Optimizing the distribution of food based on the vogel method

Haoyan Chen[1,*], *Jiarui* Zheng[2], and *Linjiaming* Lao[2]

[1]School of Statistic, Capital University of Economics and Business, Beijing, China
[2]School of Finance, Capital University of Economics and Business, Beijing, China

Abstract. Currently, numerous people still suffer from hungry and food insecurity. To solve the problem of production and distribution of food, we firstly set up a quantitative examination on food system from four dimensions, including equitability, efficiency, stability, and sustainability. As we choose 2 to 4 indexes for each dimension, we applied entropy weight method to decide the weight of each index. Secondly, we used BP neural network by MATLAB to simulate the rising trend of population based on the data of population in recent years, and predicted the population until 2030, which is about 8.5 million. In the same way, we forecast that food yield will maintain at 1.63*109 litres approximately till 2030 in the whole world. With certain assumptions, we set a model about Transportation Problem, which help us optimize the food transportation system at present. We use the Vogel method to calculate the results and chose 9 ports for exporting countries and 10 ports for importing countries. After that, we calculate the minimum costs of transportation all over the world is $4979628112343. At the end of our paper, we make sensitively analysis, the result of which proves that our model has a good stability.

Keywords: Food insecurity, Efficiency, Trading, Sustainability.

1 Introduction

With the increasing population of the world, the trend of supply and demand for food in the world is also changing. The amount of food production, from about 1.95 billion tons in 1990, has risen steadily over the past 30 years, reaching 2,744 million tons by 2020. Although food production increases year by year, a third of the world's food is wasted each year. As a result, 820 million people worldwide are still suffering from hunger. The new system is dedicated to the rational distribution of food to people in all region. In short, the system determines the rational arrangement of transport routes to reduce transport costs and ensures equity, efficiency and profitability.

Severe food insecurity affects one quarter of the world population, and it has been increasing over the past six years. Prices are expected to rise in response to declining food production and associated trends such as increasingly expensive petroleum (used for agricultural inputs such as pesticides and fertilizers). Food safety risk communication (FSRC)

* Corresponding author: estellachen0422@163.com

is a very complex two-way system. Nowadays, a novel system dynamics (SD) model involving five communication organizations and 36 controlling parameters is established to investigate the interactive relationships among them.

2 Estimate and forecast of a food system

2.1 Estimate of a food system

We believe that a good food system should be efficient, equitable and sustainable in time and space. By reviewing the literature and analyzing the relevant analysis, we evaluate the food system as comprehensively as possible using four dimensions, namely efficiency, equity, stability and sustainability.

2.1.1 Four dimensions of estimate

1. Efficiency : The efficiency of the food system is roughly divided into two parts, internal high and external efficiency. First, we use cereal production (kg per hectare) from around the world as one of our metrics. We also consider the prevalence of agricultural tools, measuring the number of large agricultural tools per 100 square kilometers. Second, for external trade efficiency, consider measuring the profitability and time-ability of trade. For profitability, the net inflow of agricultural trade in each country is used as a reference index. For timeliness, we take the mid-value of the import turnaround time in days.
2. Stability : This depends primarily on the stability of the labor force and arable land. For the labor force, we use the percentage of the population aged 15-64 relative to the total population, and for arable land, we use the arable land area per capita (hectares).
3. Equability : We use the percentage of the system that gets more than per capita cereal consumption (kg) per year as one of the evaluation indicators. We use the rate of malnutrition as the original indicator of this. Food should have good accessand the internationally common indicator is the Gini index.
4. Sustainability : For climate damage, on the one hand, carbon emissions come from food transportation, on the other hand, waste in the production process. We measure the carbon footprint of agriculture by its per capita CO2 emissions. In addition, chemical pollution is also an important factor. Based on this, we take into account the amount of fertilizer per hectare of agricultural land consumed.

