1$.

1）calculate the weight of the jth indicator in the ith country.

$$p_{ij} = \frac{r_{ij}}{\sum_{i=1}^{n} r_{ij}}$$

2) calculate entropy e_j of the jth evaluation index.

$$e_j = -ln(n)^{-1}\sum_{i=1}^{n} p_{ij} ln(p_{ij})$$

3) calculate the weight of each evaluation indicator we defined before.

$$w_j = \frac{1-e_j}{n-\sum_j e_j}, j = 1,2,\dots,n$$

4.4 The result

After determining the weight of each indicator, we weighted and summed each indicator to get CFS:

$$CFS_i = \sum_{j=1}^{n} r_{ij} w_j$$

By using BWM, we get following subjective weight:

Table3 subjective weight

Index	**Weight**	**Index**	**Weight**
Per capita grain output	0.0423	*Incidence of malnutrition*	0.009882
Average dietary energy supply adequacy	0.087788	*Prevalence of severe food insecurity in total population*	0.050977
Dietary energy supply used in the estimation of prevalence of undernourishment	0.082363	*Attrition rate*	0.044147
GDP per capita	0.061045	*Value of food imports in total merchandise exports*	0.011124
Incidence of poverty	0.013654	*Per capita food production volatility*	0.021056
consumer price index	0.183109	*Per capita food supply volatility*	0.054197
Rail lines density	0.023471	*Fertilizer usage*	0.002386
Average supply of protein of animal	0.061936	*Incidence of malnutrition*	0.017495
		Prevalence of severe food insecurity in total population	0.027305

By using EWM, we get following objective weight:

Table4 objective weight

Index	**Entropy**	**Entropy weight**	**Index**	**Entropy**	**Entropy weight**
Per capita grain output	0.816861	0.048844	*Incidence of malnutrition*	0.906345	0.022831
Average dietary energy supply adequacy	0.534339	0.130974	*Prevalence of severe food insecurity in the total population*	0.791893	0.056102
Dietary energy supply used in the estimation of prevalence of	0.730008	0.074092	*Attrition rate*	0.749492	0.070324
GDP per capita	0.777473	0.060294	*Value of food imports in total merchandise exports*	0.564603	0.122176
Incidence of poverty	0.898151	0.025213	*Per capita food production volatility*	0.859541	0.036437
consumer price index	0.564603	0.122176	*Per capita food supply volatility*	0.751785	0.067762
Rail lines density	0.920789	0.018632	*Fertilizer usage*	0.904269	0.023434
Average supply of protein of animal origin (g/cap/day)	0.807852	0.051463	*Incidence of malnutrition*	0.877577	0.031194
			Prevalence of severe food insecurity in the total population	0.853969	0.038057

5 4SD Model

According to the CFS model, we have optimized some of these variables. And we use four indicators: supply, Stability, Sustainability, security result and Demand to build a new model. We called it 4SD Model.
5.1 Introduce climate factor subsystem in sustainability variables
Since the development of the food system has had a greater impact on the environment, and environmental factors have a negative effect on the development of the food system, most directly affecting the sustainability and stability of the food system. Climatic factors directly affect global food production and food supply through factors such as precipitation and temperature, and further affect food prices, the incidence of poverty, and the incidence of malnutrition. The variability of climate factors also affects the volatility of per capita food production and per capita food supply. Therefore, it is necessary to introduce the climate factor subsystem $T = \{t_1, t_2, \ldots, t_n\}$.
Among them, due to the increasing impact of greenhouse gas emissions on food production in recent years, many experts believe that carbon dioxide emissions are a major factor in the climate factor subsystem. Therefore, we introduce average carbon dioxide emissions ACO_2E as the main factor affecting sustainability variables.

5.2 Introducing the system in fairness and sustainability

The CFS model focuses on benefits, while the 4SD Model focuses more on fairness and sustainability while pay attention to the system efficiency. Thus, we optimize in terms of fairness and sustainability, introducing subsystems and new variables.

5.2.1 Fairness is replaced by a guarantee result system

Fairness focuses on the fairness of production and the fairness of distribution, but since fairness is difficult to quantify in the production and distribution process, we choose to quantify from the results. We introduce the variable SR and sub-variables x_9(Incidence of malnutrition) and x_{10}（Prevalence of severe food insecurity in the total population）of guarantee result to construct the fairness subsystem.
Thus, our results are as follows:

$$\mathrm{SR} = k_1 \times x_9 + k_2 \times x_{10}$$

5.2.2 Sustainability is replaced by a sustainability system

Similar to fairness, due to the large number of sustainability indicators, we selected three main variables x_{15}（Fertilizer usage），x_{16}（Percentage of arable land equipped with irrigation facilities）and ACO_2E（Average carbon dioxide emissions）through indicator evaluation to construct the sustainability system SUS, which replaced the original sustainability variables.
Thus, our results are as follows:

$$\mathrm{SUS} = h_1 \times x_{15} + h_2 \times x_{16} + h_3 \times ACO_2E$$

5.3 Optimize new weights

5.3.1 Collect and standardize data worldwide

We found the required data from the FAO website and standardized them so that we can further optimize them in the future.

