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An optimal raw material procurement strategy that minimizes enterprise price risks

Arkadiy I. Maron[a*]
E-mail: amaron@hse.ru

Maxim A. Maron[b]
E-mail: maxxx-fizik@mail.ru

Anastasiia A. Kazmina[c]
E-mail: anastasiiaka@kaist.ac.kr

[a] HSE University, Moscow, Russia

[b] Cifra Bank LLC, Moscow, Russia

[c] Korea Advanced Institute of Science and Technology (KAIST), Daejeon, Korea

Abstract

This article is devoted to the problem of theoretical and information support for decision-making in strategic management of raw material procurement processes. The study is timely, because there is currently significant volatility in prices for raw materials. This poses very difficult challenges for managers. Finding solutions is one of the most important areas of business informatics. This article discusses a procurement strategy in two stages: at the beginning and middle of the month. The price of raw materials is known only at the beginning of the month. Price is a continuous random variable. You can predict only the interval of its change. Here the interval is directly used to determine the

* Corresponding Author

purchase volume at a known price. The authors derived a functional dependence of the maximum risk according to Savage on the amount of purchased raw materials at the beginning of the month. As a result, it was possible to establish the amount of raw materials to be purchased at the beginning of the month to reduce maximum risk to a minimum. Using the example of corn purchases, we carried out a comparative analysis of possible methods for determining these intervals based on an analysis of price time series. The findings are useful for managers of processing enterprises. This work is the first to solve the problem of minimizing the maximum risk when purchasing raw materials.

Keywords: statistical decision theory, risk, Savage criterion, raw material procurement

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Introduction

The cost of grain purchases is the main component of the production costs of enterprises producing products from grain. For example, at one of the largest distilleries in Russia, more than 60% of the final cost of alcohol is determined by the purchase price of grain [1]. The volatility of prices leads to uncertainty of future revenues [2].

Not only grain prices, but also production raw material prices in general are more volatile than currency exchange rates and interest rates [3]. Since 2000, the volatility of these prices has increased rapidly. Although the problem of price volatility affects many sectors of the economy, one of the most volatile segments is that of grains. While the volatility of grain prices has historically averaged 19.7 percent, between 2006 and 2011 this indicator reached extremely high values of 30 to 50 percent [4]. This is mainly due to the strong correlation of this risk with the global economic situation. Extreme weather conditions, political instability and currency fluctuations are some of the factors that affect the price of primary commodities. Based on research conducted by the British international firm Aon since 2013 the risk associated with price volatility has returned to the top 10 most dangerous risks for a company [5]. For 2019, 45 percent of respondents said they had suffered a loss related to this risk. The issue of developing new methods to manage this risk has become acute. This is a current research topic in business informatics. The theoretical results of such studies are the basis for the development and implementation of recommendation information and analytical systems that take into account price risks.

In conditions of uncertainty and an enormous number of factors influencing price changes, the goal of companies is to build a raw material procurement model that minimizes the impact of exogenous factors of price volatility on total costs.

Before constructing and analyzing mathematical models for determining the optimal procurement plan, it is necessary to accurately classify the risk associated with price volatility and identify common strategies to minimize it. This risk can be considered as a financial risk, since it has a significant impact on the economic performance of the company, as well as on the cash flow [6]. There are three main strategies to deal with this risk [7]: sourcing strategies, contracting strategies and financial strategies. In the first strategy, the company can influence the timing and quantity of raw materials to be purchased to minimize the impact of price volatility. The second approach involves a priori contracts with suppliers in the event of sudden price changes. Financial strategies use exchange-traded derivatives such as futures and options.

Let us consider approaches to determining the timing and volume of raw material purchases for manufacturing companies. A significant number of works are devoted to this issue. Their topics can be divided into the following groups.

The first group includes works devoted to determining the frequency and volume of purchases, when the requirements for production volume are met and costs are minimal. These are works on inventory management. The formulation of these problems gradually became more complex, from constant demand to variable demand [8], from finite to infinite planning period [9]. Accordingly, more and more constraints were removed, and the model of inventory management became closer to the real situation [10]. Not all constraints can be removed by analytical solution. Accordingly, simulation modeling has been used to consider a large number of factors to solve inventory management problems. The main paradigms of simulation modeling in solving inventory management problems are system dynamics and agent-based model.

