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AUCTION POLICY ANALYSIS: AN AGENT-BASED SIMULATION OPTIMIZATION MODEL OF GRAIN MARKET

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ABSTRACT

National grain reserve is important in terms of responding to disasters and the unbalance between supply and demand in many countries. In China, the government supplements grain supply through online auctions. This study focuses on the auction policy of national grain reserve. We develop an agent-based simulation model of China's wheat market with detail descriptions of different agents, including national grain reserve, grain trading enterprises and grain processing enterprises. Based on this model, the Optimal Computing Budget Allocation (OCBA) simulation optimization method is adopted to analyze the characteristics of optimal decision variables under different scenarios, with an objective to minimize the fluctuation of wheat price. We obtain some insights about operations of national grain reserve. As the first agent-based simulation model about national grain reserve and grain market, this model can be widely used in agricultural economics, and can provide policy supports to the government.

1 INTRODUCTION

Grain security is one of the most important issues worldwide. The stable development of grain market is the footstone of a country's economy system. Since China is a country feeding about 19% of the world's population using only 7% of arable land, a stable grain market price is critical to ensure social stability. This work is motivated by China's national grain reserve auction policy, and we establish an agent-based simulation model to characterize grain market participants' behavior to find some insights to support the government's grain auction strategy.

In China, the government sets a minimum purchase price every year. When grain market price is lower than that price, the government starts to procure grain until market price is higher than that price. To supplement grain supply, the government releases grain to the market through an online auction mechanism. In accordance with the mechanism, national grain reserve (NGR) decides the minimum sale price, the auction quantity and the auction time interval. The government will hold an auction periodically and public the minimum sale price and the auction quantity to all bidders. When getting auction message, bidders can bid for auction items with a bidding price higher than the minimum sale price, and bidders with higher price will have priority in bidding the auction. According to historical auction data of wheat and rice during last three years, an auction time interval is one week, and the auction quantities stay the same. Under this auction strategy, the average successful transaction rate is less than 25%. While a lot of public resources are occupied by NGR, the effect of stabilizing market price is unnoticeable. To solve this issue, we first establish an agent-based simulation model to describe the auction mechanism and grain market participants' decision strategy. Then, we evaluate NGR's optimal decision variables (includes the auction

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time interval, the auction quantity and the minimum sale price) to minimize the fluctuation of grain market price.

Existing literatures on grain market policy can be classified into three research issues: price policies, production supporting policies and grain reserve policies. Many researches use computable general equilibrium models to analyze the effect of price policies on grain market, such as Hosoe (2004), Yu and Jensen (2010) and Mason and Myers (2013). Besides, some researches focus on evaluating production supporting policies' regulation effects to grain market (Hansen, Tuan, and Somwaru 2011). However, there are few research studies about grain reserve policy, and this paper is motivated by the issue. Miao and Zhong (2006) analyzes the correlations between grain reserve and market price using the annual data from 1978 to 2005, and indicates that national grain reserve affects grain market price from its incremental level and stock level. Wang and Li (2013) analyzes the effects of state-owned grain auction on market price using vector autoregressive approach, and concludes that auction performs as a signal of demand and supply rather than a balance tool under the scenario of abundant supplies. These researches analyze the effects of national grain reserve from the view of macro-economy, and ignore the behavior strategy of different market agents and their interactions, which are quite important to evaluate the policy influences.

To mirror the real grain reserve system as closely as possible, in this paper, we develop a simulation model that comprises all participants of the grain reserve system, and simulate their operations and interactions. Agent-based modeling (ABM) offers such a conceptual framework to solve this modeling problem, because it simulates market participants as autonomous decision-making and heterogeneous entities called agents. Each agent individually assesses its decision environment, and makes decisions based on a set of rules. Besides, it is flexible and it can capture emergent phenomena (Bonabeau 2002). Although there is no direct study about agent-based modeling of grain reserve system, this method has been applied to evaluate policy effect in other fields, and obtains some influential models. Happe, Balmann, and Kellermann (2004) builds the Agricultural Policy Simulator (AgriPoliS), it analyzes farmers' structural change and endogenous adjustment reactions in response to a policy change, and many researches analyze effects of different policies or in different regions based on this model (Bert et al. 2011; Zimmermann and Heckelei 2012). In the electricity market, an Electricity Market Complex Adaptive Systems (EMCAS) simulates every participant's behavior, and it is used to evaluate efficiencies of different regulation policies (North et al.). A lot of researchers analyze different countries' regulation policies based on EMCAS model (North et al. ; Conzelmann et al.). All above literatures prove the capability of agent-based model in policy analysis field, which motivates us to develop such a simulation platform to analyze the effectiveness of grain reserve policy.

