Problem Chosen	2022	Team Control Number
C	MCM/ICM Summary Sheet	2204227

The Best Daily Trading Strategy

Summary

We need to predict the price of different assets to judge its price trend. Through observation and statistics, we set the forecast period for gold to be five days and Bitcoin to be three days. From the initial date, for the first thirty days, we continue the historical price trend to calculate the price for the next day. Each day after thirty days, we use the time series forecasting model **ARIMA(7,1,2)** to predict the market price of a period based on the data of all previous days, and take its mean as the price of the next day.Then calculate the expected rate of return and expected risk rate of the day according to the predicted price, as shown in Figure 9 and 10.

Next, we designed a **multi-objective optimization model** based on expected return, expected risk rate, fees, and the amount of assets held on the day. The model, under the condition of satisfying the constraints, aims to maximize the daily net return and minimize the maximum expected risk.

In order to improve the adaptability of the model, we set the risk degree k that can be tolerated. Under a certain risk level k, we follow the principle of not buying for small profits and not selling for small losses, so as to increase the difficulty of trading. This can help us avoid short-term investment traps and pay less fees. So we set **MLTR**(Maximum Loss Tolerance ratio), **MPAR**(Minimum Profit Acceptance Rate)).

When dealing with multi-objective programming models, we propose two solutions,"Fixed risk levels, optimized returns" & "Fixed profit level, minimized risk", and finally use the former to convert the original model into a linear programming model.

The solved daily strategy is shown in Figure 13 and 14. On September 10, 2021 our assets were worth **$65093.4668**

In order to obtain the optimal k, MLTR, and MPAR, we perform hyperparameter testing, and the results are shown in Figure 18 and 12. Based on the test results, we determined **the optimal hyperparameters: k = 6.66%, MPAR = 0.9%, MLTR = 1%**.

Judging from the final result, 64 times the starting capital is obtained through 5 years of trading, which justify our decisions. In addition, from the prediction results of the ARIMA model, the predicted price is basically the same as the actual price trend, which also shows that the time series model has good prediction performance. At the same time, in the multi-objective optimization, the expected returns and risks in the investment are fully considered, and the most reasonable risk parameters are searched, which fully improves the reliability of the model. Summarizing the above evidence, our model can give the best decision.

As can be seen from the figure 16 , when the commission rate is smaller, the overall benefit can be greater. When the commission rate of both is lower than **4%**, the income increases obviously and changes rapidly with the decrease of the commission rate. Otherwise, the income changes slowly and the overall income is obviously small, and even a loss occurs when the commission ratio is too large. It can be seen that the commission rate is not as small as possible. When the transaction commission rate of Bitcoin is **0.1%**, and the commission rate of gold is **1.7%**, the highest profit is obtained, which is **$131,829**.

Keywords: ARIMA; Multi-objective Optimization;Markowitz's Mean-variance Model ; Sensitivity Analysis; Linear Programming; Self-adaptive;

Contents

1 Introduction

1.1 Problem Background

In daily life,transactions are everywhere. In addition to daily transactions, people also like to buy assets for the possibility of asset appreciation, which is called investing. When investing, investors are not only required to pay the amount of the asset purchased, but also transaction costs. However, benefits and risks are often accompanied. Different investment projects have different benefits and risks. Therefore, we should make a trade-off between benefits and risks to obtain the maximum benefits under the risk we can bear. In market trading, traders often buy and sell volatile assets in the belief that they will maximize returns. Bitcoin and gold are two assets that people often invest in in recent years, which both have good investment value. As an emerging asset, Bitcoin is gaining more and more market share. The transaction volume in recent years is shown in the figure 1.

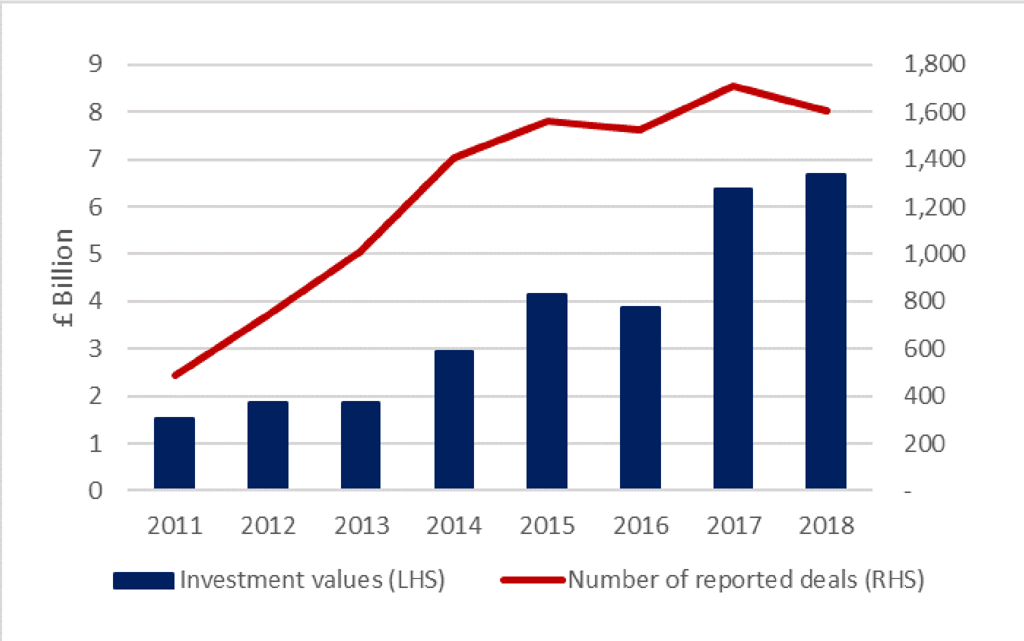

Figure 1: Increase in Investment

When making an investment, it is easy for investors to obtain the historical prices of Bitcoin and gold, however the difficulty is how to use this information to their advantage. A good investor should be able to predict the price trend of different assets from historical information, to formulate high-quality investment strategies, so as to make profits. This requires investors to have both the intelligence to foresee the future and the courage to take risks. We want to be able to make the right decisions for you and help you live a happy life.

