Deterministic Analysis and Research on Reasonable Purchase Price Range Based on Multi-Objective Fuzzy Optimization Model

Jiaqi Cao
Northeast Forestry University, Harbin, Heilongjiang, 150000, China
1393239448@qq.com

Abstract. Reasonable purchase price has multiple objectives, it is necessary to take into account the increase in food and industry income, but also take into account the development of the entire grain industry, and even to consider improving production efficiency. This paper chooses the minimum purchase price of wheat, the market purchase price, the output and the grain income and the production efficiency as variables, and takes the lower limit of the grain and farmers' income, the upper limit of the market price and the minimum purchase price, the supply and demand relationship, the inventory restriction, the financial support ability and the scope of international food price as constraints, establishing multi-objective fuzzy optimization model to explore the government's optimal minimum purchase price decision-making mechanism. Through analysis, it was found that the minimum purchase price developed by the state did not increase the area of grain cultivation, but it effectively inhibited the reduction of grain planting area. Finally, we use this model to predict the minimum purchase price for food for 2017, with a reasonable range of: (115.52, 121.54).

1. Introduction
Food is not only the necessities of daily life, but also the strategic material to maintain national economic development and political stability. However, food security issues have become a worldwide strategic issue. In order to promote grain production, increase farmers' income and avoid the sharp fluctuation of grain prices, China has started to implement the minimum purchase price policy in the main grain producing areas since 2005 and raised the minimum purchase price continuously for many years.

But when comes to evaluate the implementation effect of the minimum purchase price policy, scholars have different attitudes. Some scholars believe that the minimum grain purchase price policy distorts the law of market pricing because some local food varieties planted area does not increase. Thus the policy effect is doubtful. But there are scholars highly affirmed the minimum grain purchase price policy, reckoning that some varieties of grain planting area may fall faster in some regions without the implementation of the minimum grain purchase policy and that the policy contributes significant effect in stabilizing or increasing the food planting area.

This paper constructs a multi-objective fuzzy optimization model under the constraints such as increasing grain and agriculture, sustainable development of grain industry, production efficiency, trade difference, market price ceiling, lower limit of labor income, smooth supply and demand, inventory capacity, total area and international price to find the possible range of the minimum purchase price,
compared with the published price to make a reasonable evaluation, meanwhile to predict a sound range for the 2017 grain minimum purchase price.

2. Based on panel data collection
Through collecting the panel data of the main grain producing areas that carry out the minimum purchase price policy since 2005 (data from the China Statistical Yearbook and the national agricultural cost data compilation), using this model to find the most reasonable acquisition price model interval, evaluate the rationality of the minimum grain purchase price, and predict the reasonable range for the 2017 grain minimum purchase price.

3. Optimization model
Reasonable purchase price has multiple objectives, it is necessary to take into account increasing food and industry income, but also take into account the development of the entire grain industry, and even to consider improving production efficiency. On the other hand, we should also consider some constraints, including: the estimated cost in planting grain, the opportunity cost, the actual planting income and the production price, etc., to determine the country’s expected net income range of food and agriculture labor (at least to get the lower limit (At least the upper limit); to reach the food demand through the theory of supply and demand balance. Therefore, we could estimate the effective area of grain cultivation, inventory capacity and financial support as well as international food price.

Therefore, the ideal minimum purchase price should achieve maximum economic efficiency under multi-objective and multi-constraint conditions. By constructing a multi-objective fuzzy optimization model, we analyze the interaction relationship between the minimum purchase price policy and some variables such as the cultivated area, yield level, production cost, grain and agriculture income and technological progress, and discuss the implemented optimal decision mechanism of the minimum purchase price by the government and the optimal subsidy policy mechanism under conditions of securing food safety and WTO "trace" permission. So we built the model as follows:

3.1. Objective function
(1) The largest area of grain cultivation
We learned from the documents that farmers always determine this year's planting area based on previous experience while cultivating crops. So the choice of farmers’ decision-making to plant is influenced by previous decisions.