In this paper, we develop an agent-based simulation model of national grain market with detail descriptions of different agents including state-owned national grain reserve (NGR), the wholesaler grain trading enterprises (GTE), and grain processing enterprises (GPE). Based on this model, we analyze the optimal decision variables of grain reserve auction policy (includes the auction time interval,the auction quantity and the minimum sale price) under different scenarios using optimal computing budget allocation (OCBA) method, aiming at minimizing price influences. Some insights of NGR's operation strategy under current auction policy are provided in this research.

The remainder of this paper is organized as follows. In section two, we develop the basic model of grain reserve system, and we formulate simulation optimization structure in section three. Then a case study of wheat market is provided in section four. Finally the paper is concluded with a short summary.

2 SIMULATION: AGENT-BASED GRAIN MARKET SIMULATION

This agent-based model is established to analyze the auction policy of national grain reserve, thus, the behavior strategy, transaction process and information interactions of national grain reserve (NGR), grain trading enterprises (GTE), and grain processing enterprises (GPE) are taken into consideration. We simplify farmers and final consumers as constant parameters. We assume that all grain is purchased by national grain reserve (NGR), grain trading enterprises (GTE) and grain processing enterprises (GPE) at the beginning of simulation period, and the demand of GPE follows a distribution in accordance with empirical data.

In this model, NGR serves as the grain reservoir, which releases grain to the market through an online auction to regulate the grain market. GTEs serve as grain traders, and they sell grain purchased from farmers in the beginning to GPEs during the total period. GPEs are processors who process grain bought from NGR and GTEs into finished goods and sell them to final consumers. Behavior and decision strategies of agents and their information interactions are discussed as follows.

2.1 Agent NGR: National Grain Reserve

NGR is under the management of the government, it releases grain to the market through auction to realize regulation. The government's regulation objectives are to keep the balance between supply and demand of grain market and to minimize the fluctuation of market price. In this research, in accordance with the NGR's regulation target, the simulation model's objective is to minimize the fluctuation of market price.

According to the auction historical data from National Grain Trade Center of wheat and rice in the last three years, we find that the NGR holds an auction once a week, the auction amounts of every auction remain the same, and the auction is subdivided into items with equal quantity of grain. In addition, the minimum sale price is decided in accordance with market price. Therefore, we assume NGR holds an online auction every T days with a constant total auction quantity Q, and each auction-item's auction quantity equals B except for the last one, which equals $Q-(n-1)B$, where n is the amount of auction items. The minimum sale price of auction is $\omega P_r(t)$, where $P_r(t)$ represents raw-grain's market price in the t-th day, and ω is the minimum sale price ratio ($\omega \in (0,1)$). The objective function of the simulation model is to minimize market price fluctuation, and we describe it as

$$\min pricefluctuation = \sum_t (P_r(t) - \overline{P}),$$

where $\overline{P}$ is the long-term average market price. At the beginning of an auction, the NGR sends messages to all GPEs, and then collects bids from bidders. Every time the NGR makes deal with the bidder with highest bidding price among untreated bidders until the remain auction quantity is lower than this bidder's bidding quantity. If no bidder bids the auction, the auction will be cancelled.

2.2 Agent GTE: Grain Trading Enterprise

GTEs serve as wholesalers of the grain market, who hold an initial level of grain reserve, and sell them to GPEs to maximize their profit.

GTEs receive orders sent from GPEs at the beginning of every day and rank these orders by order price from high to low. Then, GTEs decide the total amount to sell in day t $W(t)$ according to their own inventory level, buyers' price and purchase quantity, and their expectation of grain market price in the future. If GTEs predict that the market price will rise, they will reduce the sales and leave more grain to the future. Then GTEs satisfy collected orders from the highest-price order to the lowest one until $W(t)$ is lower than the current order's purchase quantity. At the end of the day, GTEs send ships to GPEs whose order is satisfied, and orders unsatisfied will be rejected without backlog.

2.3 Agent GPE: Grain Processing Enterprise

GPEs have an explicit objective to maximize their profit. Their decision process can be classified into sales process, production process and procurement process. Details are described as follows:

Sales process: There are a large number of participants in the finished goods market, so we assume this market as a perfect competition market, where all participating enterprises are price taker. Moreover, we assume that the demand of finished goods $D(t)$ follows normal distribution

$$D(t) \sim N(u(t), \sigma).$$

The mean $u(t)$ follows a function with historical average demand A, finished product price P_w and price elasticity ε. The variance σ is constant:

$$u(t) = A \cdot P_w(t)^{\varepsilon}$$

At the beginning of every day, GPEs collect the accumulated demand and satisfy it if the inventory of finished goods $I_f(t)$ is available, and unsatisfied demand will be the lost sale without backlog.