2.1.2 Data prepossessing

All the data below are from the World Bank database official. The basic idea of applying the **entropy weight method** processes each data separately and normalizes it.

• For **positive indicators**, such as Grain Products (index per hectare), Numbers of Large Agricultural Machinery (per 100 square meters), and so on, apply the following formula:

$$\hat{\alpha}_{ij} = \frac{a_{ij} - Min(\alpha_j)}{Max(\alpha_j) - Min(\alpha_j)}$$

• For **negative indicators**, such as Turnaround Time Medium (days), Under nutrition Rate, and Gini Index, apply the following formula:

$$\hat{\alpha}_{ij} = \frac{Max(\alpha_j) - a_{ij}}{Max(\alpha_j) - Min(\alpha_j)}$$

where, $\hat{a}_{ij}$ is the adjusted i-th elements of indicator j, α_{ij} is the i-th factor of indicator j, a_j is the assemblage of all the elements indicator j. Both i & j are belongs to positive integer.

2.1.3 Calculate the weights

Calculating by the substances of data, the entropy weight method is quite subjective and reasonable. After normalization all the data, we can calculate the information entropy of each indicators via the following formulae:

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

The information entropy of indicator j is recognized as E_j and used to calculate weights:

$$w_j = \frac{1- E_j}{1-\sum E_j}$$

2.1.4 Result

The final weights are as the following table:

Primary targets	**weight**	**Secondary targets**	**weight**
Efficiency	0.251099294	Grain Products (kilogram per hectare)	0.27547075
		Numbers of Large Agricultural Machinery (per 100 square kilometer)	0.228431185
		Importing Turnaround Time (days)	0.212298707
		Net Trading Revenue (dollars per capita)	0.283799359
Stability	0.261841555	Labor Rate	0.491280708
		Area Under Cultivation (hectare per capita)	0.508719292
Equitability	0.251099294	Undernutrition Rate	0.513072365
		Gini Index	0.486927635
Sustainability	0.2605475	Carbon dioxide (metric ton per capita)	0.461203642
		chemical fertilizer applied (kilogram per hectare)	0.538796358

The current worldwide food system marks 0.7726967 (positive index, the highest score is 1, the lowest score is 0).

2.2 Forecast of the population and food yield

2.2.1 The principle of BP neural network

- Input: $net = x1w1 + x2w2+\ldots+xnwn$
- Output: $y = f(net) = 1/(1 + e - net)$

2.2.2 Result

Basing on the world population from 1951 to 2019, we made regression via BP neural network by

MATLAB. The result are as follow.

YEAR	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
POPULATION	7.795 E+09	7. 88 E+09	7. 95 E+09	8. 08 E+09	8. 11 E+09	8. 18 E+09	8. 25 E+09	8. 31 E+09	8. 38 E+09	8. 49 E+09

2.3 Forecast of global food yield

Using neural network to predict the global food yield till 2030 by MATLAB. The result are as follow.

year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
yield /liter	1.64 E+09	1.66 E+09	1.62 E+09	1.66 E+09	1.64 E+09	1.61 E+09	1.60 E+09	1.64 E+09	1.64 E+09	1.63 E+09	1.61 E+09

To simplified, we assume that the global food yield will level off at the average yield from 2020 to 2030, that is 1.63E+09 liters.

3 Optimization of food transportation

3.1 Hypothesis

3.1.1 Homogeneity foods

We assume that the food people eat all over the world is the same and it is called **standardized food (SF)**. All of the standardized foods share the same quality, which means there are no difference between any two portions.

3.1.2 One-way trade

In our model, a country’s substance in the farm trade sphere is single. Thus, there is only one kind of food in the farm market and we calculate the net input or output.

We have exporting countries whose food can not only fully meet the needs of the local population, but also have surplus food storage and **importing countries** whose food cannot meet the needs of its population and needs to be imported from other countries to meet domestic demand. Some countries are self-sufficient without surplus food, those countries will keep their current farm comedies.