1.2 Restatement of the Problem

In the trading activities with coexistence of returns and risks, it is a skill that a good investor must master to formulate the optimal investment strategy based on the known historical prices of assets. Generally, there is a positive correlation between return and risk. The greater the return, the greater the risk. In general, our task can be summarized as formulating the most profitable investment strategy for investors given the risk tolerance. The specific requirements are as follows:

- Develop a model that uses only past daily price streams to date. The model needs to determine the optimal daily investment strategy for traders and calculate the value of holdings on October 19, 2021. We will start the calculation on November 9, 2016 with a starting capital of $1000.
- Provide evidence that our model provides the best policy.
- Analyze how sensitive a strategy is to commission rate and how commission rate affect strategy and outcomes.
- Discuss our strategies, models with traders in a memo of up to two pages.

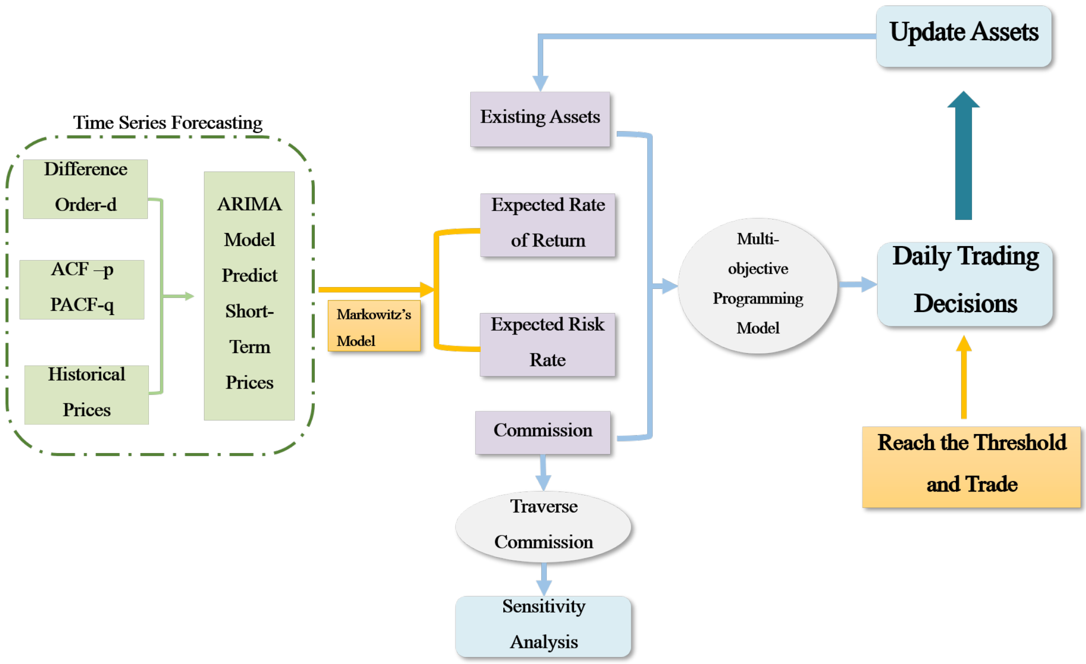

Figure 2: Flow Chart of Our Work

1.3 Our Work

The problem requires us to make the best daily trading strategy. Our work mainly includes the following:

1. Establish an ARIMA model and predict future prices based only on price data up to that day.
2. Calculate the daily expected return and risk rate according to the Markowitz model.
3. Build a multi-objective programming model and optimize the model parameters. Running the model from September 11, 2016 to get daily trading strategy.
4. Present evidence that our model provides the best strategy.
5. By traversing the trading commissions of gold and bitcoin, we observe the changes in the results when the trading commissions change, and analyze the sensitivity of Commission rate.

In order to avoid complicated description, intuitively reflect our work process, the flow chart is shown in Figure 2.

2 Assumptions and Explanations

Considering that practical problems always contain many complex factors, first of all, we need to make reasonable assumptions to simplify the model, and each hypothesis is closely followed by its corresponding explanation:

Assumption 1: **Investors make investments considering the expected return and the degree of risk, and choose the highest expected return as the principle.**
*Explanation:*Investors need to incorporate risk into the measurement and cannot invest blindly in order to reduce asset losses due to market fluctuations. And investors do not involve personal preferences when investing, but make decisions objectively with the goal of maximizing asset benefits.

Assumption 2: **Unlimited trading volume per asset.**
Explanation: Generally, the number of assets available for trading is sufficient, and the gold and bitcoin markets are huge so that there is generally no shortage of commodities. In the market, gold and bitcoin have no transaction volume threshold restrictions, giving investors more trading options and simplifying the modeling process.