5.3.2 Optimization measures

We use genetic algorithm (GA) to calculate the optimal solution $k_1, k_2, k_{3,} k_{4,} k_5$ when the maximum value of Y1 and Y2 is obtained as the optimized weight. Proceed as follows:

$$max \quad f_1(x) = \overline{x_9} \times k_1^2 \pm \overline{x_{10}} \times k_2$$

$$max \quad f_2(x) = \overline{x_{15}} \times h_1 \pm \overline{x_{16}} \times h_2 \pm \overline{x_{18}} \times h_3$$

$$s.t.\, gi(x) \geq 0, i = 1,2, \dots, p$$

$$s.t.\, k_1, k_2, h_1, h_2, h_3 \geq \max\{W_{x_6}, W_{x_1}\}$$

$$s.t.\, k_1 + k_2 + h_1 + h_2 + h_3 + W_{x_6} + W_{x_1} = 1$$

Thus, the weight and value are as followed:

Weight	k_1	k_2	h_1	h_2	h_3	W_{x_6}	W_{x_1}
Value	0.2	0.13	0.2	0.2	0.2	0.035	0.035

5.4 Building a predictive model

We use regression analysis on 4SD and CFS, predict the future development trend, and draw the following table:

YEAR	4SD	Trend prediction (4SD)	Confidence lower limit (4SD)	The confidence limit (4SD)
2013	0.283864			
2014	0.448528			
2015	0.621174			
2016	0.759767			
2017	0.772518			
2018	0.767612			
2019	0.654233	0.65423284	0.65	0.65
2020		0.72211207	0.57	0.87
2021		0.78999129	0.58	1
2022		0.85787051	0.6	1.12
2023		0.92574974	0.63	1.23
2024		0.993628958	0.66	1.33
2025		1.06150818	0.69	1.43
2026		1.1293874	0.73	1.53

YEAR	CFS	Trend prediction (CFS)	Confidence lower limit (CFS)	The confidence limit (CFS)
2013	0.154578			
2014	0.302287			
2015	0.429023			
2016	0.474715			
2017	0.612535			
2018	0.612484			
2019	0.634448	0.63444773	0.63	0.63
2020		0.72115092	0.61	0.83
2021		0.80128223	0.66	0.95
2022		0.88141354	0.71	1.06
2023		0.96154485	0.76	1.16
2024		1.041676164	0.82	1.26
2025		1.12180748	0.88	1.36
2026		1.20193879	0.94	1.46

The table shows that the difference between the
comprehensive scores calculated by the two models is not obvious. In order to effectively predict the time of change, we stipulate that when the difference between the scores calculated by the two models is ≥ 0.4, it is a sign of obvious change.
Thus, we calculate that the food system will change in 2024.

5.5 Case Study

5.5.1 Country selection

We chose the United States and Japan as representatives of developed countries, and China and India as representatives of developing countries. We used data from these four countries to perform calculations to support our model. The reasons for choosing these four countries are as follows:

Developed countries:

1. Food importing countries with small land and large population:

As the largest food importer among developed countries, Japan's imports not only account for 60% of the world's total imports, but also account for 35% of its domestic food consumption. [11]

2. Food exporting countries with more land and fewer people

The United States is the world's largest grain exporter. According to relevant data, the total US grain exports in recent years have exceeded 100 million tons, which is about a quarter of the global grain exports, of which soybeans and corn are the main products. The U.S. food production system is mainly a labor shortage type with fewer people and more land. It is mainly characterized by extensive use of agricultural machinery to increase agricultural productivity and total agricultural output.

Developing countries:

1. Food importing countries with small land and large population:

China is the world's largest food importer. China has a large land area, but the per capita arable area is smaller than the world average. The total amount of domestically produced food cannot meet the needs of a large number of people, so it needs to rely on imports to make up for this gap.

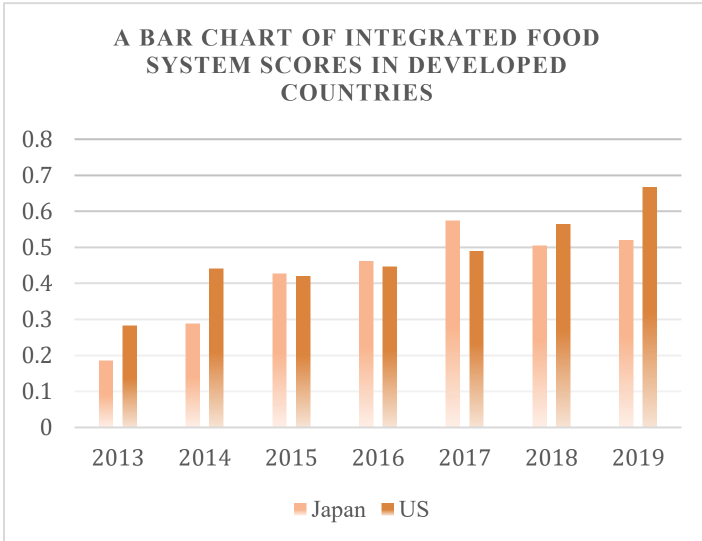
2. Food exporting countries with small land and large population:

India is a typical grain exporter. In the past three market years, India’s rice exports were all between 10 million and 13 million tons, occupying a quarter of the global rice export market.