The second group includes works that propose to make decisions about the time and volume of purchases based on forecasts of prices of purchased goods. Most of these works are related to exchange-traded commodities and instruments. Here we can distinguish two main directions: fundamental analysis and technical analysis [11]. Fundamental analysis involves the analysis of general macroeconomic factors and industry factors [12]. The conclusions drawn from fundamental analysis are based on economic theory. However, the manager in charge of purchasing commodities usually has a very short time frame in which to make a purchase. On the other hand, fundamental analysis involves a complex analysis of many factors and, most importantly, is not precise enough to decide on the choice of the moment to buy a commodity with a small acceptable time range of change of this moment.

Technical analysis is an attempt to predict the future based on the past, taking into account the behavior of market participants [13]. The apparatus of technical analysis is very diverse. It uses both a simple visual method and the most complex numerical method of successive approximations – neural networks [14]. First, technical analysis is used when working on the stock and currency markets. Many researchers are skeptical about technical analysis: they question the possibility of predicting the future from the past without a convincing explanation of the possibility of such a prediction [15].

Let's consider a situation typical of grain processors. You know how much grain you need to buy for the month. The purchase can be made at the beginning of the month and in the middle of the month. The manager responsible for the purchase knows the price at the beginning of the month. The price in the middle of the month is unknown. There are three options: the manager can buy all the grain he needs at the beginning of the month, the manager can buy all the grain he needs in the middle of the month, or he can buy part of the needed amount at a known price at the beginning of the month and the rest at a known price in the middle of the month. The manager must decide which option to choose. If the manager knew that the price of grain would increase by the middle of the month, he would choose the first option. If he knew that the price would fall, he would choose the second option. Since the price in the middle of the month is unknown, the third option is also a competitive method of minimizing unnecessary costs. To make the choice, we need to estimate the possible value of the price of grain in the middle of the month.

The question is how much grain to buy at the beginning of the month. For grain, there are several factors that make predicting its price based on numerical price series for previous years quite reasonable. These are well understood demand and seasonality [16]. Seasonality makes it possible to forecast the current value of the grain price for the middle of the month as an average of the prices for that month in previous years. The question of how many values to use for a more accurate forecast is answered differently by different researchers [17]. A stable opinion is that for forecasting grain prices one should focus on a small number of years, approximately up to 10, preceding the year in question. Sometimes a longer period is used, but the values closest to the year in question are given more weight. An alternative to the average forecast is the approach of predicting the mid-month price by extrapolation [18]. Different extrapolation functions are used [19]. The most common are exponential extrapolation and the use of polynomials. Extrapolation is used when the researcher assumes that a given year will be significantly different from previous years. When it is necessary to take into account political factors that have no direct analogues in the past, the use of expert judgment is most acceptable.

The authors of the above-mentioned works, suggesting making decisions based on the forecast, propose to forecast the future value of the price as a point. It is noted that the forecast has an error, i.e., the expected value of the real price belongs to a certain segment. The value of this segment is defined in different ways. For example, when using the mean-variance forecast, it is assumed that the forecast deviations have a normal distribution, which should be checked in each case. Despite the remark about the value segment, it is the single predicted value that is used for decision making. If it is greater than the known value, we buy everything at the known price. If it is less, we wait.

In paper [20] the problem of selling euro to obtain a given amount in rubles, given that this operation can be performed at two points in time was considered. In the first one the exchange rate is known, in the second one it is not. We find the value of the funds to be sold at the known exchange rate to minimize the maximum conversion risk. Risk is defined by Savage. It is the difference between the sum of what we will spend by selling a certain amount of money in euro at a known rate, and the rest at the rate that will be, and the minimum amount that we could spend if we knew what the rate would be at the second moment. The formula for the calculation directly involves the limits within which we are to find the rate unknown to us at the second moment of time. In [21] this approach is extended to the case when we must perform a double conversion. The approach proposed in [20] for currency conversion is also applicable to other goods when solving the problem of how much of a good to sell at a known price to get a given amount of money, while minimizing the maximum risk of unnecessary costs. The direct use of price variation bounds in choosing a solution seems more reasonable than focusing on a single value. The future value of the price is a continuous random variable. The probability that it will take a particular value is zero. The probability that the value of that quantity falls within bounds is no longer zero. Potentially, this fact makes the approach based on direct use of the bounds of possible price changes in solving the above problem more reasonable than calculations based on a single predicted value of price in the future.