Assumption 3: **Investors can only trade based on existing assets, and there will be no loans and debts.**
Explanation: Market traders need to incorporate risk into their return measurement, and cannot invest blindly..

Assumption 4: **Investors can only trade assets at market prices, and this trading behavior will not affect the price of gold or Bitcoin.**
Explanation: In reality, the gold market and bitcoin market are huge, and individual buying and selling behaviors have little impact on the overall market.

Assumption 5: **Analyze and make decisions based only on the past stream of daily prices to date.**
Explanation: When applying our model to actual transactions, all we can get is historical data. Future data is unknown, so data predictions need to be made based on historical data.

Additional assumptions are made to simplify analysis for individual sections. These assumptions will be discussed at the appropriate locations.

3 Notations

Some important mathematical notations used in this paper are listed in Table 1.

Table 1: Notations used in this paper

Symbol	Description	Range
x_i	Number of owning the i-th asset	$i = 0, 1, 2$
α_i	Commission rate within the i-th asset corresponding to Gold and Bitcoin respectively	$i = 1, 2$
r_i	Average return rate on the i-th asset	$i = 0, 1, 2$
λ_i	The price of the i-th asset on the current day	$i = 1, 2$
p_i	Number of assets owned on the day before the i-th day	$i = 0, 1, 2$
F	Net income on the current day	
q_i	Risk loss rate for the i-th asset	$i = 0, 1, 2$
Q	Total portfolio risk on the current day	$i = 0, 1, 2$
k	Risk Boundary Threshold	
$MLTR$	Maximum Loss tolerance rate	
$MPAR$	Minimum Profit Acceptance Rate	

*There are some variables that are not listed here and will be discussed in detail in each section.

4 An Adaptive Multi-objective Programming Portfolio Investment Model Based on Time Series Prediction

4.1 Data Preprocessing

After preliminary observation of the data, we find that gold not only exists in non-trading days, but also the market price is missing in some trading days. Analyzing gold price data, we discovery that gold trading period is usually 5 days, and then gold will be in a non-trading state , which indicates that the data is segmented.

Therefore, we choose "Piecewise Cubic Spline Interpolation" to get the missing data, which can not only get better interpolation results, but also avoid the Runge-Kutta situationthat occurs in high order. The missing gold market price is interpolated in a period of five trading days. Part of the interpolation results are shown in the Figure 3. Some interpolated market prices and corresponding dates are shown in Table 2.

Table 2: Several Interpolation Results And Corresponding Dates

Date	**Results**	**Date**	**Results**
12/23/2016	1090.05	12/31/2018	1290.00
12/30/2016	1157.20	12/24/2019	1500.62
12/22/2017	1251.70	12/31/2019	1510.37
12/29/2017	1302.60	12/24/2020	1873.20
12/24/2018	1205.25	12/31/2020	1900.90