1. If $I_f(t) > D(t)$, the demand is satisfied and $I_f(t)$ is reduced to $I_f(t) - D(t)$;
2. If $0 < I_f(t) < D(t)$, the demand is partially satisfied and $I_f(t)$ is reduced to 0;
3. If $I_f(t) = 0$, all demand become lost sale.

Production process: We assume that a "make-to-stock" policy is applied to conduct the production process. GPE first needs to decide whether to produce or not. If a GPE chooses to produce, the production quantity $q(t)$ is decided based on demand $D(t)$, finished-good's inventory level $I_f(t)$, raw-grain's inventory level $I_r(t)$, production capacity C and transfer rate θ (the amount of finished goods made by one unit of raw grain). Besides, $q(t)$ depends highly on the potential profitability $\phi(t)$, ($\phi(t) = P_w(t) - P_r(t)$), where $P_w(t)$ is the price of finished goods and $P_r(t)$ is the price of raw grain.

If $\phi(t)$ is larger than a given level ϕ_0, GPEs produce to replenish the finished-good's inventory up to its maximum inventory capacity F; otherwise, another inventory threshold f will take the place of F. The detail rules are characterized as follows:

1. If $\phi(t) > \phi_0, q(t) = \min\{I_r(t)/\theta, C, F - I_f(t)\}$;
2. If $\phi(t) < \phi_0, I_f(t) < f, q(t) = \min\{I_r(t)/\theta, C, f - I_f(t)\}$;
3. If $\phi(t) < \phi_0, I_f(t) > f, q(t) = 0$; enterprises do not have motivation to produce.

Procurement process: After sales and production processes, GPEs need to determine whether to procure or not. If a GPE needs to procure, it then need to choose a supplier, and to decide the purchase price and procurement amount. GPEs can procure raw grain either from NGR or GTEs. NGR sales grain through an online auction, and GTEs sale grain through traditional order form. GPEs choose procurement channel in accordance with current inventory level of raw grain, the minimum sale price, and market price. In addition, their historical procurement records and expectation of future price have important influence on the decision of procurement. If GPEs expect that the raw grain market will be oversupplied, and the minimum sale price does not meet their expectation, they prefer to purchase raw grain through order channel with GTEs. Otherwise, participating in an auction channel is a better choice.

Auction channel: When the ith GPE receives auction messages sent by NGR, it will bid for the auction if two below conditions are satisfied:

1. The ith-GPE's inventory level of raw grain $I_r(t)$ below $C_r - B$. And the bidding quantity equals $B\lfloor C_r - I_r(t))/B \rfloor$.

2. The minimum sale price of auction is lower than the acceptable price of the ith-GPE. In our simulation model, the acceptable price of ith GPE is relative to his risk attitude, the urgent degree of procurement and procurement history. For example, if a GPE fails to achieve an order or a bid last few days, he will raise his acceptable price to improve his bidding competitiveness.

When these two conditions are satisfied, a GPE bids the auction with a bidding price and bidding quantity. Otherwise, GPEs choose to purchase raw grain from GTEs.

Order channel: GPEs first decide whether to send an order to GTEs or not. If yes, then decide the purchase quantity, order price and which GTE to choose. Consider the varying raw-grain price, to mirror reality, we refer a proved price-dependent base-stock procurement policy according to Berling and Martínez-de Albéniz (2011). Base on this policy, GPE's optimal inventory upper levels change with observed raw-grain market prices, and when the current inventory level is below to that optimal level, a GPE chooses to purchase with GTEs. Otherwise, he chooses to do nothing.

The decision process of ith-GPE's order price is similar with its acceptable price of auction channel, and it randomly select its supplier among all GTEs. Finally, a GPE send an order to the selected supplier with content of order quantity and order price. When an order is rejected by the supplier, it becomes void. Thus, the GPE has to repeat the ordering process next day.

