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Research on the efficiency optimization of food reserve under the complementary reserve mode of government and enterprise in China

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Food reserve is the cornerstone of national strategic security. China strives to build a complementary reserve system between government and enterprises, and how to improve the efficiency of food reserves is a matter of great concern to the government and society. Based on the analysis of the connotation of food reserve efficiency, this paper constructs the revenue function and the cost function of food reserve in an emergency and uses the cost–benefit method to explore the best ratio of government reserve, corporate social responsibility reserve, and commercial inventory when maximizing the efficiency of food reserve. This ratio is closely related to the total food reserve, the scale of supply interruption, the reserve cost of food stored by enterprises, and the government's subsidy cost for the social responsibility reserve. The unit subsidy cost of government to social responsibility reserve is inversely proportional to the proportion of corporate social responsibility reserve to corporate reserve. Doing a good job in the social responsibility management of food enterprises is an effective way to improve the efficiency of food reserves. To expand the scale of social responsibility reserves and realize "storing food in enterprises," the subsidies given by the government for corporate social responsibility reserves should not be too high. Taking food social responsibility reserve as an important part of corporate social responsibility, it's the key to promoting enterprises to actively undertake food social responsibility reserves. The conclusion of this paper provides a theoretical basis and decision-making reference for how to improve the efficiency of food reserves.

KEYWORDS

food reserve efficiency, government reserve, enterprise reserve, corporate social responsibility reserve, social welfare

1 Introduction

Food reserves are closely related to people's livelihood security, which is not only the material basis for ensuring people's livelihood security but also the strategic cornerstone for maintaining national stability. For national food security, a certain amount of food reserves is a strong backing for people's livelihood. Food reserves can smooth out the fluctuation of food prices and stabilize market prices through an effective throughput rotation mechanism, thus playing the role of "reservoir" (Wang, 2022a,b). Most governments maintain the strong view that adequate emergency food reserves can buffer national food price shocks and shocks from

disasters and climate change (Lassa et al., 2019). Extreme climate events increase the risk of global food insecurity and adaptation needs (Hasegawa et al., 2021). In this kind of emergency, the role of food reserves as a "ballast stone" has become increasingly prominent. From the perspective of the reserve subject, China's food reserves mainly include central reserves, local reserves, enterprise reserves, new agricultural reserves, and household reserves. The Opinions on Reforming and Perfecting the System and Mechanism to Strengthen the Safety Management of Food Reserves, which was considered and adopted at the eighth meeting of the Central Committee for Deep Reform in 2019, pointed out that it is necessary to promote the complementarity between central and local reserves, government reserves and enterprise reserves, and strive to build a government-enterprise complementary food reserve system integrating central reserves, local reserves, and social responsibility reserves.

From the aspect of reserve mode, food reserve can be divided into static reserve and dynamic reserve. Among them, the central and local reserves belong to the government reserves, which are directly controlled by the state, and the reserves are controlled within a certain range, which belong to static reserves; Enterprise reserves include corporate social responsibility reserves and corporate commercial inventories, which belong to dynamic reserves. At present, China's food reserves are mainly government reserves, and the proportion of food social responsibility reserves in the overall national food reserves is very small, and the food social responsibility reserves have just begun to be expanded on a pilot basis. How to establish and improve the social responsibility reserve management system, store food in enterprises, and encourage enterprises to do a good job in social responsibility reserves is an urgent practical problem to be solved. In the dynamic reserve, the enterprise commercial inventory is the turnover inventory of the enterprise, to ensure the normal and better operation of its business activities. Corporate social responsibility reserve is the inventory established by food processing enterprises according to the clear social responsibility of laws and regulations, and it is used according to legal procedures. The food right of social responsibility reserve belongs to the enterprise, and the right to use it belongs to the government. The most obvious difference from commercial inventory is that it does not pursue profit maximization, but takes fulfilling social responsibility and contributing to social development as the benchmark, and some local governments give subsidies to various factors such as the operation of comprehensive enterprises, reputation effect and the degree of complementarity with government reserves. It should be noted that there are also views that corporate social responsibility reserves are spontaneous, such as supermarkets, stores, and farmers' reserves, and should not enjoy government subsidies, which is a voluntary behavior of enterprises. The corporate social responsibility reserve discussed in this paper is the reserve behavior of enterprises enjoying certain government subsidies.

At present, the lack of efficiency and fairness has caused great pressure on food reserves. Wang (2022a,b) pointed out that there are some problems in China's food reserves, such as simple reserve system level, high reserve cost, low management efficiency, and inadequate function of government reserves. Qian et al. (2020) have found that there is a structural imbalance in the reserve varieties and processing and transformation capacity of the government food reserve system, and it is difficult to connect logistics facilities across regions, which hinders the improvement of use efficiency and the lack of top-level design in the management system. The scheduling and use of government reserves have to go through layers of examination approval and control, and there are problems such as insensitive market response and inflexible calls. Therefore, Cao et al. (2022) believe that China's food reserve system needs to be optimized and improved in terms of objectives, functions, structure, layout, system, and mechanism. Corporate social responsibility reserve and commercial inventory can make up for this kind of defect to some extent. On the one hand, corporate social responsibility reserve has a high degree of freedom, which is an important force in regulating market supply and demand. It can effectively connect the reserve with the market, enhance the response and response to market fluctuations, and complement the government reserve. On the other hand, the enterprise's social responsibility reserve is also a positive response to the call of the country for the pilot project of social responsibility reserve. Taking the enterprise's commercial inventory as the government's revolving food can not only reduce the pressure of the government's capital cost but also improve the utilization rate of the enterprise's commercial inventory so that the enterprise can fulfill its social responsibility and improve its reputation. The above-mentioned reserve models can complement each other in three aspects: reserve scale, reserve structure, and reserve layout, and need effective coordination in case of emergency. These reserves can engage in markets according to clear and transparent regulations and within defined price ranges to facilitate market functioning (Iftekhar et al., 2021). In general, the cost of corporate social responsibility reserve is lower than that of the government, but it does not mean that the larger the scale of corporate social responsibility reserve, the better. With the continuous expansion of the scale of corporate social responsibility reserve, it will crowd out the operating resources of enterprises and the cost of corporate social responsibility reserve will continue to increase. Expanding the scale of food reserves can effectively improve the level of food emergency support, but the larger the food reserves, the higher the cost of food reserves. Therefore, the more food reserves, the better. Government reserves, corporate social responsibility reserves, and corporate commercial inventories need to be effectively coordinated to maximize the efficiency of food reserves, so as to enhance the ability and resilience of China's food reserves to cope with major risks and challenges. How to do a good job in the management of the food social responsibility reserve and further increase the comprehensive strength of the national food reserve is a realistic problem that governments at all levels and society are very concerned about.