1. Materials and methods

As the objective function for determining the quantity of grain to be purchased at a known price, we will consider the risk of excessive procurement costs (REPC). This risk is the difference between the amount of money we will spend by purchasing a certain amount of grain at the beginning of the month at a known price and the remaining portion at the price that will be in the middle of the month, and the minimum amount we could spend if we knew the price of grain in the middle of the month. Minimizing the maximum of this risk is necessary. The criterion for minimizing the maximum risk is the Savage criterion. Accordingly, the results presented below are based on methods of statistical decision theory. Existing data on grain prices, grain price indices, and agricultural product price indices [22] are used to assess the effectiveness of the proposed approach.

2. Results

2.1. Statement of the Mathematical Problem

The company needs to purchase grain in the amount of V units per month. Purchases can be made at the beginning and in the middle of the month. The price at the beginning of the month, C_1 is known. The price in the middle of the month, C_2 is unknown. It is assumed that it will be within the range $[C_{min}; C_{max}]$.

It is required to determine the quantity of grain, denoted as x^*, that should be purchased at the beginning of the month to minimize the maximum risk.

2.2. Solution

Let x be the amount purchased at the beginning of the month. Then the amount $F(x, V)$ that needs to be spent to buy V units of grain is as follows:

$$F(x,C_2) = x + \left(V - \frac{x}{C_1}\right)C_2. \quad (1)$$

To determine the function that describes the maximum risk, two possible cases of the price relationship between C_1 and C_2 need to consider.

If it were known in advance that $C_2 \geq C_1$, then the purchase should be made for the amount $x_1 = C_1V$ at the beginning of the month. The risk in this case is the difference between the actual expenses $F(x, V)$ and the minimum possible ones:

$$R_1(x,C_2) = x + \left(V - \frac{x}{C_1}\right)C_2 - C_1V. \quad (2)$$

In expression (2), the third term is constant. The fraction subtracted from V in the second term does not exceed it. Therefore, the second term in (2) is non-negative. Consequently, with a fixed value of x, the risk $R_1(x, C_2)$ reaches its maximum value when $C_2 = C_{max}$. Expression (2) can be written as

$$R_1(x,C_2) = x\left(1 - \frac{C_2}{C_1}\right) + V\left(C_2 - C_1\right). \quad (3)$$

Substituting $C_2 = C_{max}$ into (3), we obtain the expression for the maximum risk when $C_2 \geq C_1$:

$$R_{1max}(x) = x\left(1 - \frac{C_{max}}{C_1}\right) + V\left(C_{max} - C_1\right). \quad (4)$$

The fraction subtracted from 1 in the first term of (3) is not less than 1. Therefore, in (4), the coefficient for x is negative. The second term is a positive constant. From expression (4), it follows that when $C_2 \geq C_1$, the maximum risk $R_{1max}(x, C_2)$ decreases as x increases. The maximum value is reached at $x = 0$:

$$R_{1max}^{max} = V\left(C_{max} - C_1\right). \quad (5)$$

As x increases, the maximum risk decreases to 0 when $x = C_1V$.

If $C_2 < C_1$, it is advantageous to make all purchases in the middle of the month for the amount $x_2 = C_2V$. The risk in this case is:

$$R_2(x,C_2) = x + \left(V - \frac{x}{C_1}\right)C_2 - C_2V = x\left(1 - \frac{C_2}{C_1}\right). \quad (6)$$

In (6), the fraction subtracted from 1 does not exceed 1. This fraction is minimized when $C_2 = C_{min}$. Therefore, with a fixed value of x, the maximum risk will be at $C_2 = C_{min}$, and we have:

$$R_{2max}(x) = x\left(1 - \frac{C_{min}}{C_1}\right). \quad (7)$$

At $x = 0$, this maximum risk is 0. As x increases, it grows and reaches its maximum value at $x = C_1V$:

$$R_{2max}^{max} = V\left(C_1 - C_{min}\right). \tag{8}$$

The maximum of the maximum risk for grain procurement, given that $C_2 \in [C_{min}; C_{max}]$ is the greater of the values determined by formulas (5) and (8).