5.5.2 CFS assessment results

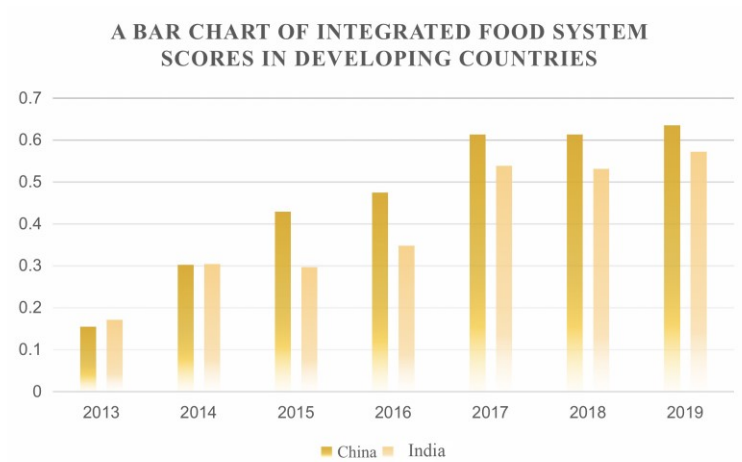
We calculate the comprehensive score through the CFS model, and standardize the collected data into CFS for calculation, and obtain 4 comprehensive scores.

For developed countries：

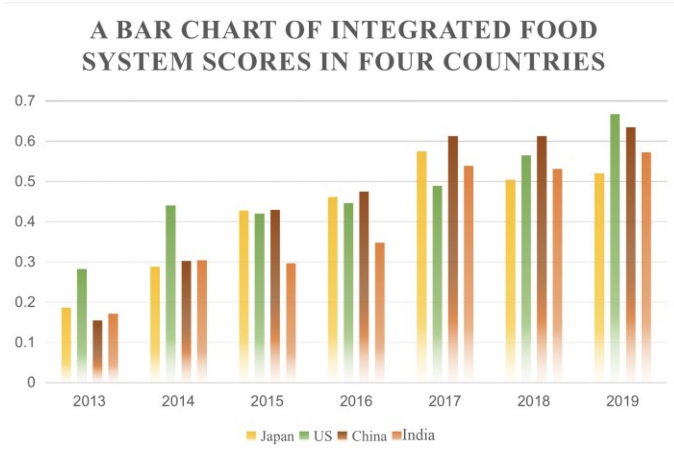


It can be seen from the figure that in developed countries, the United States and Japan, their food system comprehensive scores are relatively stable. The overall score of the US food system surpassed that of Japan before 2015 and after 2017, and has basically maintained steady growth since 2013, especially in 2013 and 2018, where the growth rate increased significantly. For Japan, the overall food system scores basically maintained a steady increase before 2017, but declined in 2017, and then rebounded.

For developing countries：



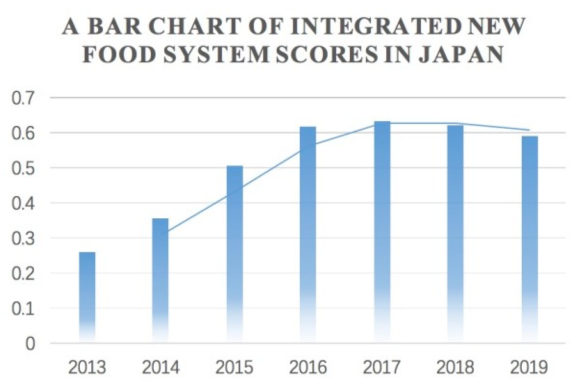
As the largest developing country, China's food system comprehensive score has basically maintained rapid growth in recent years, and has consistently exceeded India's score. In recent years, India's food system comprehensive score has always maintained an upward trend, indicating that the efficiency of the food system is continuously improving.

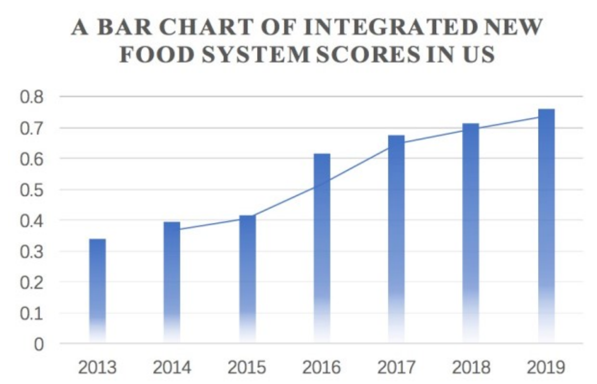


On the whole, there is still a big gap between the comprehensive scores of food systems in developing countries and developed countries, but the gap is shrinking, indicating that the efficiency and stability of the global food system are continuously improving, but there is still an unbalanced development.