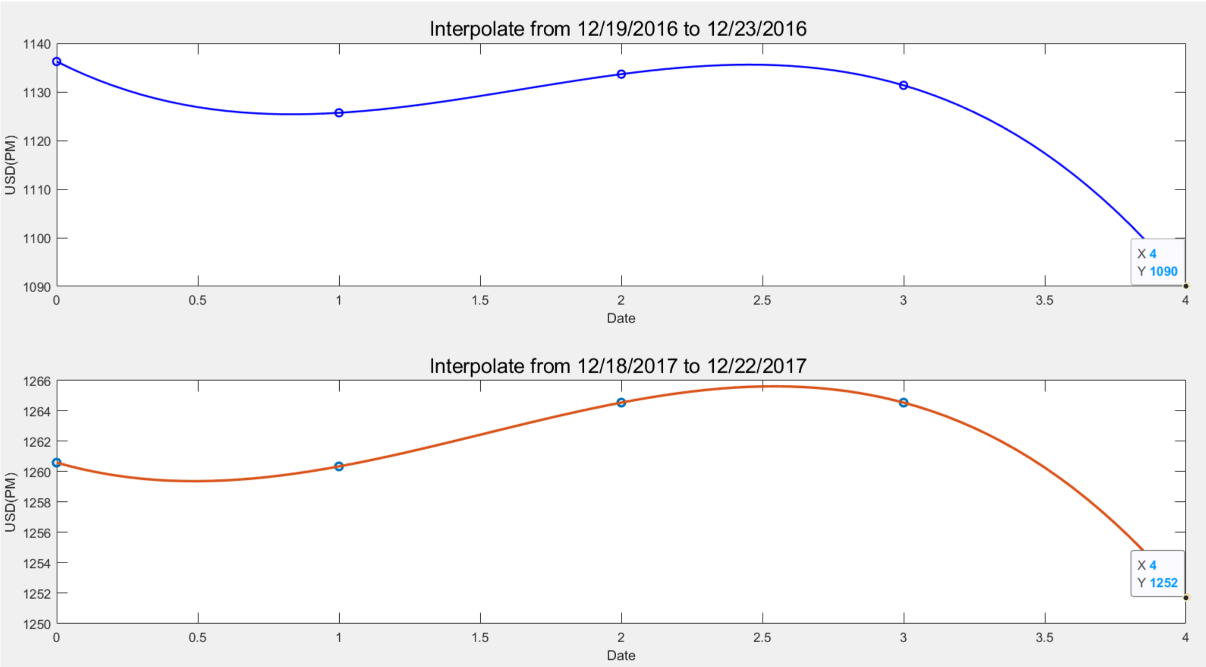

Figure 3: Visualization Of Interpolation Results

4.2 Time Series Prediction Model Based on ARIMA

4.2.1 Preprocess Data for Stationarity

In order to get the yield of gold and bitcoins respectively, we have to forecast the prices of each commodity through their history prices. The frequently-used prediction methods often hope that the fluctuation of data has a certain law, besides the data is a stable sequence that can go along the current form. Because the price fluctuation data of gold and bitcoin is difficult to keep stable, we have to preprocess the price data of each commodity. Difference is a data preprocessing method that we are familiar with, which convert the data into a stationary series through difference processing. The formula for difference operation is as follows:

$$\Delta y_t = y_t - y_{t-1}$$

After trying first-order and second-order difference, we found that when the amount of data is greater than or equal to 30, the first-order difference results of gold and Bitcoin are approximately stable, and the second-order difference is not much different from the first-order difference. The figures which illustrate the first-order difference of first 30 data and first 1000 data of gold and bitcoins respectively are in figure 4 and figure 5. And ADF(Augmented Dickey-Fuller) Test results are shown in Table 3,which proves that the data is stable after 30 days.

Therefore, we end up performing first-order differencing on both gold and bitcoin to process the raw data into a stationary series to improve the accuracy of the predictions.

4.2.2 Building ARIMA Time Series Model

ARIMA model is a popular and widely used statistical method for time series forecasting. The applicable conditions of the ARIMA method can be roughly summarized

Table 3: ADF Testing Results

Sample days	ADF	99% Confidence interval	95% Confidence interval	90% Confidence interval
15	-2.6356	-4.0120	-3.1041	-2.6909
30	-3.5350	-3.6790	-2.9678	-2.6231
60	-6.0021	-3.5463	-2.9119	-2.5936
100	-10.2208	-3.4981	-2.8912	-2.5825
500	-22.1770	-3.4435	–2.8673	–2.5698
1000	-17.4119	-3.4369	-2.8644	-2.5683

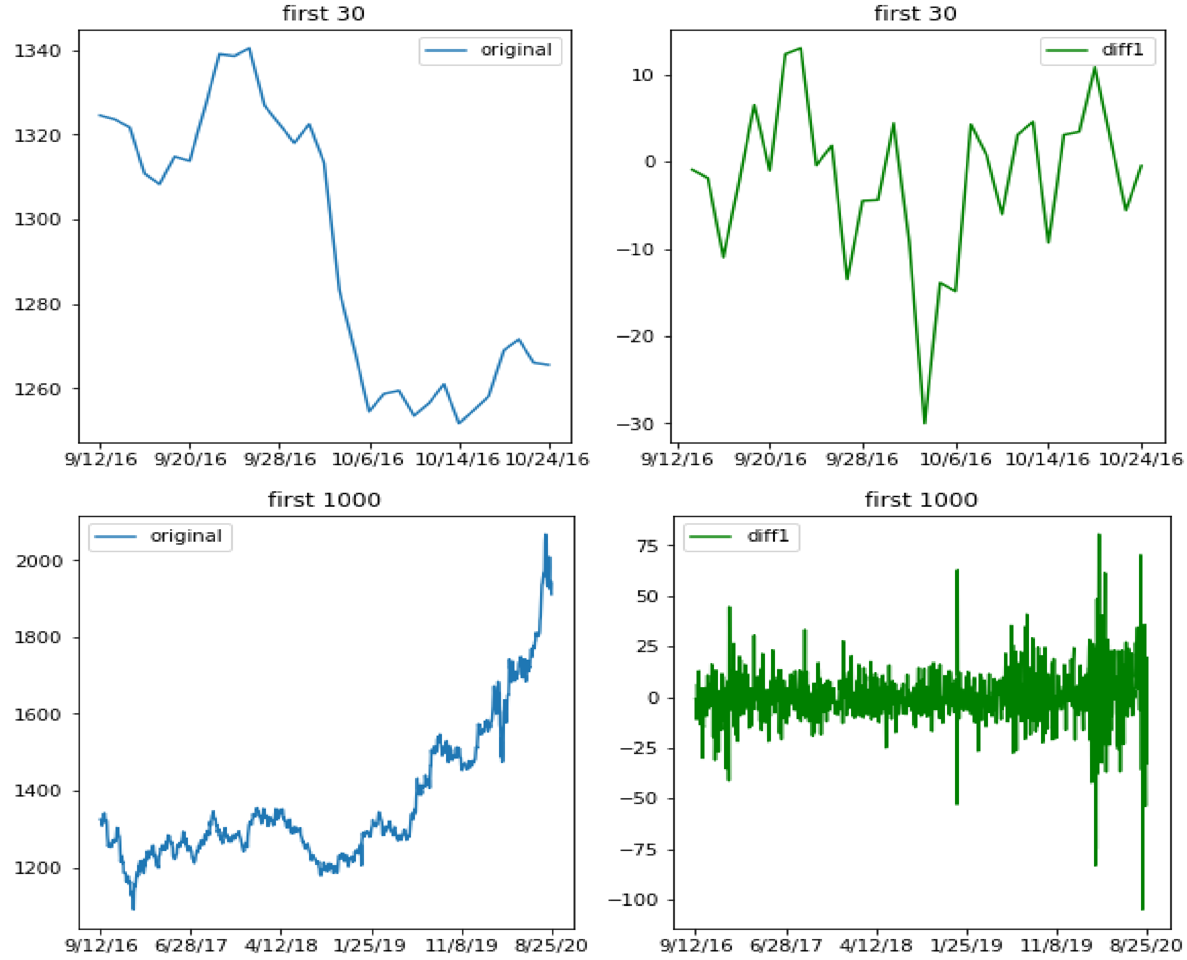

Figure 4: First Order Difference Of Gold Price Data

into the following two points:

- The data series is stationary, or we can transform the data into stationary form.
- The input data must be a univariate series.