3 SIMULATION OPTIMIZATION USING OCBA

Based on the simulation model we proposed, this paper intends to minimize the fluctuation of grain market price. We then use wheat market as an example. Considering the practicability of the government's operation, we define the optimization model as discrete. Because the scale of simulation designs in our problem is large, and it is difficulte to obtain optimal objective solution with limited computing budget. To solve this problem, an optimization method is adopted to design the optimal computing budget allocation rules to simulation designs to reduce the total computation cost. To identify the best simulated design, the criterion used to compare the designs need to be first specified. One commonly studied measure is the alignment probability or the probability of correct selection (PCS), which is defined as the probability that the selected design is the true best. The indifference-zone (IZ) approach for the budget allocation problem typically allocates the simulation budget to provide a frequentist guarantee for the probability of correct selection (Dudewicz and Dalal 1975, Nelson, Swann, Goldsman, and Song 2001). That is, we need to determine how to measure the evidence of correct selection. The optimal computing budget allocation (OCBA) framework follows a Bayesian methodology and allocates additional simulation replications by solving the problem as an optimization problem, in which PCS is maximized given a fixed simulation budget (Chen et al. 2000, Chen et al. 2008, Chen). Since Optimal Computing Budget Allocation (OCBA) framework is proved more efficient than other classical methods (Branke, Chick, and Schmidt 2007), and it is widely used in various complex problems (He, Chick, and Chen 2007; Lin and Huang 2014; Song, Qiu, and Liu 2016), we adopt OCBA as our simulation optimization methodology.

The objective function of OCBA is to find an optimal budget allocation rule to maximize the probability of correct select (PCS) the true best design under a constant computing budget.

$$\begin{aligned} &\max \ P(CS) \\ &s.t. \ n_1 + n_2 + ... + n_k = N, n_i \in n, i = 1, ...k, \end{aligned}$$

where N is the total number of simulation replications (budget), k is the total number of designs, n_i means the replications of i-th design, and n is the set of non-negative integers. Its main idea is to efficiently allocate replications based on the sample means and variables of each iteration. The details of the computing budget allocation rule are described as follows (Chen, Lin, Yücesan, and Chick 2000):

Step 1: Input N, k, Δ (additional computing budget of each iteration).
Step 2: Set initial iteration r as 0, then perform n_0 simulation replications for each design, which satisfies

$$n_1^r = n_2^r = ... = n_k^r = n_0$$

Step 3: If $\sum_{i=1}^{k} n_i^r < N$, go to Step 4. Otherwise, go to Step 7.
Step 4: In accordance with the outputs of the simulation runs, we calculate the sample mean $\overline{f_i}$ and sample standard deviation s_i, $i = 1, 2, ..., k$ of each design, and $b = \arg\min_i \overline{f_i}$.
Step 5: Increase the computing budget as Δ, and calculate the new budget allocation $n_1^{r+1}, n_2^{r+1}, ..., n_k^{r+1}$ according to

$$\frac{n_i^{r+1}}{n_j^{r+1}} = \left(\frac{s_i/(\overline{f_b} - \overline{f_i})}{s_j/(\overline{f_b} - \overline{f_j})} \right)^2, i \neq j \neq b$$

$$n_i^{r+1} = s_b \sqrt{\sum_{i=1, i \neq b}^{k} \left(\frac{n_i^r}{s_i} \right)^2}$$

Step 6: Perform additional $\max(n_i^{r+1} - n_i^r, 0)$ simulations for design i, $i = 1, ..., k$, and let $r = r + 1$, go to Step 3.

Step 7: In accordance with the outputs of the simulation runs, we identify the optimal design $b = \arg\min_i \overline{f_j}$.

4 CASE STUDY OF WHEAT MARKET

The agent-based simulation was implemented using the software AnyLogic. It is the first and only tool that brings System Dynamics, Discrete Event, and Agent Based methods together within one modeling language and one model development environment.

In this paper, we simulate China's wheat market as a numerical case, because wheat is one of the most important agricultural products in China, and it is the major grain that the Chinese government is regulating under current reserve policy.

The simulation time period covers the whole non-acquisition period, from October to May in the next year. In order to study the efficiency of the decision variables, including the auction time interval T, the auction quantity Q and the minimum sale price ratio ω under current auction policy, we analyze the optimal variable combination (T, Q, ω) in three different scenarios of supply and demand.

In these experiments, we define the auction time interval T to be 3, 4, 5, 4, 7, 8, 9, because the average auction time interval in these years is seven days. For the auction quantity Q, the average auction quantities of 2013, 2014, 2015 are 900000, 640000, and 840000 ton. Therefore, we define the alternatives set of Q to be 400000-1000000 ton, with 50000 a step (totally 13 alternatives). The minimum sale price ratio ω is defined as 99%, 99.2%, 99.4%, 99.6%, 99.8%, 100%.

In addition, we define the total computation budgets N as 5000, the initial number of simulations n_0 as 5, and the one-time increment Δn as 30. The average computation time of one replication is 6.17s.