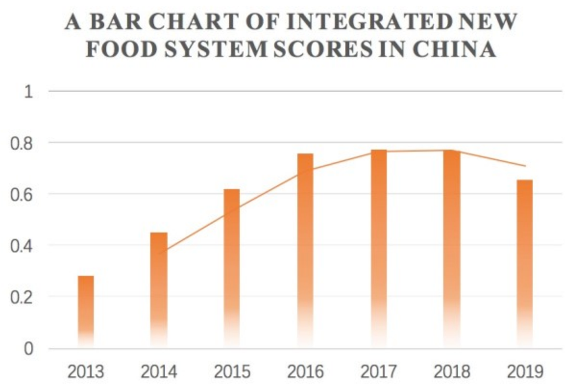
5.5.3 4S evaluation results

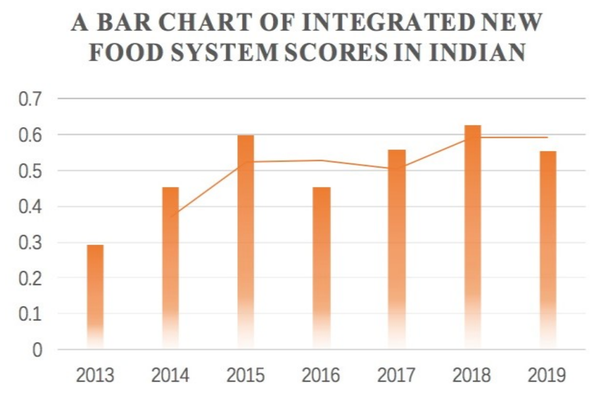
According to the optimized system, we calculated and compared the comprehensive scores of food systems in developed and developing countries under the new system.
Developed countries:





Compared with CFS, Japan's food system comprehensive score has shown a downward trend in recent years under the new system, while the United States has continued to rise. The new system more clearly exposes the stability and sustainable development problems of developed countries.
Developing countries:



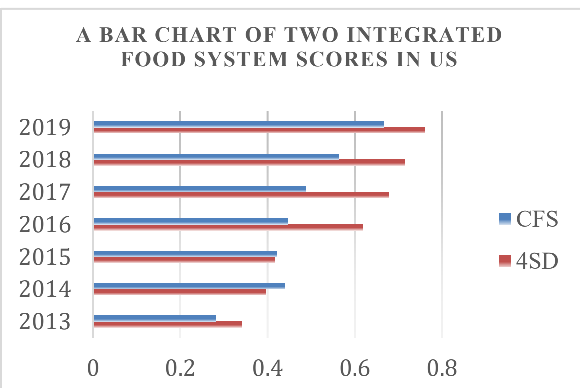


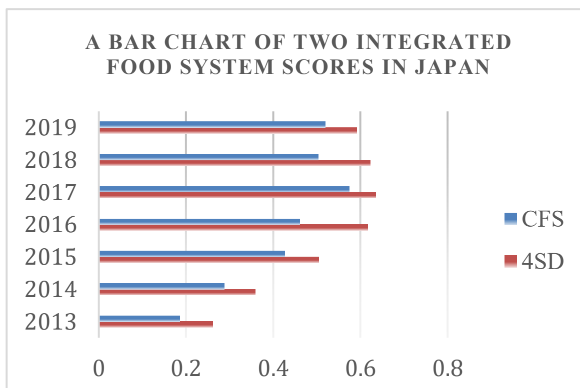
Under the new system, the overall food system scores of developing countries are more volatile than those of developed countries, especially in developing countries such as India that are underdeveloped, where stability and sustainable development capabilities are still weak.

5.5.4 Analysis of optimization results

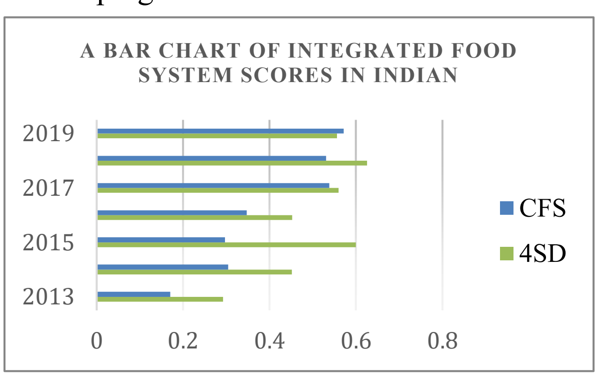
We compare the two models in developed and developing countries to evaluate the degree of influence of the optimized new model on the food systems of developing and developed countries:

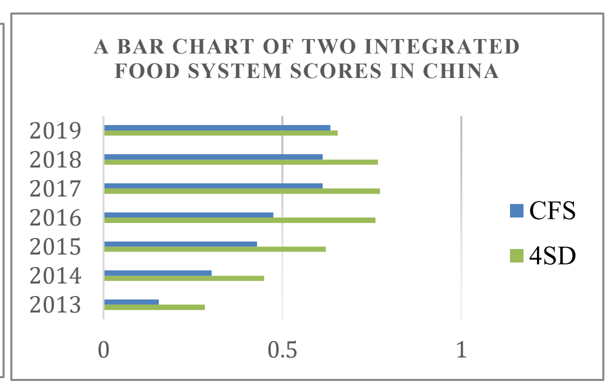
Developed countries:





Developing countries:

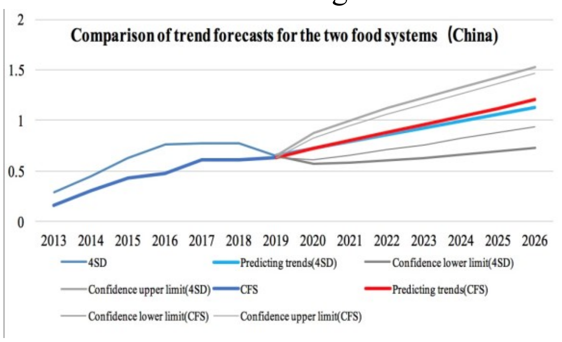


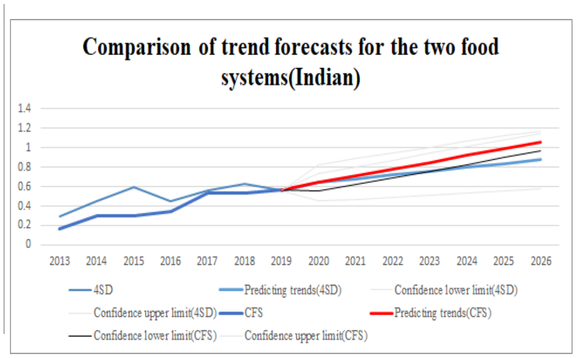


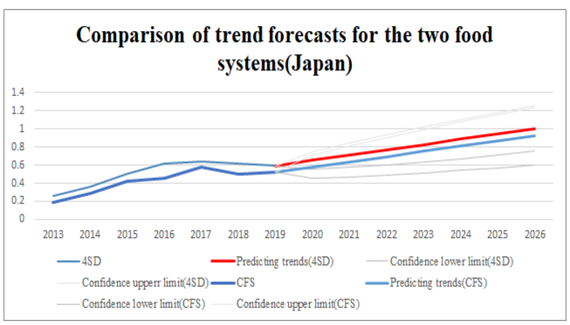
We calculated the comprehensive food system scores of developing countries and developed countries under CFS and 4SD respectively, and made the results in the form of charts.
After comparison, we found that the new system has a greater impact on developing countries. It may be because developing countries have neglected to pursue the sustainability and fairness of the food system in order to pursue the speed and efficiency of food system development.

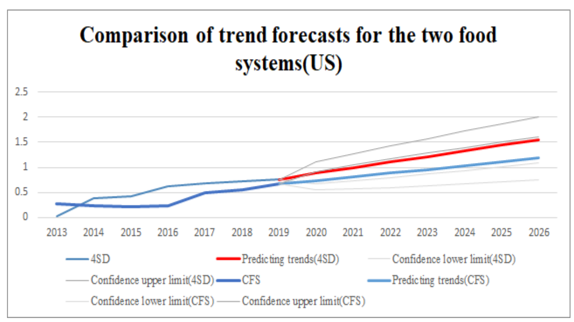
5.5.5 Time of forecast change

We substituted the standardized data of the four countries into the four models and compared and predicted the trends of the CFS and 4SD models of the four countries through linear regression, and obtained the following results:









By comparing the trends in the two models between developed and developing countries, we find that the predicted change time of developed countries is earlier than that of developing countries. It shows that the development of food systems in developed countries is relatively complete, stable and sustainable, and governments in developed countries pay more attention to the comprehensive development of food systems.

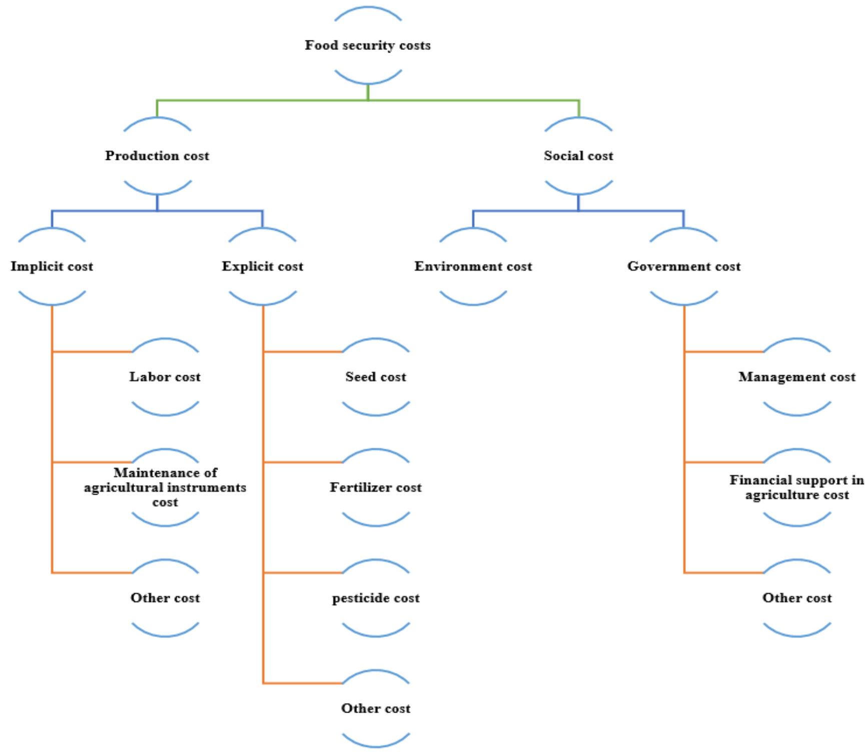
6 Cost benefit analysis

In the food system, the cost function is $C = C(d)$ and the income function is $\mathrm{P} = P(d)$. After the model changes, we analyze the impact on the cost function and the income function.