3.1.3 Fully participation

Importing countries are able and willing to spend money to buy food from other countrieswhile exporting countries are willing to sell surplus food to food-strapped countries without reservation.

3.1.4 Stable location and transportation system

The optimal distribution of transportation routes will remain unchanged. We implement the new program for the long term. Only after time has passed, such a scheme can stabilize the surrounding environment.

3.2 Definition of importing and exporting countries

We apply the Pareto Improvement and propose new solutions for food distribution. Pareto Improvement mainly determines how to improve social welfare. In this section we mainly focus on food distribution.

We assume that the distribution of the world's population remains constant and the population of each country is multiplied by a fixed ratio of the total population of the world.

At the same time, the arable land area remains unchanged, and the grain yield is linearly related to the arable land area. Each country's current year's grain production is a fixed proportion multiplied by the world's grain production for that year.

3.2.1 Model building

$$\begin{cases} GS_i(x) = TG_i(x) - (1+\alpha) * GSW_{pc} * P_i(x) \\ TG_i(x) = GPR(x) * TS_i \\ SR_i(x) = \frac{TG_{i(x)}}{TS_{i(x)}} \end{cases}$$

Mark	Meaning
$GS_i(x)$	the grain surplus in the country NO.i in year x
$TG_i(x)$	total grains product in the country NO.i in year
GSW_{pc}	grains security weight per capita, which is 400 kilograms
$P_i(x)$	the population in the country NO.i in year x
$GPR(x)$	the grains production rates in year x
TS_i	Total space area under grains cultivation in the country NO.i
$SR_i(x)$	Surplus rate of grains in the country NO.i in year x

3.3 Food trading system

1. **There is only one mode of transportation:** we default mode of transport is sea transport.
2. **The shortest path assumption:** we default that exporting countries can export food that meets the needs of the importing country.
3. **The same costs of transportation:** we default that the haulage is only decided by the distance among exporting and importing countries. What's more, there is no connection between the quality of food and the haulage. The transportation costs of two bording countries are zero.
4. **The preservation equipment is complete and good**: the food can be transported to the importing country and are fresh and safe. We assume that storage equipment is good and advanced.

Specific process: After we analyze the food production all over the world, we found 37 exporting countries and 27 importing countries, excluding importing countries and exporting countries that are bordered. So, we build a model by Transportation Problem.

In order to optimize the route better, we chose 9 exporting harbors and 10 importing harbors. Those harbors include all the 64 countries. We use the Vogel method to solve the optimal route.

Build the model: We have A_i for the exporting country (i=1,2,3,......,9) and B_j for the importing country (j=1,2..., 10). a_i (i=1,2...,9) represents the volume of food exports from nine exporting countries, b_j (j=1,2,......,10) represents the import volume of 10 importing countries, x_{ij} and represents the volume of food transported from the exporting country to the importing country in tons.

$$minz = \sum_{i=1}^{9}\sum_{j=1}^{10} x_{ij}$$

$$\begin{cases} \sum_{j=1}^{10} x_{ij} = a_i (i = 1,2, \dots \dots ,9) \\ \sum_{i=1}^{9} x_{ij} = b_j \;(j = 1,2, \dots \dots ,10) \\ x_{ij} \geq 0 \;(i = 1,2 \dots ,9; j = 1,2, \dots 10) \end{cases}$$

At the same time, we assume that the shipping cost is 1 \$/km, then $C_{ij} = 1 \times s_{ij}$ is the total haulage.

The export ports are marked with pink circles: Hamburg Port, Arkhangelsk Port, Bangkok Port, Turkey, Peru, Vancouver Port, New York Harbor, Sierra Leone, Tanzania.