4.1 Initialization of Wheat Market

We design simulation runs using historical data in 2014. According to the statistical information published by State Grain Administration, there are 3248 wheat processing enterprises (GPE) in China. The GPEs' scale (daily processing capacity) follows a distribution in Table 1. Most of GPEs are medium scale (200-400), there is a big group of small-scale GPEs in Chinese wheat market, and large-scale wheat GPEs are relatively few.

Table 1: GPEs' production scale distribution.

Daily capacity(ton)	<30	30-50	50-100	100-200	200-400	400-1000	>1000
No. of GPE	247	197	492	724	898	567	123
Daily output (ton)	7.4	23.9	43.3	93.5	181.7	362.2	1066.9

A grain trading enterprise(GTE) also stores grain. Thus we suppose that all GTEs provide wheat reserve. Based on the Chinese Grain Almanac of 2013, the number of market-oriented GTE is about 15500 (excluding state-owed GTE), and the scale distribution is described in Table 2.

Table 2: Scale distribution of GTEs.

Scale(kiloton)	<25	25-50	50-100	>100
No. of GTE	11964	1814	1114	608

We first input the full size and $1/5$ size of GTEs and GPEs in the simulation model, and we run 1000 times to obtain mean and variance values. In order to improve simulation speed, we reduce the scale of the GTEs and GPEs into $1/5$ equidistantly, which means 1 agent in our simulation represents 5 enterprises in reality. Under this assumption, there are 650 GPEs and 3100 GTEs in our model. For full size simulation, the run time is 30s for each replication, and for $1/5$ size, the run time is 6.17s for each replication. The mean value of the two cases are 5632.25 and 5503.90, the difference is acceptable and the simulation run time is much shorter for the $1/5$ size case.

Because it is difficult to find the data of wheat daily demand, we use the demand tendency by searching news and interviewing some wheat processing enterprises. We find two peaks of wheat demand in one year: one in September, and the other one in January. We assume that the demand A(t) follows the demand tendency in Figure 1. Other parameters about system environment, agent behavior strategies and GPEs' expected grain values in the simulation are listed in Table 3.

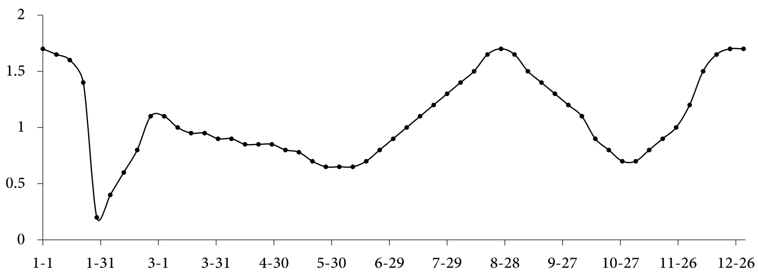

Figure 1: The curve of wheat demand tendency.

Table 3: Other parameters and values, where A_i and C_i represent ith-GPE's demand and production capacity.

Parameters	Values	Data source
Initial price(RMB)	2500	National Grain and Oils Information Centre
Price elasticity of finished goods	-0.7	Assumption
GPEs' transfer rate	73.1%	http://www.grainnews.com.cn
F_i: ith-GPE's maximum inventory level of finished goods	$10A_i$	Survey from Beijing Grain Group
f_i: ith-GPE's minimum inventory level of finished goods	$5A_i$	Survey from Beijing Grain Group
r_i: ith-GPE's inventory level of raw grain	$40C_i$	Survey from Beijing Grain Group
B: the average quantity of grain for an item (ton)	800	Survey from Beijing Grain Group

From Figure 2, we find even though the annual demand of wheat is relatively stable, the annual yield varies because of the change of grain-support policies and natural disasters. Firstly, in order to motivate farmers to produce grain effectively, the government establishes production support subsidies (includes subsidies for superior crop varieties, machine purchasing subsidies), direct subsidy and minimum purchase price policy to improve farmers' income. The change and abolition of these policies may reduce farmers' enthusiasm, according to the yield data and policy from 1999 to 2003. Secondly, China is one of the few natural disaster-prone countries in the world, droughts, floods and earthquakes great influence the yield. All these reasons bring about the scenario of insufficient supply.

We design three scenarios according to the yield and demand, which are the oversupply scenario, the insufficient supply scenario and the balance scenario. The oversupply scenario is a situation that the annual supply is more than the annual demand (we suppose a 5% surplus of supply). On the contrary, the insufficient supply scenario describes a situation that the annual supply is less than the annual demand, and the balance scenario means a balance of annual supply and demand of grain market. The initial grain reserve of each types of agents (NGR, GTE and GPE), the price tendency and the expectation of agents vary quite a lot in different scenarios. Thus, the optimal variable combination (T,Q and ω) under different scenarios shows different characteristics. We analyze the characteristics of the optimal variable combination under different scenarios using OCBA simulation optimization methods in 4.2-4.4.