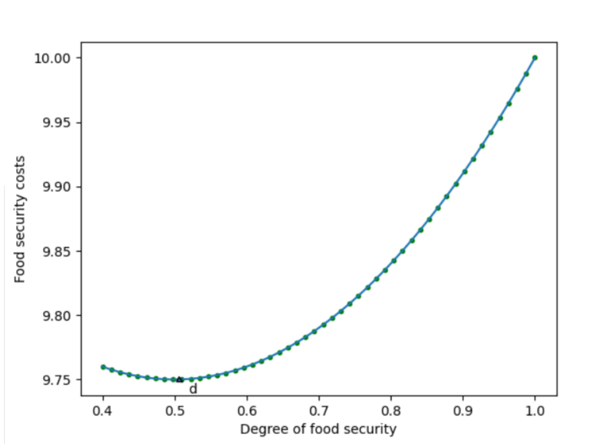
6.1 Cost changes caused by model changes

6.1.1 The cost structure of the food system

The cost in CFS is mainly food security cost, and food security cost mainly includes production cost and social cost. The cost of food production includes two parts: explicit cost and hidden cost. The main measurement standard is whether it is directly visible in food production. The social cost of food includes the cost borne by the government such as investment and subsidies and the cost borne by the environment, and the destruction and pollution of land and water resources caused by food production.



6.1.2 The cost curve of food security

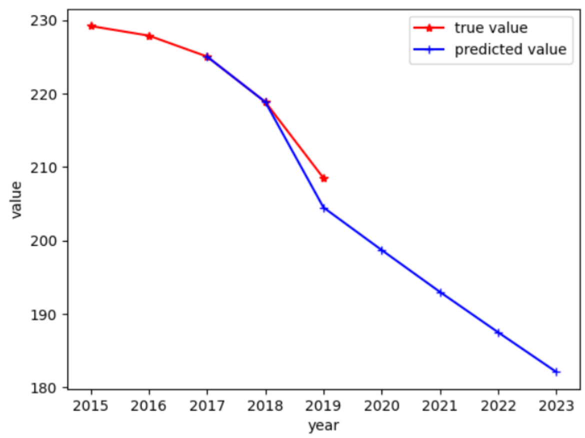


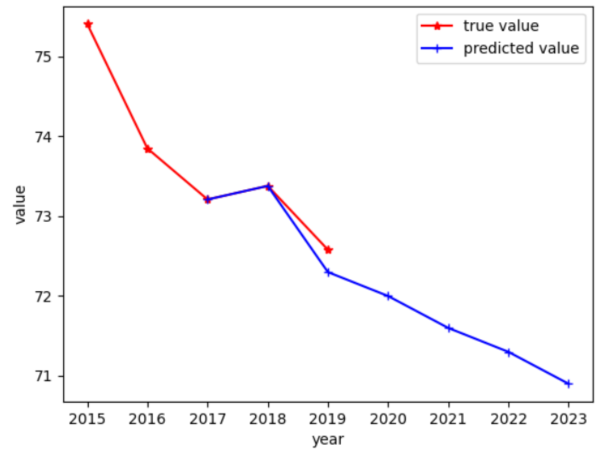
It can be seen from the figure that the cost of food security increases with the continuous improvement of food security, and the food security cost curve is a line extending to the upper right. The social losses caused by food insecurity will improve with the improvement of the food supply situation, but with the increase in production costs, the cost of food security will slowly increase. When food security reaches the desired level of food security d, the input to food security will become invalid input, and the marginal cost will continue to increase.[12]

6.1.3 The impact of model changes on costs

1) Variable reflection
Among the 17 variables of the model, the cost changes caused by the adjustment of the model will be shown through indicators: Food price（D_2）,sub-variable Rail lines density(x_7) of Availability（D_3）, sub-variable Fertilizer usage(x_{15}) of Environmental discharge pressure（SUS_1）, sub-variable Percentage of arable land equipped with irrigation facilities(x_{16}) of Cultivated land resource (SUS_2) and Fiscal expenditure(x_{17}) .
Therefore, we performed linear regressions on these variables and costs in developed and developing countries respectively, and obtained the impact of model changes on the cost of the food system.