It is obvious that our data satisfies the conditions for using the ARIMA model when the sample days are larger than 30 from Table 3 , Figure 4 and 5, so we try the ARIMA model. ARIMA model consists of the AR model and the MA model, and I stands for adaptive. In order to use ARIMA model, we need to determine three parameters, namely p, d, q. Where d represents the order of the difference, p is the order of the AR

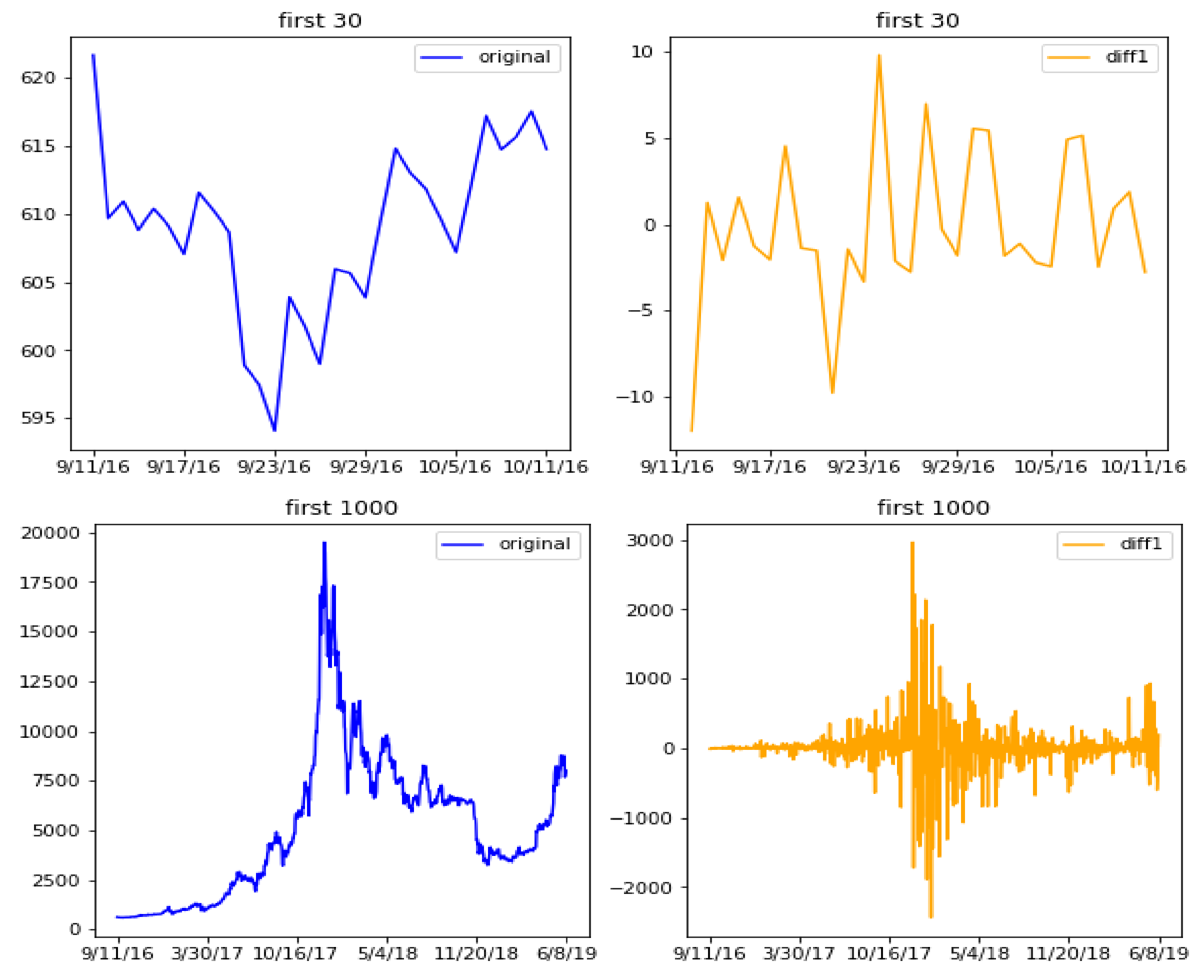

Figure 5: First Order Difference Of Bitcoin Price Data

(autoregressive) term and q is the order of the MA (moving average) term. As we use first order difference, the value of d is one. Parameters p and q are determined by ACF and PACF, with rules in figure 6.

MODEL	AR(p)	MA(q)	ARMA(p, q)
ACF	Trail	Truncate after q-order	Trail
PACF	Truncate after p- order	Trail	Trail

Figure 6: Determine The Value Of p And q

The ACF and PACF results of history prices are shown in figure 7 . Thus, the best values of p and q are 7 and 2 respectively.