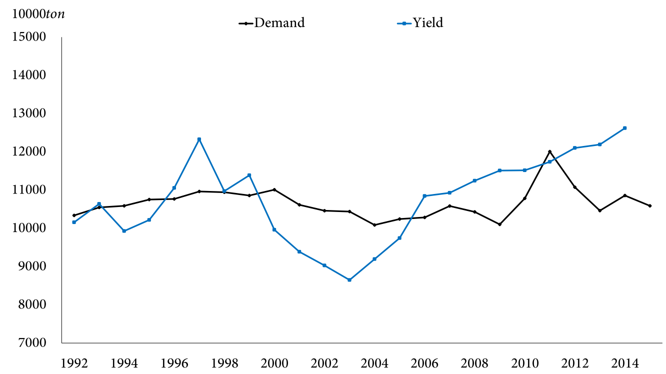

Figure 2: The supply and demand chart of wheat (1992-2015).

4.2 Oversupply

China's wheat production has increased for eleven straight years. However, the demand does not grow at that speed, and the imports of wheat and other succedaneums increase the situation of oversupply. The oversupply scenario is the most common scenario in China's grain market under the background of continuous growth of wheat yield.

In this scenario, the price of wheat decreases to the minimum purchase price that the government sets during the acquisition period, and then the government implements the procurement policy. On the contrary, GTE and GPE do not have a strong desire to reserve many wheat considering that the supply of market is sufficient enough to fulfill their demand. Therefore, a large amount of wheat is purchased by the government. We assume that in this scenario, the supply is 5% more than the demand of wheat market, and the average ratios of total grain reserve from NGR, GTE, GPE are 40%, 50% and 10% respectively.

The optimal auction strategy for the government under this oversupply scenario is $T = 4$, $Q = 600000$ and $\omega = 99\%$, and the optimal result is 2483. The result represents that when the NGR holds an auction every 4 days with 600000 auction quantity, and set the minimum sale price as 99% of the market price, we can obtain the minimum annual price fluctuation as 2483. Based on this result, we analyze each variable's sensitivity of T, Q and ω in Figure 3, while the other two variables are constant.

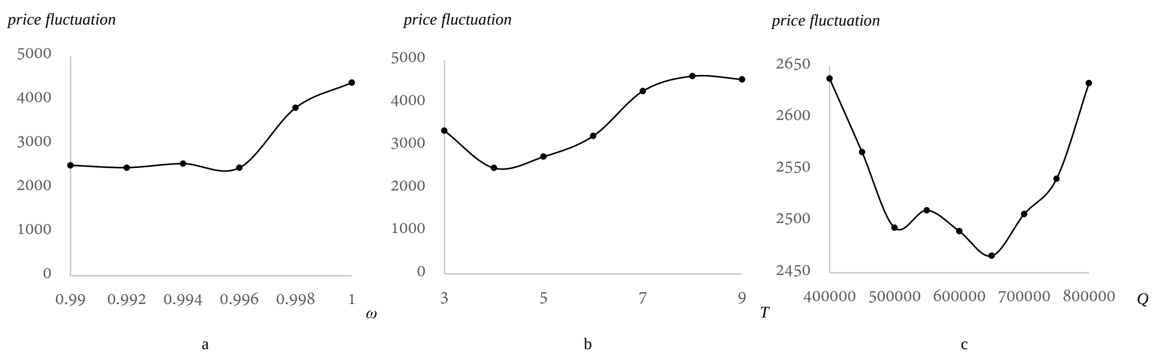

Figure 3: Variable sensitivity of ω, T and Q under oversupply scenario, where 3-a, 3-b and 3-c represent the fluctuation of wheat price under different ω, T and Q.

- When T and Q are constant ($T = 4$ and $Q = 600000$), from Figure 3-a, we find that the fluctuation of wheat price keeps stable and low when ω equals 99%-99.6%. When the value of ω becomes larger, the fluctuation of price increases rapidly. We conclude that the minimum sale price ratio ω plays an important role in stabling wheat price, and the critical point to stable wheat price is 99.6%.