2) The impact and prediction of model changes on the cost of food systems in different countries



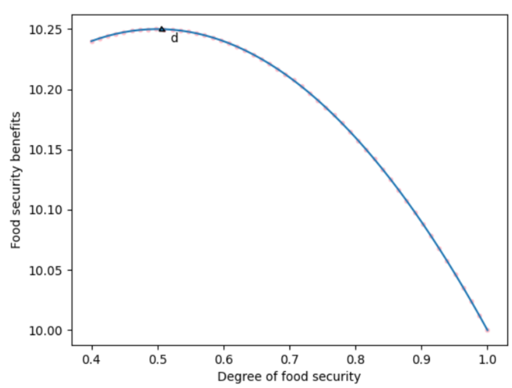


6.2 Changes in revenue brought about by model changes

6.2.1 The income structure of the food system

The benefits of the food system refer to the increase in social and economic development and residents' welfare brought about by ensuring food security, sustained and efficient development. The benefits of CFS mainly include economic benefits and social benefits. Economic benefits include the increase in farmers' income brought about by the improvement of the grain system, the development of the grain industry and its related industries, and the improvement of the national economy. Social benefits refer to the improvement of the social welfare level and the stability of people's lives brought about by the model improvement.

6.2.2 The benefits curve of food security



Changes in food security benefits include three stages. When the degree of food security is low, increasing food supply will produce obvious food security benefits. As food security further improves, the benefits continue to increase. When the degree of food security is d, the total benefit of food security reaches the maximum. Later, when the food supply increased again, there was a phenomenon of food surplus, which instead led to a decline in the total income of food security.

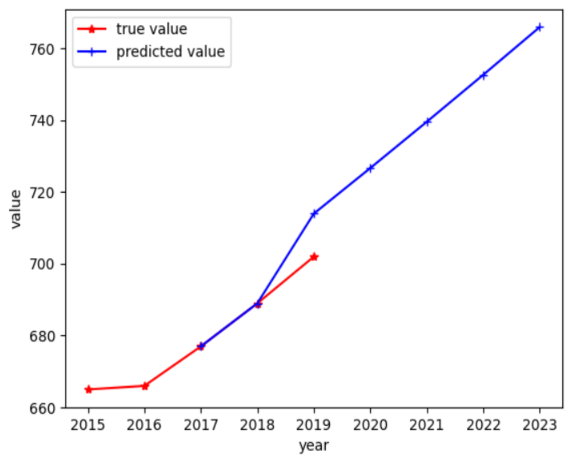
6.2.3 The impact of model changes on revenue

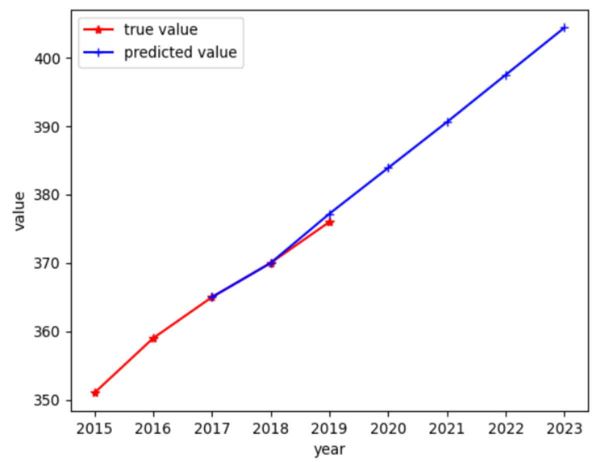
1) Variable reflection

The changes in revenue brought about by model adjustments will be reflected by Per capita grain output（x_1）, Dietary energy supply adequacy (x_2),Dietary energy supply used in the estimation of prevalence of undernourishment(x_3), GDP per capita (x_4), Average supply of protein of animal origin(x_8), Incidence of malnutrition(x_9), Prevalence of severe food insecurity in the total population(x_{10}).

Therefore, similar to the cost analysis method, we respectively performed linear regressions on these variables and the benefits of the food system in developed and developing countries, and obtained the impact of model changes on the benefits of the food system.

2) The impact and prediction of model changes on the income of different countries' food systems.





By comparing the two figures, it can be seen that the optimized model (4SD) makes the income of developed countries rise much faster than that of developing countries. It can be seen that the effect of 4SD on the income increase of developed countries is higher than that of developing countries. The combination of the prediction curves shows that 4SD has a better optimization effect on developed countries.

7 The food system under the impact of the epidemic

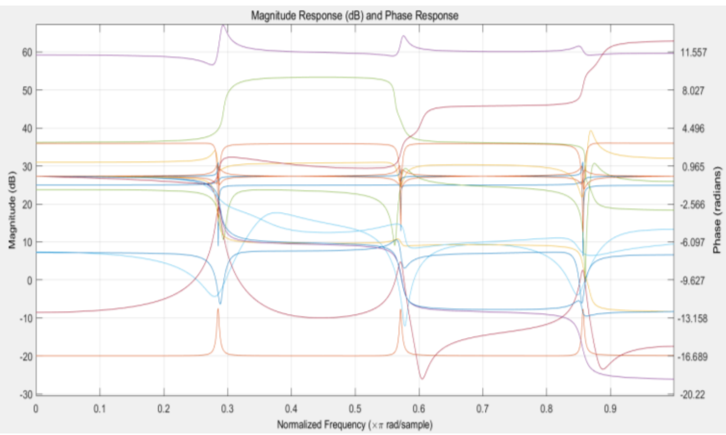
7.1 The current situation of the epidemic