4.2.3 Predict Prices Based on Historical Data

Considering the price characteristics of the two products, the price of gold is usually relatively stable and suitable for long-term investment, while Bitcoin fluctuates greatly

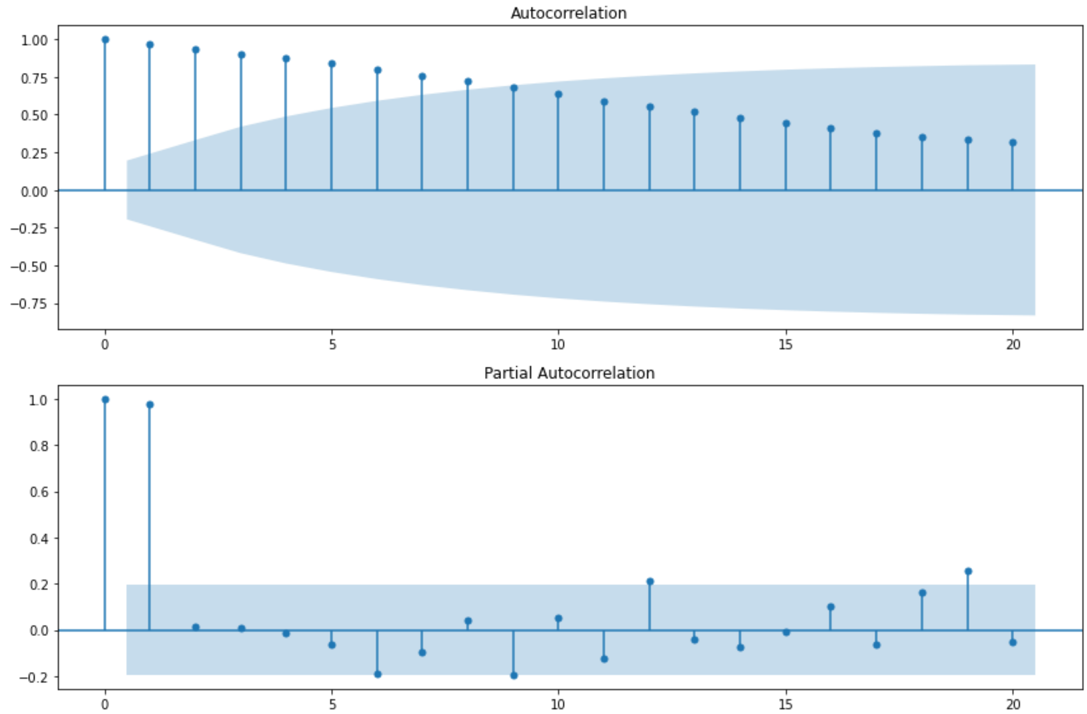

Figure 7: FAC And PFAC Of First-order Difference

and is suitable for short-term investment.

Besides, we use only the past stream of daily prices to date to predict the prices in the future. Therefore, when forecasting on daily data we use the historical price data from December 16, 2009 to the day before to predict the price of gold in 5 days and the price of bitcoin in 3 days.

The figure 8 shows the forecast results of gold and bitcoin using 40 days of price data from December 16, 2009.

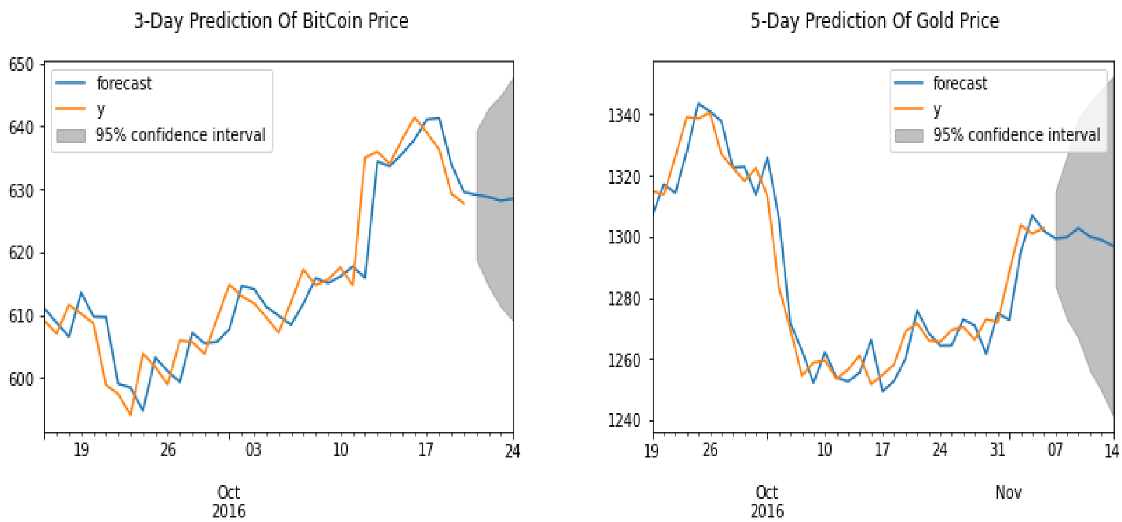

Figure 8: Price Prediction Results

4.3 Adaptive multi-objective programming model

4.3.1 Calculate the average return rate and risk loss rate

According to the time series forecasting model, we have predicted and obtained the market price for a period of time in the future. How to make full use of the market data known and predicted on a certain trading day ? We selecet r_i, p_i as the expected average return and risk loss rate of the ith asset, respectively, which will be important indicators for decision making someday.