Food production and supply have certain seasonality, so it is impossible to expand production in the short term. Even if there are food imports, it is impossible to rapidly increase the total social supply of a country or region in the short term. Because the duration of the emergency state is mostly short, this paper takes the maximization of the efficiency of food reserves as the starting point, explores the best balance between government reserves, social responsibility reserves, and commercial stocks on the premise that the total food supply of the whole society will not change in an emergency state, with a view to effectively improving the efficiency of food reserves, stabilizing the fluctuation of food prices, improving the corporate social responsibility reserve system, effectively coordinating government reserves, corporate social responsibility reserves, and commercial

stocks, and improving the market sensitivity and flexibility of food delivery in an emergency.

2 Literature review

2.1 Research on government reserve

In terms of government reserves, the central reserve is the floor force to deal with major emergencies, while the local reserves pay more attention to emergency protection and give consideration to market regulation. In order to optimize the regional distribution of government food reserves, Gao and Hu (2021) suggested that the distribution path of government food reserves should be improved from four aspects: strengthening macro-control, strengthening capital guarantee in production and marketing areas, coordinating the interests of production and marketing areas and ensuring food circulation. Pu and Zheng (2020) proposed to determine the reasonable food reserve scale, moderately destock, separate the multiple policy objectives undertaken by purchasing and storage, improve agricultural support policies, encourage food reserves for farmers and enterprises, reduce the burden on national reserves, and improve food security. Wu and Gan (2019) pointed out that the size of permanent residents, the ratio of urban population to rural population, food output, and traffic conditions will have a significant impact on the local government's willingness to reserve food. The first three factors have a more significant positive impact with the increase of the proportion, and the less convenient the traffic is, the less willing the local government is to preserve food.

2.2 Research on enterprise's commercial inventory and farmers' household food storage

In the research of enterprise commercial inventory and farmers' household food storage, enterprise commercial inventory and household reserve belong to social reserve. Liu J. et al. (2022) proposed that local food reserve enterprises need to adapt to the changes in the market, improve their management ability and management level, realize the complementary functions of government reserve, corporate responsibility reserve, and commercial inventory, and enhance their own advantages. Zeng (2021) discussed the construction of an effective internal control mechanism for food reserve enterprises and suggested that enterprises should constantly strive for perfection in the quality of internal management and the ability of risk prevention, so as to better consolidate the goal of ensuring food security and realize the double income of social and economic benefits. Weng (2021) believes that rural reserves, as an important supplement to central and local reserves, also help farmers to further resist risks, positively promote farmers' initiative in the market, and then actively stabilize the market supply and demand of food and smooth the price of food and oil. Wei and Shi (2020) analyzed the situation of farmers' families, and found that when farmers were storing food, their storage scale and storage utilization time decreased significantly with the passage of time, farmers' dependence on the market increased, and family food security changed from "self-protection" to "social or market protection."

2.3 Research on corporate social responsibility reserve

In terms of corporate social responsibility reserve, Ding (2023) believes that to practice the big food concept, it is necessary to continuously optimize the local food reserve, and at the same time, actively explore the establishment of corporate social responsibility reserve to ensure the market supply, so that the market will not be out of stock, and the market will be stable. Fang et al. (2022) put forward that to ensure the effective supply of food and important agricultural products, it is necessary to accelerate the promotion of social responsibility reserves of food processing enterprises, promote the synergy and complementarity of central reserves, local reserves, and social responsibility reserves, and consolidate the safety bottom line of domestic food reserves. Wu (2023) and Zhao (2023) started from the government documents in Guangxi, and Henan, respectively, and proposed that processing enterprises above designated size should be guided to establish social responsibility reserves in an orderly manner, and food management enterprises should maintain reasonable commercial stocks, give full play to the role of throughput regulation, and form a diversified food reserve system with complementary functions, clear rights and responsibilities, and high efficiency. In addition to advocating food as the object of social responsibility reserve, Liu W. et al. (2022) also advocated the establishment of a coal reserve system with the main thermal power plants, coal key, and storage and transportation enterprises as the main body, supplemented by local government reserves. Wang C. et al. (2023) proposed to establish and improve a hierarchical reserve system that organically combines and complements government reserves, corporate social responsibility reserves, and production and operation inventories to enhance the oil and gas reserve capacity. There are few literatures about the study of corporate social responsibility reserve, and most of them are issued by the government and advocated by the government. However, how to effectively manage corporate social responsibility reserve and how to improve its efficiency still needs further analysis.

2.4 Literature review

To sum up, the existing research mainly analyzes the effectiveness and shortcomings of China's food reserves from the perspective of a "single center" government. And a combination of individual level, corporate level, and government level, such as strategic stockpiling, can better cope with food disruptions (Davis et al., 2021). In terms of material reserve, Hu et al. (2023) used the quantitative elastic contract in the supply chain contract to study how to make rational decisions on material purchase pricing and inventory on the basis of building a cooperative relationship between government and enterprises. Wang Z. et al. (2023) used the cost-sharing contract to build a dual-supplier joint emergency material reserve model. By analyzing the game process of joint reserve between the government and suppliers, the government's emergency material support ability to cope with natural disasters was effectively improved, supply chain coordination was realized, and government costs and suppliers' profits were improved. Zhang and Kong (2023) designed a two-stage combined double auction and negotiation mechanism to realize the cooperation between multiple buyers and sellers in multiple periods, thus

improving the emergency reserve capacity of the market. Zhang (2021) puts forward the optimal reserve allocation strategy of local government departments based on the scenario integer programming method and cooperates with local enterprises or shops to reserve materials to improve the government's ability to meet sudden emergencies quickly. All of the above are based on the game or option model to maximize the profits of the commercial reserves of the government and enterprises. There is a lack of analysis and discussion on corporate social responsibility reserves, and there is no study on how to improve the efficiency of food reserves by taking government reserves, corporate social responsibility reserves, and commercial stocks as a whole.

In this study, the government reserve, corporate social responsibility reserve, and commercial inventory make up the consumer's remaining losses in time to quantify the reserve efficiency. At the same time, drawing on the experience of government-enterprise joint reserve of emergency materials, the main bodies undertaking government reserve, corporate social responsibility reserve, and commercial inventory are taken as the food emergency support consortium to explore the best ratio of government reserve, corporate social responsibility reserve and commercial inventory under the complementary reserve mode of government and enterprise, so as to maximize the efficiency of food reserve.