At the same time, the impact of the minimum purchase price on the acreage is time lagged, and we analyze the correlation between the first order lag and the second order lag of the area and time. Therefore, we have established the autoregressive distribution hysteresis model for the rest index wheat planting area. The second order is the most reasonable lag order determined by AIC \ SC criterion. The model is as follows:

\[ S_t = \beta_1 S_{t-1} + \beta_2 S_{t-2} + \beta_3 x_{t-1} + \beta_4 x_{t-2} \]

Using the Eviesws software to estimate the result of parameters, \( S(-1) \) and \( S(-2) \) are not through the significance test. So we remove it from the model, and then test the remaining variables, the results are as follows:

Table 1. Test results for the remaining variables

| Variable | Coefficient | Std.Error | T-Statistic | Prob |
|----------|-------------|-----------|-------------|------|
| \( x_{t-1} \) | 42.6478 | 2.013 | 1.8463 | 0.0450 |
| \( x_{t-2} \) | -36.492 | 1.244 | -1.5899 | 0.0271 |
| C | 35354 | 75.35884 | 26.05493 | 0.0000 |
| R-squared | 0.852067 | | | |
| Durbin-Wastron stat | 2.7573 | | | |
As can be seen from the table above, the coefficient $\beta$ passed the test in the case of a significance of 0.01 with a significance, the model eventually is:

$$S_t = 42.67x_{t-1} - 36.49x_{t-2} + \varepsilon_t$$

It can be seen from the model that the minimum grain purchase price at No.(t-1) period has a positive effect on the acreage, while the grain purchase price at No.(t-2) period has a negative effect, but it is not as good as No.(t-1) period because of its poor notability. On the whole, the grain acreage is affected by the hysteresis effect. Raising the minimum purchase price of grain will promote the expansion of the latter grain area.

(2) The highest income of grain farmers

From the economic point of view based on the analysis of rational people, each producer is in the pursuit of the greatest interests. Similarly grain farmers pursue profits through grain cultivation. If grain farmers’ income is lower than their opportunity cost, planting costs, etc., the grain farmers will reduce or abandon the grain cultivation, which will affect grain production in China. Therefore, in order to protect China's food security and improve the competitiveness of China's food in the international arena, protecting grain farmers’ income is essential. So the goal is:

$$\max_{y_t, o_t} c_{2t}, \quad t = 1, 2, \ldots, n$$

Among them, $y_t$ represents the market purchase price, $o_t$ denotes the total annual output, $c_{2t}$ denotes the cost.

(3) Keep balance between supply and demand as much as possible

As a special commodity, grain has great price elasticity of supply and tiny price elasticity of demand. Grain production cycle and fluctuation intertwined leading to difficult control. Simultaneously food issues have a "magnification" effect. The tension of supply and demand may cause large fluctuations and bring a chain reaction because food is a kind of necessity. China's grain demand shows rigid growth, but at the same time a variety of factors restrict the improvement of supply capacity. In the face of China's food security risks, enhancing the grain production ability is critical to achieve balance between food supply and demand. So the goal is:

$$\min_{s_t, o_t} \text{abs}(k_s s_{t-1} + s_t - r_t)$$

Among them, $s_t$ represents inventory in current year, $r_t$ represents that year’s crop demand (consumption), $o_t$ represents the annual total output.

3.2. Constraints

(1) To restrict the upper limit of the minimum grain purchase price:

Too-fast growth of the minimum grain purchase price will also have negative impacts and will widen the gap with the international food prices, which makes China's food be in a disadvantageous position and weaken our competitiveness. So the upper limit of the minimum grain purchase price should be restricted to stabilize the food market price.

$$\frac{x_t - x_{t-1}}{x_{t-1}} < \frac{GDP_t - GDP_{t-1}}{GDP_{t-1}}$$

Among them, $x_t$ represents the minimum grain purchase price when the year is $t$, $GDP_t$ represents per capita GDP when the year is $t$. 
(2) To restrict the market price which consumers can bear

Too-fast growth of the minimum grain purchase price has negative impacts. Previous analysis shows that the increase of the variable $x$ will lead to increased food prices, increase the burden on consumers and bring social pressure, which is not conducive to sustainable socio-economic development. So market prices should be constrained to stabilize the economic development and improve the level of social welfare.