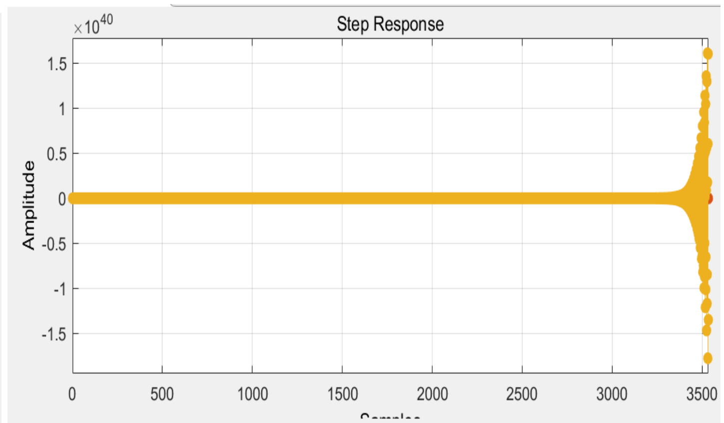
The COVID-19, a global pandemic, which show the problems and pressure on getting food access, completely reveals the instability of the world food system. Blockade has a direct impact on food chain and led to panic of buying and empty shelves in supermarkets. Prices of food in the market increase. This also lead to changes in the production process that farmers' decision changes when they grow crops.

Besides, government take some measures to respond to the pandemic. China assured the sucient nourishment of the local population by releasing at least 300,000 tons of pork reserves [13]. Italy implemented relevant laws to force food makers to keep reserves for emergency purposes [14]. This practice resulted in a moderate reduction of agricultural production.
As an exogenous variable that has a huge impact on the food system, we found the latest data after the outbreak of the 2019 epidemic through FAO to analyze the current status of the global food system. Based on the impact of the epidemic on the food system, we use grey prediction to predict the impact of the epidemic on the future world food system.

7.2 Forecast the future development of the food system

We use GM(1,1) Model to calculate the predictive value, the result as follows：

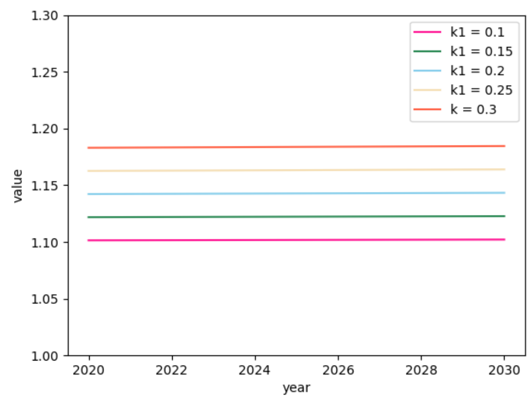




According to the model, the epidemic has a relatively large impact on the stability of the food system, and it is difficult to return to a normal level in the short term. It is expected that it will take about 7 years to fully return to the level before the epidemic.

8 Sensitivity analysis

In the calculation of the annual global food system comprehensive score, we used the sub-index with the highest weight in the optimized food system（4SD） and the largest contribution to the stability of 4SD, namely the incidence of nutrition, as the final result of the change in the annual food system score, with the weight K_1 =0.2, to analyze the sensitivity of K_1.
Set k_1 = 0.1, 0.15, 0.2, 0.25, 0.3 to get:



As we can see from the figure, when K_1 value changes, the trend of new comprehensive scores does not change, indicating that our model is stable.

9 Strengths and Weaknesses

9.1 Strengths

Our model inherits the advantages of BWM (BWM, Best Worst Method) and EWM(EWM, Entropy Weight Method).

When weighing the indicators, we utilize weight average method combining the BWM (BWM, Best Worst Method) with (EWM, Entropy Weight Mothed). To some extent, this method covers the shortages that indicator weight under EWM vary with samples and is even overwhelmingly dependent on sam-ples. Moreover, this method reduces subjectivity of BWM.

Genetic algorithm is more accurate to solve optimization problems.

We use the genetic algorithm to solve the optimization model, it directly uses the objective function value as the search information, and it only uses the fitness function value to measure the degree of excellence of individuals, which has a high advantage in solving the programming problem.

Our model is more stable through validation.

Introducing factors related to the epidemic, Our model is much more resistant to external contingencies, especially when global natural disasters have affected the food systems of various countries.

9.2 Weakness

Indicators are not comprehensive.

Other factors, like the type of grain each country exports, were not taken into account when setting the system, so it's not accurate in terms of profitability.

The prediction model has little data.

Due to the limitation of data, we consider the data of a very short time (6 years) when making the prediction model, which reduces the accuracy.

10 Conclusion

On the basis of the basic indicator system, we introduced fairness and sustainability subsystems, and established a 4SD model. We analyzed the differences between developing and developed countries under the new system and CFS, and predicted future trends and changes. time. Establish a cost-benefit model, analyze the cost-benefit changes brought about by model changes, and analyze the degree of response of developed and developing countries to model changes. It is found that developing countries are more sensitive to model changes. Finally, through sensitivity analysis, we can see that our model is stable.

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