3 Analysis of food reserve efficiency

Generally speaking, efficiency is a measure of the degree to which a system can meet the requirements of a specific task, or it is used to characterize the system's ability to complete a specified task under specified conditions (Zheng et al., 2018). Efficiency can be divided into single efficiency, system efficiency, and support efficiency (Deng and Yang, 2022), support efficiency is a dynamic process, which is the degree (time, conditions, and tasks) to which the system transforms its ability into actual support effect in the support process. In the practice of reserve, each subject's orientation in dealing with the relationship between reserve and market, reserve quantity and quantity, and demand and possibility directly affects the decision-making and implementation of reserve (Chen et al., 2022). The key and difficult point of the material reserve is to weigh the necessity, economy, and risk of the material reserve (Han, 2022). For food reserve, the necessity is mainly to consider the probability of crisis and the emergency demand for food in different scenarios. The economy is mainly about how to effectively reduce the cost of food reserves, and the risk mainly includes the purchase risk and the reserve risk. The purchase risk mainly comes from the fluctuation of market price in an unreasonable range or the inappropriate timing of reserve operation, and the reserve risk mainly comes from the deterioration of food in the process of food reserve and the inability to safely store food.

At present, the connotation of food reserve efficiency has not been clearly defined. While food trade has been the subject of intensive investigations in recent years, food reserves remain poorly quantified (Laio et al., 2016). This paper holds that food reserve faces an effective balance between reserve cost, reserve timeliness, and market demand, and food reserve efficiency can be considered from three aspects: "economy, timeliness, and easy use." "Economy" refers to economic benefits. The larger the food reserves and the more reserve subjects, the higher the reserve cost of storage and rotation. Different reserve subjects need to cooperate effectively to determine the best reserve quantity and reduce the food reserve cost as much as possible. "Prescription" is to ensure that food can be supplied in time under abnormal conditions and make up for the market demand gap in time; "Easy to use" means that the stored food meets the needs of consumers, the quality is stable, the stored varieties can be effectively docked with the market demand, and the reserve strain is highly flexible. In an emergency, the three factors are closely linked and influence each other, which together constitute the food reserve efficiency.

From the perspective of the welfare economy, the social benefits of food reserves are mainly reflected in the improvement of consumer surplus. Under the premise of real quantity, stable quality, and safe storage, food reserves can be adjusted, supplied, and used well at critical moments, thus improving the efficiency of food reserves. Considering these three points, the reserve efficiency can be quantified, and the remaining losses made up by consumers after the reserve is put into use can be used as an index to measure the reserve income.

4 The model

4.1 Problem description and variable description

Public goods refer to products or services with non-exclusive and non-competitive characteristics. From the nature and purpose of reserve products in emergencies, food reserves are limited non-exclusive, and non-competitive, and are between public goods and private goods, which can be called quasi-public goods (Jia, 2012). From the perspective of microeconomics, if the food reserve, as a quasi-public product, wants to achieve the balance between fairness and efficiency and find the Pareto optimal solution, it needs to satisfy that the marginal social welfare brought by the reserve is equal to the marginal supply cost (Liu et al., 2014). In this paper, the government and enterprises are regarded as the main bodies of food reserves, and the theory of welfare economics and cost–benefit method are comprehensively used. The government and enterprises are regarded as the main bodies of food reserves, and a model for measuring the scale of emergency reserves between them is constructed. Based on the expected marginal income of reserves equal to marginal cost, the equilibrium conditions of the optimal scale of government reserves, social responsibility reserves, and commercial emergency reserves are obtained. Table 1 is the variable symbols and explanations of the model analysis.

4.2 Assumptions

Before modeling, make the following general assumptions to ensure that the model conforms to the reality of food reserves and is feasible.

(1) This model is aimed at food reserves, and food is a necessity of life, which has the characteristics of large demand, short shelf life, and long production cycle, and the total food supply of the whole society will remain unchanged in a short period. National food reserves include government reserves (denoted by S_1) and enterprise reserves (denoted by S_2), and enterprise reserves include corporate

TABLE 1 Symbols and descriptions of variables.

Variable symbol	Symbol description	Variable symbol	Symbol description
Total social reserve (unit: "daily food consumption")	S	Total social reserve cost	C
Government reserve cost	Cg	Enterprise reserve cost	Cs
Government subsidizes enterprise costs.	Z	Food consumption	Q
Government reserve quantity	S_1	Enterprise reserve quantity	S_2
Government subsidies per unit of social responsibility reserve	g	The cost per unit of food reserved by the government	a_1
Cost per unit of food reserved by enterprises	a_2	Scale of interruption of food supply (unit: "daily food consumption")	t

social responsibility reserves and commercial stocks. The total national food reserves are $S=S_1+S_2$. Therefore, this paper comprehensively explores how to organically combine government reserves, corporate social responsibility reserves, and commercial stocks to ensure that they are "well prepared" and "well stored" at ordinary times, and at the same time, they can be "adjusted," "transported" and "supplied" under abnormal conditions (Du and Xiao, 2022), so as to enhance the effectiveness of food reserves.

(2) The government and enterprises are completely rational and symmetrical in information. Enterprises use all government food reserve subsidies for social responsibility reserves, and there is no immoral behavior; When enterprises do not reserve social responsibility according to the principle of maximizing their own interests, it is difficult for the government to punish enterprises.

(3) Food reserves are mainly government reserves, supplemented by corporate social responsibility reserves and commercial stocks; Within the range of enterprise resources, corporate social responsibility reserve has a scope economy effect, which can save reserve costs. The corporate social responsibility reserve cost (a_2) of storing unit food is lower than the government reserve cost (a_1), and the government reserve cost is higher than the social responsibility reserve cost, that is, $a_1 > a_2$.

(4) There are two states in the food supply and demand market, one is that the normal state of spontaneous regulation by the market reaches the normal state of supply and demand balance, and the other is the abnormal state of food supply interruption due to major natural disasters or emergencies. In a state of supply interruption, the supply in the market will decrease rapidly, and it is difficult to meet the needs of consumers. It is necessary to release the emergency reserve of food to make up for the demand gap for food. For the convenience of description, the basic unit of the food supply interruption scale and food reserve scale is set as "daily food consumption."

$$\mathrm{f}(t)=\begin{cases} 0 & t\in(365,\infty) \\ \frac{1}{\lambda}\mathrm{e}^{-t/\lambda} & t\in(0,365] \\ 0 & t\in(-\infty,0] \end{cases} \quad (1)$$

In Eq. 1, where: t is the scale of food supply interruption, that is, the demand gap of food in the emergency with "daily food consumption" as the unit, which belongs to a random variable, assuming that it obeys an exponential distribution with an average value of λ; f(t) is the density function of the random variable t. Since the scale of food interruption will not exceed the food consumption of 365 days a year, the minimum food consumption is 0 days, it is assumed that f(t) is 0 when $t>365$ and $t\leq 0$. The average value of the food supply interruption scale t is λ, $\lambda>0$.