In order to constrain the growth of grain market prices, we define the constraint coefficient $\lambda$ which represents the maximum rate of grain market price’s growth (based on the previous year) relative to $CPI$, and therefore the formula below should be met:

$$\frac{y(t)}{y(t-1)} \leq \lambda CPI(t)$$

Among them, $y$ represents market price, $CPI$ represents per capita consumption price index of residents when the year is $t$.

(3) To constrain Stable supply and demand

On the one hand, with the development of China’s economy and the improvement of urbanization level, more and more land is used for development and construction, which is bound to reduce the area of cultivated land in China. At the same time, more and more rural youth choose to develop in large cities, so that the agricultural labor force will be reduced. The reduction in the area of grain cultivation coupled with the decline in the labor force engaged in agricultural production will reduce food production, which will exaggerate the tight balance of grain production in China and threaten China’s food security.

On the other hand, that food supply and demand for a long time stay in an unbalanced state that food is in short supply, not only will increase the market price of food, but also exacerbate the burden on consumers, which is not conducive to the improvement of living standards. As domestic food prices are more expensive than international food prices for a long time, China will import a large number of foreign food in order to reduce the cost and obtain greater profits. China’s food competitiveness at a disadvantage can not be effective protection of China’s agriculture; long-term imports of foreign food will cause China’s food deficit, which constitutes a great threat for China’s food security.

To constrain Stable supply and demand, we define parameters of balance between supply and demand:

$$k \cdot s_{t-1} + o_t - r_t > 0$$

Among them, $o_t$ the total output (years), $s_t$ represents inventory that year, $r_t$ and represents the demand.

At the same time to meet: the annual production must also be greater than the demand, but the future demand for food is difficult to obtain, so we study the link between the demand of food and other indicators by establishing regression equation. We selected some indicators, using the data of previous years to do the relevance test. The selected indicators need to meet two conditions:

A. There is a high correlation between the index and the demand.
B. There is no significant correlation between indicators and indicators.

According to the test results, we chose per capita GDP and population as independent variables.

| Table 2. Correlation coefficient |
|----------------------------------|
|                                | Demand | Per capita GDP | population |
| Demand                          | 1      | 0.975          | 0.989      |
| Per capita GDP                  | 0.975  | 1              | 0.634      |
| population                      | 0.989  | 0.634          | 1          |
We constructed the regression equation model for grain demand as follows:

Let the observed value of independent variables \( x_1, x_2, x_3, \ldots, x_p \) and the observed value corresponding to the dependent variable satisfy the relation:

\[
Q_i = \beta_0 + \sum_j \beta_j x_{ij} + \epsilon_i, \quad i = 1, 2 \cdots n; \quad f = 1, 2 \cdots p
\]

According to the least squares method, we could get:

\[
\hat{\beta} = (X^T X)^{-1} X^T Y
\]

(4) To constrain the expected net income of farmers labor every acre (planting costs, opportunity costs, etc.)

The expected net income of farmer’s labor every acre reflects grain farmers’ expectation towards profits which are estimated based on the previous planting costs, the opportunity cost, the actual planting income and the production price. If the estimated net grain income is lower than previous income actually, the grain farmers are likely to reduce or abandon the cultivation of food and plant other high-yield cash crops or engage in other industries, which will lead to the reduction of grain acreage, so we need to limit the expected net income of farmers labor every acre to ensure the labor planting grains and stabilize grain production.