Importing port	*The needs of food (ton)*	*Exporting port*	*Distance*	*Haulage ($)*
Rotterdam	*26745849*	*Port of Hamburg*	*414km*	*11072781519*
Port of Singapore	*76385631*	*Port of Bangkok*	*1432km*	*109384223943*
Port of Tokyo	*303325709*	*Arkhangelsk*	*6876km*	*2085667572179*
Port of Dubai	*138047322*	*Sierra Leone*	*4818km*	*665111998784*
Port of Colombo	*231426939*	*Arkhangelsk*	*7107km*	*1644751255407*
Alexandria	*6248210*	*Port of Hamburg*	*3124km*	*19519406759*
Gabon's port	*47080113*	*Tanzania*	*2984km*	*140487057542*
Madagascar	*26594750*	*Tanzania*	*1906km*	*50689593189*
Panama	*53636154*	*New York Harbor*	*3591km*	*192607429548*
Ecuador	*13342944*	*New York Harbor*	*4522km*	*60336793474*

Import ports are marked with black circles: Port of Rotterdam, Port of Singapore, Port of Tokyo, Port of Dubai, Port Colombo, Port Alexandria, Port Gabon, Madagascar, Panama, Ecuador.

So, $minz$= *4979628112343 $*

4 Sensitivity analysis

For coefficient of equity and sustainability, we assume that there will be a volatility from +10% to -10%. We set volatility= +10%, +5%, -5%, -10% respectively and get the result here:

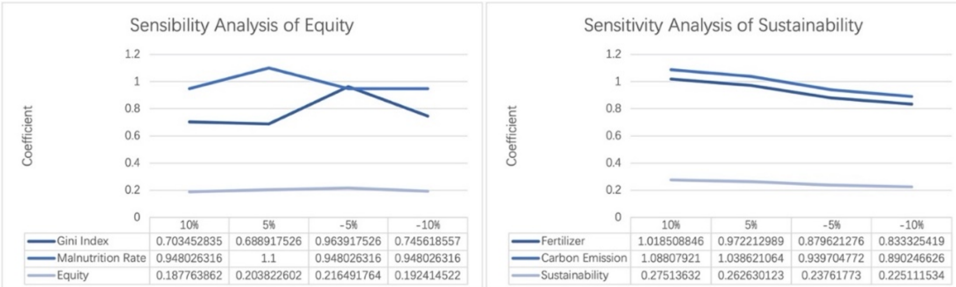

Fig. 1 &2: Sensitivity analysis of sustainability and equity.

5 Conclusion

Food is the most important part of life. In order to promise that there is no starvation, people would corporate with each other. Our food supply system model can strengthen the cohesion of the global village. Therefore, we can jointly develop green science and technology and pursue mutually beneficial situation.

References

1. Sze S M 1969 *Physics of Semiconductor Devices* (New York: Wiley–Interscience)
2. Dorman L I 1975 *Variations of Galactic Cosmic Rays* (Moscow: Moscow State University Press) p 103
3. Caplar R and Kulisic P 1973 *Proc. Int. Conf. on Nuclear Physics (Munich)* vol 1 (Amsterdam: North-Holland/American Elsevier) p 517
4. Szytula A and Leciejewicz J 1989 *Handbook on the Physics and Chemistry of Rare Earths* vol 12, ed K A Gschneidner Jr and L Erwin (Amsterdam: Elsevier) p 133
5. Kuhn T 1998 Density matrix theory of coherent ultrafast dynamics *Theory of Transport Properties of Semiconductor Nanostructures (Electronic Materials* vol 4*)* ed E Schöll (London: Chapman and Hall) chapter 6 pp 173–214
6. Shah Fahad, Osman Sonmez, Shah Saud, et al. Developing Climate Resilient Crops:Improving Global Food Security and Safety. 2021.
7. Liang Lang. A study of system dynamics modelling and optimization for food safety risk communication in China. 2021, 60(1):1917-1927.
8. Marc F. Müller, et al."Impact of transnational land acquisitions on local food security and dietary diversity." Proceedings of the National Academy of Sciences 118.4(2021)