(5) Because Chinese consumers conform to the general assumption made by Hausman (Ni et al., 2022), combined with this paper, it is assumed that China's food demand function has the property of a constant elastic demand function, and its inverse demand function $P(Q)$ can be expressed as: $P(Q)=P_0+\mu Q^{\frac{1}{\varepsilon}}$ Where: Q represents the food demand, and $P(Q)$ is the price function, which indicates the price P that changes with the demand in the market when the food demand is Q, that is, the inverse function of the demand function Q (P), ε is the price elasticity of food demand, and the demand decreases according to the price increase; The price decreases and the demand increases, which are opposite, so ε is negative; μ is the coefficient of q and is a constant; P_0 is the minimum value of food price when the food demand is 0, and it is also a constant.

(6) Some local governments require enterprises to establish social responsibility reserves through legislation and clarify the responsibilities, rights, conditions of use, supervision subjects, and penalties of corporate social responsibility reserves. The government stipulates that certain financial subsidies should be given to food processing and retail enterprises that guarantee a certain amount of finished food stocks, but the policies of governments in different regions on the minimum amount of corporate social responsibility reserves are quite different. For example, in Zhejiang Province, based on the average operating volume of the annual food trading enterprises for 10 days, after deducting the necessary socially responsible food reserve stocks and the quantity of other policy food entrusted for storage, the approved socially responsible food reserves are given necessary financial subsidies; Ningxia stipulates that processing enterprises above designated size should establish corporate social responsibility reserves according to the raw food processing volume of not less than 5 days, and encourage the establishment of reasonable commercial inventories; Sichuan province stipulates that the social responsibility reserve of finished food is not less than 10% of the average monthly sales volume; Henan province stipulates that the scale of social responsibility reserve shall not be less than 20% of the actual daily average processed food in the previous year; Jilin Province stipulates that the total amount of social responsibility reserves of food processing enterprises in cities (states) and counties (cities, districts) should not be lower than the average processing volume of the local processing enterprises above designated size in the annual food circulation statistics report for 5 days; Hainan Province stipulates that

the regional reserve scale should meet the needs of the resident population in the jurisdiction for at least 3 days in principle, and the reserve scale of a single enterprise should keep the inventory of the responsible enterprise not less than 40% of the daily processing capacity in principle; In principle, Shandong Province stipulates that the food reserve scale should at least meet the 5-day ration demand of the resident population in its jurisdiction. From the policies of the above provinces on the minimum reserve of corporate social responsibility, it can be found that the minimum ratio of corporate social responsibility reserve to corporate commercial inventory should not be less than 5: 365. However, the more corporate social responsibility reserves, the better. Enterprises have idle warehouses and equipment that can be used for food reserves, which is similar to the "U" curve of marginal cost. At first, with the increase of social responsibility reserves, the production efficiency of fixed factors and the improvement of specialization make marginal product increase, and the cost of socialized responsibility reserves is less than that of government reserves. However, with the continuous increase of social responsibility reserves, the cost of social responsibility reserves will increase by an order of magnitude, and will be higher than that of government reserves after exceeding the equilibrium point. It can be seen that there is an optimal ratio of corporate social responsibility reserve. At first, the cost of corporate social responsibility reserve is lower than that of government reserve, but with the continuous increase of corporate social responsibility reserve, the cost of corporate social responsibility reserve is higher than that of government reserve. Based on this, this paper assumes that the ratio of corporate social responsibility reserve to corporate reserve is k.

4.3 Model and solution

4.3.1 Food reserve income function

Figures 1–3 show whether the food reserve can make up for the impact of the supply gap on market price fluctuations and how much the consumer surplus is filled under different food reserves. As shown in Figure 1, it means that in a non-emergency state, that is, in a normal state, there is sufficient supply in the market, and the market can play the role of a "stabilizer" and spontaneously adjust price fluctuations to achieve the welfare effect corresponding to the balance between supply and demand. The shaded part is the ideal consumer surplus when supply and demand reach a balance in this state. Figures 2, 3 respectively show the gap between market supply and consumption demand made up of different amounts of food reserves when the supply and demand are unbalanced and the scale of food emergency reserve is less than or equal to the scale of supply interruption, as well as the reduction of welfare effect caused by the supply gap and the remaining recovery amount of consumers after putting it into use. In Figures 1–3, the market price of food P "Yuan" is taken as the vertical axis, and the food consumption Q "Daily food consumption" is taken as the horizontal axis, and the food demand function in the market is expressed by $P(Q)$, the food supply function in normal state is expressed by $S(Q)$, and the food supply function in abnormal state is expressed by $S_1(Q)$ and $S_2(Q)$.

Under normal conditions, as shown in Figure 1, the market, as an "invisible hand," can adjust the balance of supply and demand spontaneously. At this time, the intersection of the food supply curve $S(Q)$ and demand curve $P(Q)$ reaches the balance of supply and demand at point E^*, corresponding to the equilibrium price P^*. Therefore, in the case of sufficient food supply, according to the annual food demand of 365 "daily food consumption," the consumer surplus can be expressed as $\int_0^{365} P(Q)\mathrm{d}Q - 365P^*$. That is, the area under the demand curve $P(Q)$ in Figure 1, the straight line E^*P^*, and the area surrounded by P^* along the longitudinal axis, as shown by the shaded part in Figure 1.

However, Figures 2, 3 show that when the supply and demand are unbalanced, such as sudden emergencies, the food supply cannot meet all consumers' needs because some consumers snap up and transportation logistics are interrupted, so the supply curve cannot extend to the upper right corner, thus becoming an inelastic vertical straight line, that is, the new food supply curve $S_1(Q)$ consists of the curve of CA on the original curve $S(Q)$ and the straight line of the upward portion of AE_1 on the line corresponding to $(365-t)$ "days of food consumption." If the supply interruption scale is t "daily food consumption," the food consumption of consumers is only $(365-t)$ "daily food consumption." At this time, the new supply curve $S_1(Q)$ and the demand curve $P(Q)$ intersect at the new equilibrium point E_1. In this new state, the new equilibrium price also climbs from the original P^* to P_1, and the consumer surplus is reduced to the area surrounded by upward rays above the straight line P_1E_1, below the demand curve $P(Q)$ and starting from the point P_1 on the vertical axis. Therefore, the consumer surplus when supply and demand are unbalanced without reserve supply can be expressed as $\int_0^{365-t} P(Q)\,\mathrm{d}Q - (365-t)P_1$. As can be seen from Figure 2, under the abnormal situation, the shortage of food supply loses its elasticity, which leads to the market price fluctuation crisis. The remaining net loss of consumers is the area of $P_1E_1E^*P^*$ surrounded by the left side of the E_1E^* curve, straight line E^*P^*, straight line P^*P_1, and straight-line P_1E_1 on demand curve $P(Q)$.