- When Q and ω are constant ($Q = 600000$ and $\omega = 99\%$), from Figure 3-b, we find the minimum fluctuation of wheat price at $T = 4$. When $T < 4$, the auction is held too often that it may convey the signal of oversupply to wheat market, which results in the decline of wheat price. When the auction time interval $T > 4$, the supply of wheat in the grain market become insufficient, and GPEs have to raise their auction price to win the bid, which leads to the growth of wheat price.
- When T and ω are constant ($T = 4$ and $\omega = 99\%$), from Figure 3-c, the fluctuation of wheat price follows a u-shape curve, and the minimal fluctuation point is located in $Q = 650000$. The reason is similar to that of T: when Q is small, the market supply is insufficient, and to win the bid, GPEs have to increase the auction price in the end of the non-acquisition period. When the value of Q is large, the auction conveys the signal of oversupply to the market, and the signal cause price fluctuations.

4.3 Balance

The most idealized state of the market is the balance of supply and demand scenario. Under this scenario, the wheat price is relatively stable. The government purchases moderate grain reserve in the beginning, while GTEs and GPEs purchase more raw grain compared with the quantity under oversupply scenario. We assume the average ratios of total grain reserve from NGR, GTE and GPE are 30%, 55% and 15%.

The optimal design under balance scenario is the same with oversupply scenario ($T = 4, Q = 600000, \omega = 99\%$), and the result is 2842. The optimal auction strategy in balance scenario is same with that in oversupply scenario, because the NGR holds a moderate regulation under oversupply scenario and it does not release all reserved grain purchased in this year.

The variable analysis of T, Q and ω are shown in Figure 4.

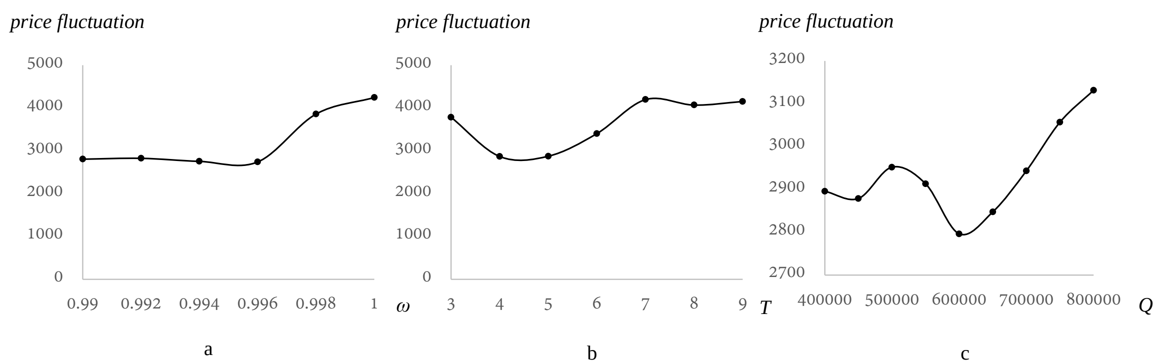

Figure 4: Variable sensitivity of ω, T and Q under balance scenario, where 4-a, 4-b and 4-c represent the fluctuation of wheat price under different ω, T and Q

- When T and Q are constant ($T = 4$ and $Q = 600000$), from Figure 4-a, we find the fluctuation of wheat price keeps stable and low when ω equals 99%-99.6%, but increases rapidly when $\omega > 99.6\%$. The curve is similar to that of oversupply scenario. The minimum sale price ratio ω plays an important role in stabling wheat price, and the critical point to stable wheat price is 99.6%.
- When Q and ω are constant ($Q = 600000$ and $\omega = 99\%$), we obtain the minimum fluctuation of wheat price at $T = 4$ (see Figure 4-b). When $T < 4$, the auction is held too often that it may convey the signal of oversupply to wheat market, which results in the decline of wheat price. When the auction time interval $T > 4$, the supply of wheat in the grain market become insufficient, and GPEs have to raise their auction price to win the bid, which leads to the growth of wheat price.
- When T and ω are constant ($T = 4$ and $\omega = 99\%$), the curve of price fluctuation in balance scenario is different with the oversupply scenario (see Figure 4-c). The minimal fluctuation point is located

in $Q = 600000$. When Q is small, the market supply may be insufficient, GPEs have to increase the auction price to win the bid, which causes a large price fluctuation; and when Q becomes larger, the auction conveys the signal of oversupply to the market, therefore, the price fluctuation increases when $Q > 600000$.

4.4 Insufficient Supply

In this scenario, wheat market price is higher than the government's minimum purchase price, and the government's reserve level is lower. Under this scenario, GTE and GPE have stronger desire to purchase as many wheat as possible, in case of the increase of market price in the future. Therefore, at the beginning period, wheat is mainly purchased by GTE and GPE. We suppose that the insufficient supply ratio is 5%, and the average ratios of total grain reserve from NGR, GTE, GPE are 15%, 60% and 25%.