Method of calculating the expected rate of return

We refer to the **Markowitz mean-variance** model and consider the calculation method of the actual securities market to define Equation 1 as follows. P_t is the expected price for the next day, P_{t-1} is the price today.

$$r_i = ln(\frac{P_t}{P_{t-1}}) \tag{1}$$

This is slightly different from the origin model, we use the $'ln\ method'$ to calculate,which means continuous compounding. According to the mathematical logic, when the price series volatility is small, the results of the two yields are approximately equal. According to the limit theorem, when r is infinitely small, the two calculation results are basically indistinguishable.

The prediction will be inaccurate, when calculating the expected rate of return of gold in the first thirty days. Because of the lack of data, we choose to use statistical methods. From 31 days, we use data from 9/11/2021 for time series analysis to predict the gold price for the next five days. $AFP(AverageForecastPrice)$ is regarded as the market price of gold in the next day, and the daily rate of return is calculated as the expected rate of return for decision-making.

λ_t is the gold market price on t-th day. Similarly, the formula can be used in Bitcoin calculations, which just changes the summing interval to three days and modifies the range of t. The specific piecewise function is as follows:

$$P_t = \begin{cases} \lambda_t & t \in [1, 30] \\ \frac{\sum_t^{t+5} \lambda_t}{5} & , t \geq 31 \end{cases} \qquad P_{t-1} = \begin{cases} P_{t-1}, & t \in [2, 5] \\ \frac{\sum_{t-5}^{t} \lambda_t}{5}, & t \in [6, 30] \\ \lambda_t & t \geqslant 31 \end{cases} \tag{2}$$

Method of calculating the expected risk loss ratio

Investors are most concerned about returns, but they cannot ignore risks. We adopt the risk measure employed in the Markowitz model, which is to use the standard deviation of returns to quantify the expected risk loss rate p_i of the i-th asset. Standard deviation is used because of its excellent mathematical properties.

$$p_i = \sqrt{\frac{\sum_t^{t+n} (r_t - \mu)^2}{n}} \tag{3}$$

As before, for gold, we use the market price for the past 5 days and the forecast for the next 5 days to find the standard deviation. For Bitcoin, our interval is changed to 3 days. In addition, only statistical methods are used for the first 30 days without forecasting. Following our methodology, the daily expected returns and risk-to-loss ratios for gold and Bitcoin are shown in Figure 9 and Figure 10, respectively.