On this basis, the revenue function of food reserves can be divided into two types: the first is when the emergency food reserve scale s is less than the supply interruption scale t, as shown in Figure 2 because the emergency food reserve cannot meet all the demand gaps, the supply decreases, and the supply becomes $365-t+s$ "daily food consumption," and the supply curve changes from the original $S(Q)$ to a new supply curve $S_2(Q)$, and $S_2(Q)$ is composed of the curve from C to B on the original $S(Q)$ and the vertical straight line BE_2 corresponding to "daily food consumption" of $365-t+s$. As a result, $S_2(Q)$ and demand curve $P(Q)$ intersect at a new equilibrium point E_2, reaching a new equilibrium price P_2, but at this time, although the price P_2 is still higher than the equilibrium price P^*, it is obviously better than the price P_1 without emergency reserve, and the price has declined.

Therefore, in this case, although the price increase has caused some losses to the consumer surplus, some of the consumer surplus has still been recovered. At this time, the consumer surplus is $\int_0^{365-t+s} P(Q)\mathrm{d}Q - (365-t+s)P_2$. That is, the area shown in Figure 2 is the area surrounded by the demand curve $P(Q)$, the new equilibrium

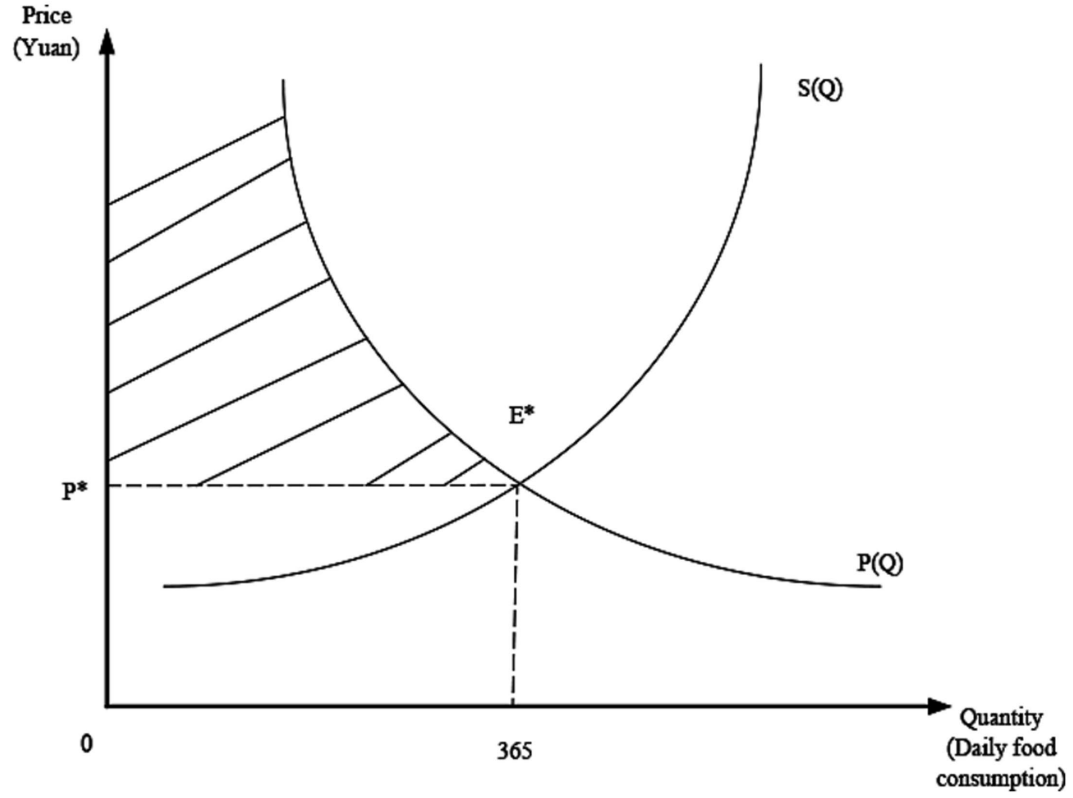

FIGURE 1
Welfare effect in normal state.

price line E_2P_2, and the price P axis. Therefore, the consumer's residual losses recovered due to food reserves can be expressed as $\int_0^{365-t+s} P(Q)\mathrm{d}Q - \int_0^{365-t} P(Q)\mathrm{d}Q + P_1(365-t) - P_2(365-t+s)$. It is shown in the figure as the area surrounded by P_1P_2 on the vertical axis, dotted lines P_1E_1, P_2E_2 and E_1E_2 on the $P(Q)$ curve, as shown by the shading in Figure 2.

Second, as shown in Figure 3, at this time, the reserve scale S is greater than or equal to the interruption scale t. Due to the sufficient reserve, it can be supplied in time, and the food consumption of consumers can return to the normal level, that is, 365 "daily food consumption," which can achieve a balance between supply and demand under the spontaneous adjustment of the market, and the supply curve returns to the position of $S(Q)$ and the state of Figure 1, reaching equilibrium at E^*, and the price is the initial equilibrium price P^*. The consumer surplus at this time can be expressed as $\int_0^{365} P(Q)\mathrm{d}Q - 365P^*$. As shown in Figure 3, the area surrounded by the straight line E^*P^* and the ray whose vertical axis starts from P^* below the demand curve $P(Q)$. In this case, all the remaining losses of consumers are recovered. Therefore, the net loss of social welfare recovered by the food emergency reserve can be expressed as $\int_0^{365} P(Q)\mathrm{d}Q - \int_0^{365-t} P(Q)\mathrm{d}Q + P_1(365-t) - 365P^*$, as shown by the shaded part in Figure 3.

Combining the above two situations, the income of food reserves can be expressed as:

$$B(t,s) = \begin{cases} B_1(\mathrm{t,s}) = \int_0^{365-t+s} P(Q)\mathrm{d}Q - \int_0^{365-t} P(Q)\mathrm{d}Q \\ \quad + P_1(365-t) - P_2(365-t+s) & (s < t) \\ B_2(\mathrm{t,s}) = \int_0^{365} P(Q)\mathrm{d}Q - \int_0^{365-t} P(Q)\mathrm{d}Q \\ \quad + P_1(365-t) - 365P^* & (s \geq t) \end{cases} \quad (2)$$

The above formula is Eq. 2, which reflects the relationship function between the scale of food emergency reserve and income. Because the revenue function $B(t,s)$ of food emergency reserve is continuous at the subsection point $s=t$, the first derivative of the revenue function about the reserve scale S can be obtained:

$$\frac{\partial B(t,s)}{\partial s} = \begin{cases} \frac{\partial B_1(t,s)}{\partial s} = -\frac{\partial P(365-t+s)}{\partial s}(365-t+s) & (s<t) \\ \frac{\partial B_2(t,s)}{\partial s} = 0 & (s \geq t) \end{cases} \quad (3)$$

According to the previous assumptions, the function of food reverse demand is $P(Q) = P_0 + \mu Q^{\frac{1}{\varepsilon}}$. Substituting it into Eq. 3, the first derivative of the food income function can be further expressed as Eq. 4:

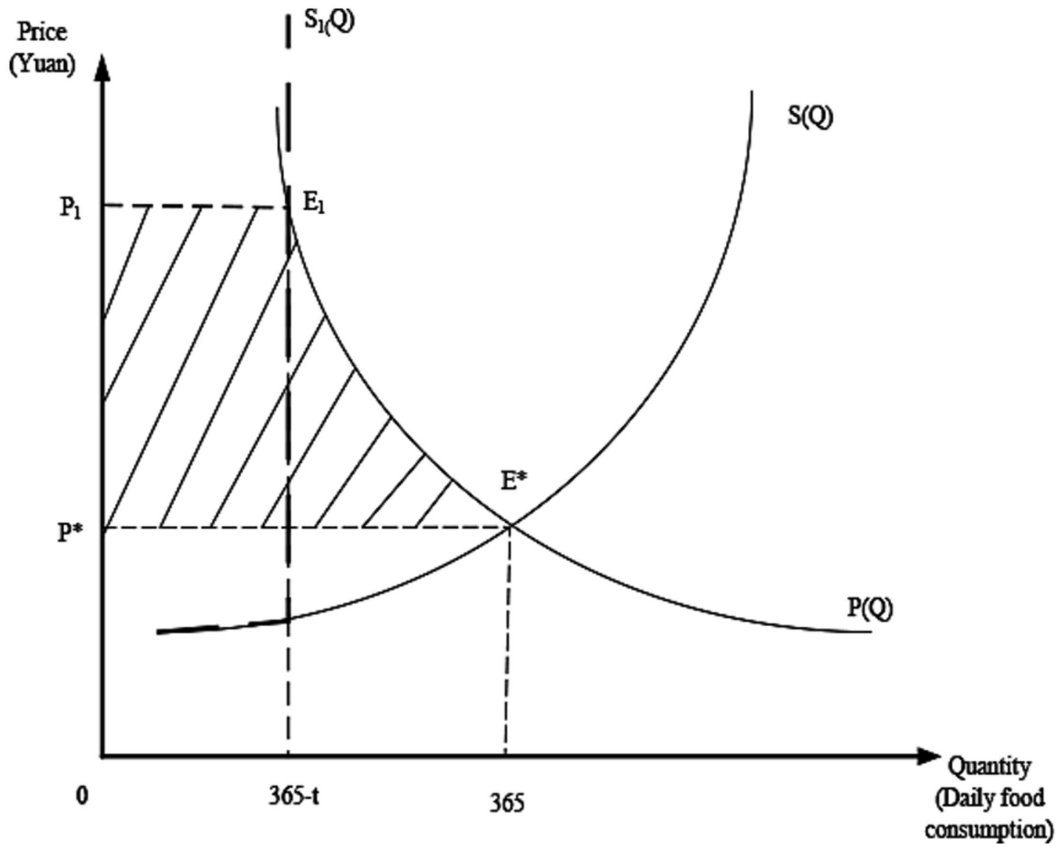

FIGURE 3
The welfare effect of emergency reserve scale greater than or equal to the scale of supply interruption.

$$\frac{\partial B(t,s)}{\partial s}=\begin{cases}\dfrac{\partial B_1(t,s)}{\partial s}=-\dfrac{\mu}{\varepsilon}(365-t+s)^{\frac{1}{\varepsilon}} & s<t\\ \dfrac{\partial B_2(t,s)}{\partial s}=0 & s\geq t\end{cases} \quad (4)$$

Combining this result with the economic reality, it shows that when $s<t$, it is of a certain value to increase one unit of food reserves in society, and its social value is the marginal consumer surplus of consumers in the market, that is, the consumer surplus generated by consumers consuming another unit of food, which can be expressed quantitatively as $-\frac{\mu}{\varepsilon}(365-t+s)^{\frac{1}{\varepsilon}}$.When $s\geq t$, the consumer demand has been fully met and reached saturation, and the marginal social value is equal to zero, which means that no matter how much marginal unit reserve is increased at this time, it cannot drive the increase of consumer surplus.

4.3.2 Food reserve cost function

Based on the above analysis, this paper divides the food reserve cost into government reserve cost and enterprise reserve cost. Because the government reserve is static and can be set as a fixed parameter, the main goal of this model is to find the best ratio of corporate social responsibility reserve and commercial inventory in the dynamic reserve of enterprises, to optimize the reserve efficiency. As the government reserve belongs to a static reserve, it can be set as a constant S_1; The enterprise reserve is dynamic, and it is set as a variable S_2, in which it is assumed that the proportion of social responsibility reserve in the enterprise reserve is k, then the social responsibility reserve is kS_2 and the commercial inventory is $(1-k)S_2$. The ratio of social responsibility reserve to commercial inventory is $k/(1-k)$. Where k is the proportional coefficient. Under normal circumstances, $(1-k)\,S_2>S_1>kS_2$ and $k<0.5$, because commercial inventory > government reserve > social responsibility reserve. At the same time, it is assumed that the ratio of corporate social responsibility reserve to commercial inventory should not be less than 5: 365, that is, $k/(1-k)\geq 5/365$, that is, $k\geq 1/74$. Government reserve cost can be expressed as Cg, which is a function of government reserve S_1. Enterprise reserve cost can be expressed as Cs, including social responsibility reserve cost and commercial inventory cost, which is a function of enterprise reserve S_2. The cost of government subsidies to enterprises can be expressed as Z, which is a function of the reserve of corporate social responsibility kS_2.

Assuming that the unit cost of government reserve is a_1 for each additional unit of food, the reserve cost Cg of government reserve with the scale of S_1 is a_1S_1; Similarly, the unit cost of each additional unit of food enterprise reserve is a_2, and the enterprise reserve cost Cs is a_2S_2. In addition, as far as the total cost is concerned, there is also the cost of government subsidies to corporate social responsibility reserves. Assuming that each unit subsidizes g, the subsidy cost Z is gkS_2.