In the case where the assumed range of possible values of C_2 is symmetrical with respect to the C_1 value, the values determined by these formulas coincide. In this case, by denoting d as half of the length of the assumed possible price change range, we get the following expression for the maximum of the maximum risk:

$$R_{max}^{*} = Vd. \tag{9}$$

Based on the analysis of two possible relationships between C_1 and C_2, the maximum risk in grain procurement is as follows:

$$R(x) = \begin{cases} R_{1max}(x), \text{ if } C_1 \le C_2 \\ R_{2max}(x), \text{ if } C_1 > C_2. \end{cases} \tag{10}$$

We will increase x from $x = 0$ to $x_1 = C_1V$. At $x = 0$, according to formulas (4) and (7), is positive, while $R_{2max}(0) = 0$, which $R_{1max}(x) > R_{2max}(x)$. As x increases, the value of $R_{1max}(x)$ decreases, and $R_{2max}(x)$ increases. Consequently, at the beginning, the maximum risk is determined by the line $R_{1max}(x)$ and decreases until the corresponding lines intersect at the point x^*, where:

$$x\left(1 - \frac{C_{max}}{C_1}\right) + V\left(C_{max} - C_1\right) = x\left(1 - \frac{C_{min}}{C_1}\right). \tag{11}$$

This point is:

$$x_1^* = \frac{C_1\left(C_{max} - C_1\right)}{\left(C_{max} - C_{min}\right)}V. \tag{12}$$

With further increases in x, when x becomes greater than x^*, $R_{1max}(x)$ becomes smaller than $R_{2max}(x)$. Accordingly, the maximum risk increases, but now its values are determined by the $R_{2max}(x)$. Therefore, point x_1^* is the desired value at which the maximum risk is minimized.

The optimal strategy to minimize the maximum risk is as follows:

- Formula (12) determines the quantity of grain purchased at the beginning of the month, at the price C_1 for an amount of .
- In the middle of the month, the remaining grain is purchased at the current actual price, denoted as C_f, in the following quantity

$$V_2 = V - \frac{x_1^*}{C_1}. \tag{13}$$

3. Discussion

The found value of guarantees the minimum maximum risk under the condition that C_2 is within the range $[C_{min}; C_{max}]$ However, the actual price in the middle of the month may not necessarily fall within these assumed boundaries. Therefore, it is necessary to examine, using retrospective data, the actual effectiveness of the proposed strategy – the interval strategy (IS). To do this, we will compare it with a strategy based on the forecasted price in the middle of the month –Price Forecast Strategy (PFS). This strategy is as follows:

- If the forecasted price value is $C_p \ge C_1$, then the necessary quantity of grain is purchased at the beginning of the month at the price C_1.
- If the forecasted price value is $C_p < C_1$, the necessary quantity of grain is purchased in the middle of the month at the actual price C_f at the time of the purchase.

Note that to apply the IS (interval strategy), it is necessary to determine the boundaries: C_{min} and C_{max}. If their forecasted values are such that C_1 is not within $[C_{min}; C_{max}]$, then the actions recommended by the IS coincide with the actions of the PFS (Price Forecast Strategy).

The comparison will be conducted using retrospective data, specifically, for monthly corn purchases throughout the year. We will compare these strategies based on two criteria:

1. Minimum maximum risk.
2. Minimum annual total purchasing costs.

The manager prefers the second criterion if the company conducts monthly grain purchases and has enough funds to withstand large excess costs that may arise from one or several purchases. The first criterion is applicable when this is not the case, and additional expenses, even with a single purchase, could be significant. The purchasing manager wants his actions to be optimal according to both criteria, but this is impossible, and a balance must be found. We will take this into account when comparing the strategies.

To compare the strategies, we will apply them to the purchase of corn in the years 2022 and 2021. These years significantly differ in the number of months in which the price relationship between the beginning and middle of the month changed. This relationship is crucial for the results when both strategies are applied. In 2022, in 10 months, the price at the beginning of the month was lower than in the middle, and in only two months was it higher. In 2021, this ratio was 7 and 5. Retrospective corn prices were obtained from [22]. To align prices from past years with the years under investigation, price indices for grains from [22] and price indices for agricultural products from [22] were used.

The price of grain in the middle of the month and the boundaries of possible price changes can be forecasted using various methods. The authors proceeded on the assumption that the practical implementation of the forecasting method should be feasible with the manager's available software tools, such as Excel or MathCad. As a result, forecasting based on the average and exponential extrapolation was chosen. In the first case, the forecasted price in the middle of each month of the study year was calculated as the average of comparable prices in the same months of the six previous years. For extrapolation, data from the 10–15 trading days preceding the beginning of the month were used. Indexing was used to obtain comparable prices. Since [22] and price indices are referenced to the base year of 1982, a conversion was necessary.