The optimal auction interval T is 5, the auction quantity Q is 400000 ton, and the minimum sale price ratio ω is 99%, under this optimal design, the minimum annual price fluctuation is 3688, which is much larger than those of other two scenarios. That is because of the restriction of initial reserve of the NGR, NGR has to increase its auction interval T and reduce the auction quantity Q to realize a long-time regulation to the wheat market. The minimum sale price ratio ωs are the same in three scenarios. The variable analysis of T, Q and ω are shown in Figure 5.

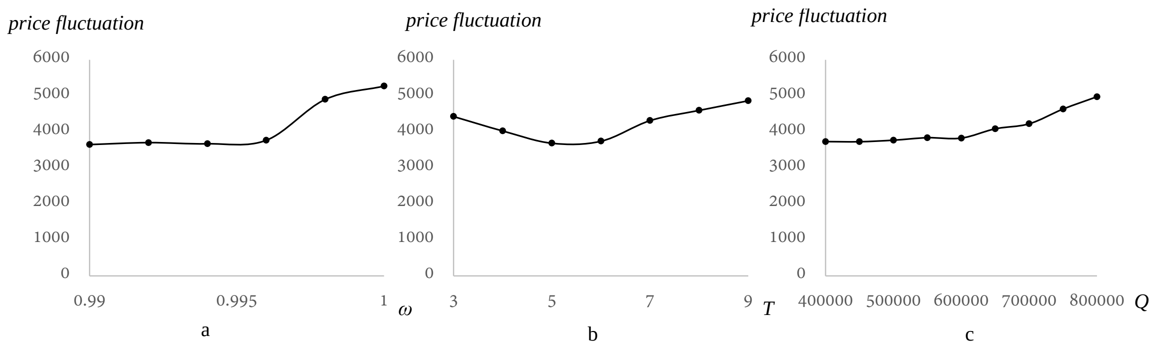

Figure 5: Variable sensitivity of ω, T and Q under insufficient supply scenario, where 5-a, 5-b and 5-c represent the fluctuation of wheat price under different ω, T and Q

- When T and Q are constant ($T = 4$ and $Q = 600000$), we find that variable sensitivities of ω is similar to those of other scenarios (see Figure 5-a), but the annual price fluctuation is higher than other two scenarios because of the insufficient supply.
- When Q and ω are constant($Q = 600000$ and $\omega = 99\%$), we obtain the optimal auction interval T between 5 and 6. When T become larger, the fluctuation rate of wheat price is less than the other two scenarios (see Figure 5-b). Because the NGR has insufficient wheat reserve to regulate the wheat market for a long time as T becomes larger.
- When T and ω are constant ($T = 4$ and $\omega = 99\%$), from Figure 5-c we find that the fluctuation of wheat price increases with the auction quantity Q, which is quite different with those of two above scenarios. The reason may be that the NGR will realize a longer regulation of grain market when Q is small under the situation that the NGR has insufficient wheat reserve under this scenario.

5 CONCLUSIONS

This paper develops an agent-based simulation model of China's grain market with detail descriptions of different agents, including national grain reserve, grain trading enterprises and grain processing enterprises. Based on this model, we analyze the characteristics of optimal combination of decision variables under different scenarios using OCBA simulation optimization method. In summary, the insights of this simulation model are as follows.

1. The minimum sale price ratio ω and auction time interval T have greater influences on the fluctuation price than the auction quantity Q in any scenario. 2. The optimal auction strategy of oversupply and balance scenarios are similar. Both the value of auction time interval T and the value of auction quantity Q are close to the mean value, and a lower minimum sale price ratio ω contributes to stable market price. 3. The minimum fluctuation price under insufficient supply scenario is larger than those of other two scenarios. To ensure an overall regulation effect, the government should increase the auction time interval T and reduce the auction quantity Q.

This is the first agent-based simulation model about China's national grain reserve auction policy and the grain market. To simulate the accurate decision strategy of market agents in this simulation model, we referred to relevant literatures, investigated grain processing enterprises and grain trading enterprises, and interview several officials of State Administration of Grain. This model can be modified to evaluate the response of grain market under different situations, such as the breakout of emergencies and implementation of the new policies. This simulation model can further be modified through subdividing market agents, and correspondingly, more uncertainties need to be consid ered. We also can subdivide the GPE agents in accordance with the usage of raw grain they purchased. Furthermore, the performance measures of simulation can be more comprehensive through considering more objectives. We leave all these work to the future study.

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