At the same time, because the corporate social responsibility reserve takes the finished food of the government as the working food

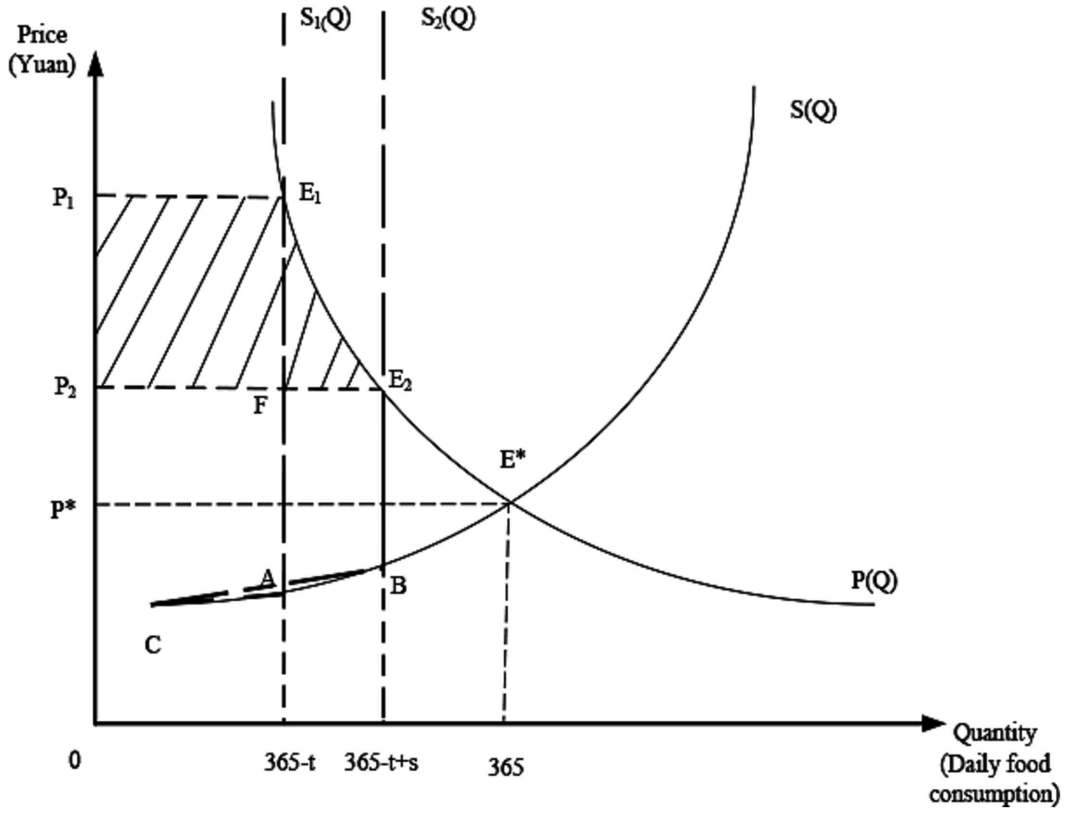

FIGURE 2
Welfare effect of emergency reserve scale less than supply interruption scale.

of the enterprise, it can reduce the liquidity pressure of the enterprise, has a convenient food reserve warehouse, and can bring the advantages of improving the reputation of the enterprise and preferential interest rates for bank loans, so the corporate social responsibility reserve can bring savings in reserve costs, $Cg < Cs$. However, according to the law of diminishing returns to scale, if we continue to increase the social responsibility reserve after reaching a certain level, it will bring additional costs such as introducing new equipment and building new warehouses, and the management difficulties and costs will become greater and greater, which will lead to the social responsibility reserve cost being greater than the government reserve cost, so enterprises will also control the social responsibility reserve within a certain range, making $Cg < Cs$.

The total food reserve with the scale of S is $S = S_1 + S_2 \quad a_1 > a_2$, Thus, the reserve cost can be expressed as Eq. 5:

$$\begin{aligned} C &= Cg(S_1) + Cs(S_2) + Z \\ &= Cg(S_1) + Cs(S_2) + gkS_2 \\ &= a_1 S_1 + a_2(S - S_1) + gk(S - S_1) \\ &= a_1 S_1 + (a_2 + gk)S - (a_2 + gk)S_1 \\ &= (a_1 - a_2 - gk)S_1 + (a_2 + gk)S \end{aligned} \tag{5}$$

According to the assumption that the total reserve S = the government reserve S_1 + the enterprise reserve S_2, and $a_1 > a_2$, the corporate social responsibility reserve in the enterprise reserve is kS_2, and the corporate commercial inventory is $(1-k)S_2$. The marginal cost derived from the total cost of the social reserve to the total reserve S can be obtained:

$$\frac{\partial C}{\partial S} = a_2 + gk \tag{6}$$

The economic implications of Eq. 6 are as follows: under the condition that the total social food supply remains unchanged, the scale of government reserve remains unchanged, and the scale of supply interruption is t "daily food consumption," that is, the food demand gap in the market is t "daily food consumption," and when the corresponding reserve is needed to balance supply and demand, every increase in the dynamic reserve of one unit of food will bring about an increase in the reserve cost of one unit of food enterprises and the social responsibility reserve cost of government-subsidized enterprises. That is to say, the marginal cost of the dynamic reserve consists of the sum of the reserve cost of the enterprise unit and the subsidy cost of the government to the social responsibility reserve unit, and the reserve cost of enterprise social responsibility is determined by the proportion of social responsibility reserve to commercial inventory and the social responsibility reserve subsidy of unit food.

4.3.3 Cost–benefit analysis of food reserve

The food emergency reserve pursues the state of maximizing the efficiency of the emergency reserve, and in this state, the food emergency reserve scale is the best. According to the income and cost

function of the food emergency reserve obtained before, the objective function can be established by subtracting the two formulas, to maximize the net income of the food emergency reserve, namely:

$$\max B^*(t,s) = \int_0^{365} f(t)B(t,s)\mathrm{d}t - C(s) \tag{7}$$

The condition of maximizing the net income of food reserves is that the expected marginal income of food reserves is equal to the marginal cost, that is, the recovered marginal consumer surplus is equal to the marginal cost. Find the first derivative of the total reserve scale S of the Eq. 7, substituting $\frac{\partial B_1(t,s)}{\partial s}, \frac{\partial B_2(t,s)}{\partial s}$ and $C'(s)$ to make the expected marginal revenue related to S equal to the marginal cost, we can get:

$$\int_s^{365} f(t)\left[-\frac{\mu}{\varepsilon}(365-t+s)^{\frac{1}{\varepsilon}}\right]dt = a_2 + gk \tag{8}$$

The economic significance of Eq. 8 is that only when the marginal social welfare net loss recovered by the reserve, that is, the marginal consumer surplus, is equal to the marginal cost of the reserve, can the expected food reserve efficiency be maximized, and the total emergency reserve scale S is the most reasonable reserve scale.

In order to make the process more clear and reasonable, it is necessary to verify the above formula, and the second-order condition of the optimization problem can be used to judge whether the first-order condition of Eq. 8 is sufficient. In Eq. 7, the second derivative of the total reserve scale S is:

$$\frac{\mu}{\varepsilon}365^{\frac{1}{\varepsilon}}f(s) + \int_s^{365} f(t)\left[-\frac{\mu}{\varepsilon^2}(365-t+s)^{\frac{1-\varepsilon}{\varepsilon}}\right]dt \tag{9}$$

According to the definition, since the function $f(t)$ represents the density function of the food supply interruption scale of t "daily food consumption" and $f(s)$ represents the density function of the total food reserve scale of S "daily food consumption," both $f(t)$ and $f(s)$ are positive values. ε is the price elasticity of food demand. Because food is a normal product, not a Giffin commodity, this paper assumes that it is an elastic demand function, and ε is negative according to the inverse relationship between price and demand. μ is a constant and greater than 0, so both the first and second items in Eq. 9 are less than 0, and the two values less than 0 are in Eq. 9, and the values are still less than 0. Therefore, under the first-order condition, that is, the optimal reserve scale S obtained according to Eq. 8, the objective function can reach the maximum value under this condition, and the optimal value S is the only value.