In order to constrain the expected net income of farmers labor every acre, we define that the income of the crops is greater than or equal to the income of other crops; the income of the crops is greater than or equal to the income of the other industries; and the increase rate of grain farmers’ income is greater than or equal to the growth rate of GDP, so it should meet the conditions as follows:

\[
\begin{align*}
G_t &= \max(P_{t1}, P_{t2}, P_{t3}) \\
\frac{P_{at} - P_{at-1}}{P_{at-1}} &> \frac{GDP(t) - GDP(t-1)}{GDP(t)} \\
P_{at} &> G_t
\end{align*}
\]

Among them, \( G_t \) represents the opportunity cost, the cost of planting, \( P_{t1}, P_{t2}, P_{t3} \) represents the profits of three other crops (years) respectively, \( P_{at} \) represents the selected crop profits (years), \( GDP(t) \) represents capita GDP that per.

(5) To constrain food stocks

At present, although China's grain shows new phenomenon called "three volume Qi Zeng" as for total output, inventory, imports. On the one hand, granary almost have no place for food with harvest year after year. On the other hand, the grain import is increasing and the number strikes the new record over and over again. The new "Three volumes Qi Zeng" phenomenon is not only affected by domestic and foreign grain upside down and other factors, but also shows clear deviations and structural contradictions in China's grain supply structure and demand structure. In order to promote the structural reform at the supply side of the grain industry, consuming high food stocks reasonably and orderly is the normal performance for grain industry taking the initiative to adapt to the new economic development. Therefore, facing the situation that China’s food stocks are too high, the government needs to reduce the grain stock to promote reform at the supply side.

In order to restrain grain stocks, documents show that it is reasonable when grain stock is equal to 18% of the crop demand that year, so we need to meet:
Among them, \( o_t \) indicates the total output (years), \( s_t \) represents the stock that year, \( r_t \) said the year crop demand (consumption).

(6) To constrain financial support ability

Too high grain minimum purchase price will not only increase the food market price and thus increase the burden on consumers, but also increase the pressure on grain inventory and national financial expenditure risk, which may bring the fiscal deficit and then appear "stagflation situation" which is not conducive to economic development. Therefore we need to limit the government's financial support.

In order to restrain the financial expenditure, we have learned that it is reasonable when the difference between the minimum purchase price and the market purchase price is less than or equal to 10% of the market purchase price, so we need to meet:

\[
\frac{s_{t+1} + o_t - r_t}{r_t} - d^+ + d^- = 18\%
\]

Among them, \( r_t \) said the current market grain pricing.

(7) To restrict international food prices

By collecting the international grain price data (take the United States as example), we establish the linear regression relationship with China's grain market purchase price:

\[
y''_t = 0.56 y'_t + 24.04
\]

Among them, \( y'_t \) represents international food price.

According to the fluctuation range of international food prices, we determine that it should fluctuate in (40, 80), so we get the constraint:

\[
40 < y'_t < 80
\]

3.3. Multi-objective fuzzy optimization model based on the above constraints and objective functions

According to the above constraints and objective functions, we can get the following multi-objective fuzzy optimization model:
3.4. Solution to Multi-objective Fuzzy Optimization Model Based on SA

Simulated annealing algorithm originates from the solid annealing principle which is described as follows: make the solid heated to full high and then let it slowly cool, the solid particles get into disorder with the temperature rise when heating and the internal energy increases, and particles tend to be orderly when slowly cooling, to reach equilibrium state at each temperature, finally reach the ground state at room temperature and the internal energy can be reduced to a minimum. By giving the search process time-varying and ultimately towards-zero probability of sudden jump, simulated annealing algorithm is a kind of serial structure optimization algorithm which can effectively avoid falling into the state of local minimum and finally towards the global optimization.