The following comparison algorithm was adopted:

1. Determine the method of forecasting the mid-month price for which the total annual costs are minimized when using the PFS strategy.
2. Compare these best PFS results with the results provided by the IS using various approaches to determine the boundaries of possible price changes in the middle of the month.

In the first stage, it was determined that the best result is achieved when forecasting based on the average using prices indexed specifically to grain price indices, rather than overall agricultural product price indices. This is true for both considered years.

In the second stage, the following boundary determination methods were examined.

1. In each month, the boundaries are taken in the form of a segment with a middle at the forecast point C_p, the boundaries of which are spaced from C_p by the confidence interval of the forecast at a given confidence probability. Confidence values of 0.95 and 0.99 were considered.
2. In each month, the boundaries are taken as a segment with the middle at the forecast point based on the average C_p for this month, the boundaries of which are spaced from C_p by the maximum range of price changes in this month over the previous 6 years, considering price indexation.
3. In each month, the boundaries are taken as a segment with the middle at the forecast point based on the average C_p for this month, the boundaries of which are spaced from C_p by the average range of price changes in this month over the previous 6 years, considering price indexation.
4. In each month, the price boundaries in the middle of the month are determined based on the data from the previous year. The left boundary is less than C_1 by the maximum price decrease in the middle of the month relative to the beginning, recorded on one of

the days of the corresponding month in the previous year. The right boundary is greater than C_1 by the maximum price increase in the middle of the month relative to the beginning, recorded on one of the days of the corresponding month in the previous year.

5. The boundaries are determined based on the maximum deviations over the previous six years, similar to the method described in point 4.

In addition, symmetric boundaries relative to C_1 were considered in variants like those mentioned in points 2–3. It should be noted that with symmetric boundaries relative to C_1 and $C_1 \in [C_{min}; C_{max}]$, the value of suggests splitting the purchase into two equal batches.

As a result, it was found that in all cases, the IS compared to the PFS provides the minimum maximum risk for both the volatile year 2021 and the year 2022. It is worth noting that if the manager, assuming a stable trend in 2022 and unconditionally adopting the PFS strategy, would have incurred significant excess costs in one of the months. However, the application of the IS would only slightly increase the annual costs but significantly reduce the maximum risk (*Table 1*). Moreover, the IS strategy resulted in lower annual costs than the PFS strategy only in the case of boundary determination according to point 4, and only for the year 2022.

Consistently over the years, the best results in terms of a compromise between the two criteria are achieved by applying the IS with the boundary determination method specified in point 1 at a confidence level of 0.99.

Conclusion

As a result of the study, the following main scientific results were obtained, which are presented in this article.

- For the first time, the problem of minimizing the maximum risk when purchasing raw materials for a processing enterprise was solved.
- The authors derived a functional dependence of the maximum risk on the amount of purchased raw materials at the beginning of the month. As a result, it was possible to establish the amount of raw materials, the purchase of which at the beginning of the month would result in a minimum of maximum risk.

The results were used to develop a raw material procurement strategy for one of the largest distilleries in Russia. A further direction of research could be to analyze how best to predict price boundaries in the middle of the month – with the help of experts or using prices time series [23, 24] or combination of this methods [25]. Another important area of research is considering many real factors influencing the price. This could be done by simulation [26, 27]. ■

Table 1.

Total amount and maximum risk

Criterion	Amount (RUB)		Max risk (RUB)	
year/strategy	IS	PFS	IS	PFS
2022	24 633 961	24 624 450	56 286	93 000
2021	20 559 750	20 620 885	106 648	112 500

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About the authors

Arkadiy I. Maron

Cand. Sci. (Tech.);

Associate Professor, School of Applied Mathematics, HSE Tikhonov Moscow Institute of Electronics and Mathematics (MIEM HSE), 34, Tallinskaya St., Moscow 123458, Russia;

E-mail: amaron@hse.ru

ORCID: 0000-0003-4443-3329

Maxim A. Maron

Cand. Sci. (Phys.-Math.);

Senior System Analyst, Cifra Bank LLC, 5/10, 2, Karetny Ryad St., Moscow 127006, Russia;

E-mail: maxxx-fizik@mail.ru

ORCID: 0000-0002-8337-5099

Anastasiia A. Kazmina

PhD Student, Department of Industrial & Systems Engineering, Korea Advanced Institute of Science and Technology (KAIST), 291, Daehak-ro, Yuseong-gu, Daejeon 34141, Republic of Korea;

E-mail: anastasiiaka@kaist.ac.kr

ORCID: 0009-0002-3753-7429