5 Results and analysis

Therefore, according to Eq. 8, this paper constructs the relationship between the optimal total reserve scale S and the optimal proportion of social responsibility reserve.

$$k = \frac{\int_s^{365} f(t)\left[-\frac{\mu}{\varepsilon}(365-t+s)^{\frac{1}{\varepsilon}}\right]\mathrm{d}t - a_2}{g} \tag{10}$$

In case of emergency, it is impossible to effectively increase the total food supply of a country or region in a short period of time, so in a short period of time, the total reserve S can be regarded as unchanged. According to Eq. 8, Eq. 10 is obtained, and since $\int_s^{365} f(t)\left[-\frac{\mu}{\varepsilon}(365-t+s)^{\frac{1}{\varepsilon}}\right]\mathrm{d}t$, a_2 and g are known constants. The optimal reserve ratio k of available social responsibility reserve to enterprise reserve can be obtained, to determine the social responsibility reserve kS_2, commercial inventory $(1-k)S_2$, and the ratio $k/(1-k)$ between social responsibility reserve and commercial inventory. This ratio is closely related to the total food reserve, the scale of supply interruption, the reserve cost of food stored by enterprises, and the government's subsidy cost for the social responsibility reserve. From the above analysis results, it can be found that the proportion of corporate social responsibility reserves to corporate reserves is inversely proportional to the reserve subsidies given by the government, which means that when the government encourages enterprises to carry out social responsibility reserves, the unit subsidies given to corporate social responsibility reserves should not be too high.

Therefore, doing a good job in social responsibility management of food enterprises is an effective way to improve the efficiency of food reserves. The social responsibility of food enterprises is non-profit and an important part of the national food security system. The primary goal is to ensure the stability of regional food supply, promote corporate social responsibility reserves through commercialization, and reshape the social responsibility of food enterprises to hold voluntary food reserves. This is also consistent with the view that enterprises should actively respond to the call of the state and fulfill their social responsibilities instead of aiming at maximizing profits when making social responsibility reserves. From the perspective of national food security, the corporate social responsibility reserve is the most direct and effective means to deal with emergencies and ensure the safety of the food supply, which can further increase the comprehensive strength of the national food reserve. Enterprises should take the initiative to set up food social responsibility reserves in line with government regulations from the national interests. In practice, enterprises mix the social responsibility reserve and commercial reserve stipulated by the state and realize "storing food in enterprises" through the operation of the social responsibility reserve system. However, the larger the scale of the corporate social responsibility reserve, the more the reserve accounts for, and the greater the operating pressure on enterprises, the greater the safety risk of food reserves. The prerequisite for "storing food in enterprises" is that enterprises must be "rich," that is, Tibetans must have economic strength and be able to afford the investment in food reserves and the resulting operational risks.

6 Conclusion

This paper takes the government and enterprises as the main bodies of food reserves and studies the pluralistic relationship

among government reserves, corporate social responsibility reserves, and commercial inventories. Based on the social welfare theory and cost-benefit analysis method of welfare economics, this paper constructs a model to maximize the efficiency of joint reserve between government and enterprises and analyzes the dynamic proportional relationship between total food reserve and social responsibility reserve. In an emergency, the total food reserves will remain unchanged for a short period. According to the dynamic proportional relationship between the total food reserves and the social responsibility reserves, the optimal proportion of the corporate social responsibility reserves to the enterprise reserves is calculated, which is closely related to the total food reserves, the scale of supply interruption, the reserve cost of food stored by enterprises and the subsidy cost of the government for social responsibility reserves. In an emergency, determining these parameters can provide guidance and reference for enterprises to carry out the scale of food social responsibility reserve and commercial inventory, realize the synergy and complementarity between dynamic reserve and static reserve in the food reserve market in an emergency, operate efficiently, and improve the efficiency of food reserve.

From the perspective of national food security, the food social responsibility reserve is the most direct and effective means to deal with emergencies and ensure food supply security. The social responsibility reserve of food enterprises is non-profit, and the primary goal is to ensure the stability of the regional food supply. Enterprises should do a good job in food social responsibility reserve from the national interests and reshape the social responsibility of food enterprises to hold voluntary food reserves. It is also found that the unit subsidy cost of the government's social responsibility reserve is inversely proportional to the proportion of the corporate social responsibility reserve in the enterprise's reserve. To increase the scale of the social responsibility reserve and realize "storing food in the enterprise," the government's subsidy for the unit food social responsibility reserve should not be too high. Taking the food social responsibility reserve as an important part of the corporate social responsibility, it is the key to promote the enterprise to actively do a good job in the food social responsibility reserve.

To do a good job in encouraging enterprises, in the process of promoting the management of food enterprises' social responsibility reserves, government functional departments can strengthen the information release mechanism of food storage enterprises' social responsibility. First, fully publicize the food social responsibility reserve system, and timely publish and update the list of social responsibility reserve storage enterprises. The second is to give policy inclination and public opinion propaganda to the responsibility of storage enterprises and realize a virtuous circle of responsibility of storage enterprises-public active propaganda-government policy inclination. Third, the storage enterprises found in the supervision and inspection should be publicized and supervised in time, and measures such as canceling the storage qualification should be taken. The fourth is to introduce the reputation mechanism of public participation. According to the public's evaluation of enterprises, enterprises with good reputations will be rewarded and enterprises with poor reputations will be punished. In the long run, enterprises can establish a good brand image and social reputation through social responsibility reserve, increase consumers' trust in enterprises, further affect the market scale of enterprises, obtain more profits, and also establish a trust negotiation mechanism among enterprises, governments, and consumers, to build a platform to build a balanced development model and promote regional harmonious development.

This paper analyzes the optimization of food reserve efficiency under the short-term emergency mode of the government-enterprise complementary reserve, mainly focusing on the research of emergency direction, but does not consider the fixed cost, variable cost, risk occurrence probability, multi-cycle reserve, and other factors. In the future, based on this model, more relevant influencing factors will be added to study the long-term situation, and corporate social responsibility reserve will be introduced during the transition period from normalization to emergency. In the future, we will conduct further in-depth research based on this model, combining short-term and long-term conditions, to make the model closer to reality and guide reality.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

QJ: Writing–review & editing, Conceptualization, Formal analysis, Funding acquisition, Methodology, Project administration, Supervision, Validation. XJ: Conceptualization, Formal analysis, Methodology, Project administration, Writing–original draft, Writing–review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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