Simulated annealing algorithm can be decomposed into solution space, objective function and initial solution. The implementation process is as follows:

Step 1: initializing, set an enough high temperature $T_0 = 100\, \text{K}$, set the initial value for each variable to determine the Metropolis chain length that is the number of iterations at each temperature $\text{iter} = 100$;

Step 2: for the current temperature, according to the length of the iteration, circulate the following step 3 and 4,

Step 3: Generate the value of a new variable by random number, and find the difference between the new solution and the current solution objective function $\delta e$. According to the Metropolis principle: if $\delta e > 0$, then accept the new solution, otherwise accept the new solution with probability $\exp(\delta e / T)$, amongst $T$ is the current temperature;

Step 4: If get termination speed after the cooling, then exit the output of optimal solution, otherwise let $T_0 = q * T_0$, $q$ is the cooling rate. In this question, let the value of $q$ be 0.99 and the value of termination temperature be 0.01.

According to the above steps, the simulated annealing algorithm model for solving the optimal projection direction can be expressed as follows:
Use matlab software to simulate the iterative process of annealing, and select the maximum objective function value constantly, finally exit cycle after meeting the termination temperature $T_{end}$. (See appendix for procedures)

For each year during Twelveth Five-Year Period, we can get the actual range of each variable, use SA to search the range of each variable, so that the objective function will achieve the maximum, thus get the value of optimal minimum purchase price. Since SA is the algorithm for approximating the optimal value, the optimal minimum purchase price is a range, the results are as follows:

**Table 3. Model results**

| Year   | minimum purchase price range | the largest farmers in the country | largest total income area |
|--------|-------------------------------|-----------------------------------|---------------------------|
| Year2011| (101.68, 110.27)            | 3.29*10^8                        | 36405.57                  |
| Year2012| (109.24, 115.34)            | 3.59*10^8                        | 36402.42                  |
| Year2013| (105.71, 112.53)            | 3.48*10^8                        | 36175.50                  |
| Year2014| (108.39, 116.87)            | 3.45*10^8                        | 36104.13                  |
| Year2015| (110.58, 118.23)            | 3.61*10^8                        | 36212.05                  |

3.5. Evaluation on the Rationality of National Minimum Purchase Price during the Twelfth Five-Year Plan Period

According to China Statistical Yearbook, the minimum purchase price issued by the government during the Twelfth Five-Year Plan Period is as follows:

**Table 4. The minimum purchase price during the Twelfth Five-Year Plan Period**

| period | Year 2011 | Year 2012 | Year 2013 | Year 2014 | Year 2015 |
|--------|-----------|-----------|-----------|-----------|-----------|
| Minimum purchase price | 95        | 102       | 112       | 118       | 118       |

According to the above-mentioned range of best and lowest prices, the three-year data for 2011, 2012 and 2014 don’t fall within the optimal minimum purchase price range, they overtake half of the total number, so we think the constitution of the state's lowest purchase price was unreasonable.

3.6. To forecast reasonable range of minimum purchase price in 2017

By predicting the range of each variable in 2017, we can search values within the range by SA to maximize the weighted target value.

**Table 5. Minimum purchase price of each year**

| variable                           | Variable range    |
|------------------------------------|-------------------|
| Minimum purchase price for 2015    | (130,135)         |
| Minimum purchase price for 2016    | (135,140)         |
| 2015 market purchase price         | (120,125)         |
| 2016 market purchase price         | (123,127)         |
| Per capita GDP                     | (60000,65000)     |
The range of the optimal minimum purchase price is (115.52, 121.54). Therefore, the forecasted range of the lowest purchase price in 2017 is (115.52, 121.54).

4. Conclusion
In this paper, through the establishment of multi-objective optimization model to reasonably infer and analyze the price of grain purchase price in recent years, we found:

(1) The data in 2011, 2012 and 2014 calculated through model are not consistent with the minimum grain purchase price in the three years. Therefore, it is considered that the minimum purchase price of the country is unreasonable.

(2) Through our prediction, we found that the best price for grain acquisition in 2017 was (115.52, 121.54), which was lower than previous value. We analyzed that this was mainly caused by excessive supply and short demand because of the increase of grain production in whole country.

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