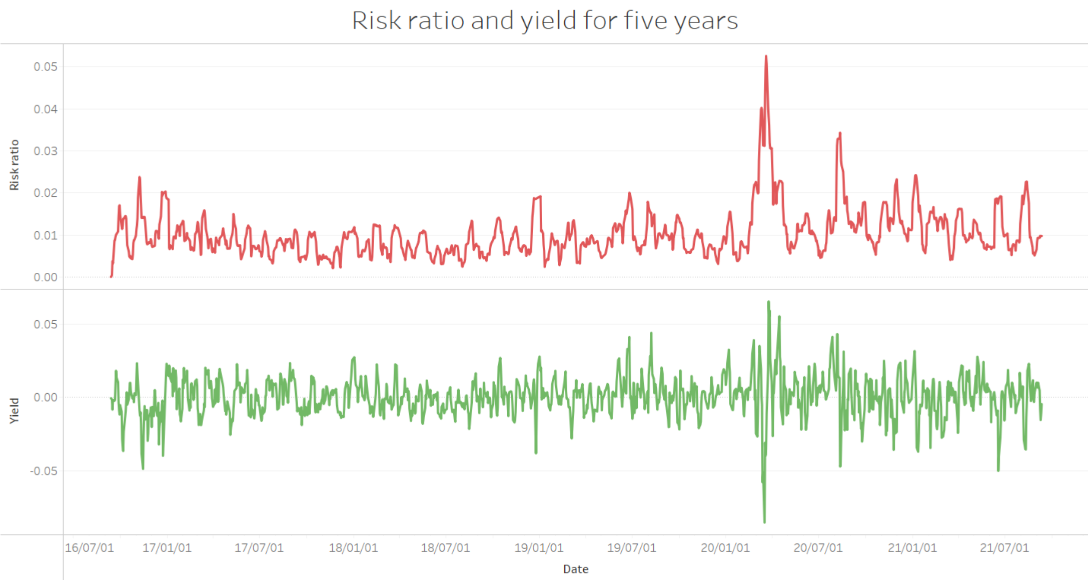

Figure 9: Gold's Risk ratio and yield for five year

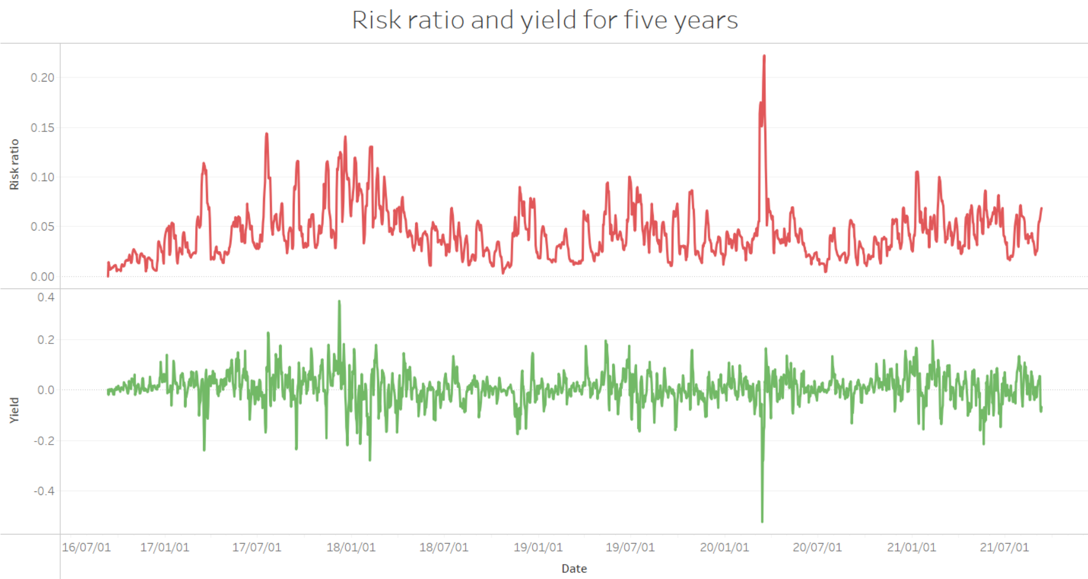

Figure 10: Bitcoin's Risk ratio and yield for five year

4.3.2 Multi-objective programming model for portfolio

Portfolio analysis plays an important role in economic activity. Suppose there is a fund M that can be invested in n assets in the market during a period. In this article, $M = [C \quad G \quad B], n = 2$, which means that the asset is composed of cash, gold and Bitcoin, and can be invested in gold and Bitcoin. We measure the pros and cons of an investment plan with two metrics:

- **Net income should be as large as possible.**
- **The total risk is as small as possible.**

After 4.3.1, we have calculated the expected rate of return and risk loss rate of each investment asset. And considering that commissions α are linear, we can derive the commissions formula as follows And considering that the commission α is linear, we can derive the total commissions C as Equation (4), where x_i is the quantity of a certain asset, λ_i is the market price, and p_i is the quantity of the asset on the day before the decision.

$$C = \sum_{i=1}^{n} |x_i - p_i| \lambda_i \alpha_i \tag{4}$$

We can calculate the single-day net income F based on Equation (4).

$$F = \sum_{i=1}^{n} x_i r_i \lambda_i - \sum_{i=1}^{n} |x_i - p_i| \lambda_i \alpha_i \tag{5}$$

We take the maximum risk of an asset as the total risk R of the portfolio. q_i is Risk loss rate for the i-th asset.

$$Q = \max_{1 \leqslant i \leqslant n} q_i x_i \lambda_i \tag{6}$$

Constraints: The cash balance before and after the decision should be equal to the sum of the commission and the cost of purchasing assets.

$$\sum_{i=1}^{n} \{(x_i - p_i)\lambda_i + |x_i - p_i| \lambda_i \alpha_i\} = p_0 - x_0 \tag{7}$$

Finally, we establish a multi-objective programming model as Equation (8).

$$\begin{aligned}
&\max F = \sum_{i=1}^{n} x_i r_i \lambda_i - \sum_{i=1}^{n} |x_i - p_i| \lambda_i \alpha_i \\
&\min Q = \max_{1 \leqslant i \leqslant n} q_i x_i \lambda_i \\
&\text{s.t.} \left\{ \begin{array}{l} \sum_{i=1}^{n} \{(x_i - p_i)\lambda_i + |x_i - p_i| \lambda_i \alpha_i\} = p_0 - x_0 \\ x_i \geq 0, \quad i = 0, 1, 2, \cdots, n. \end{array} \right.
\end{aligned} \tag{8}$$

There are two models to convert multi-objective programming into single-objective programming.

- **Model A: Fixed risk levels, optimized returns.**

In actual investment, the degree to which investors can bear risk varies. So we set a risk boundary threshold. Given a risk boundary threshold k, if the maximum risk is less than k, the corresponding investment plan can be found, thus turning the multi-objective programming into a linear programming with one objective. The model is as follows:

$$\begin{aligned}
&\max F = \sum_{i=1}^{n} x_i r_i \lambda_i - \sum_{i=1}^{n} |x_i - p_i| \lambda_i \alpha_i \\
&\text{s.t.} \left\{ \begin{array}{l} q_i x_i \lambda_i \leq kM, \quad i = 1, 2, \cdots, n \\ \sum_{i=1}^{n} \{(x_i - p_i)\lambda_i + |x_i - p_i| \lambda_i \alpha_i\} = p_0 - x_0 \\ x_i \geq 0, \quad i = 0, 1, 2, \cdots, n. \\ M = p_0 + \sum_{i=1}^{n} p_i \lambda_i \end{array} \right.
\end{aligned} \tag{9}$$

- **Model B: Fixed profit level, minimized risk.**

If the investor wants the total profit to be at least above the level k, the model seeks the corresponding investment portfolio with the least risk. The model is as follows:

$$\min Q = \max_{1\leqslant i\leqslant n} q_i x_i \lambda_i$$
$$\text{s.t.} \begin{cases} \sum_{i=1}^{n} x_i r_i \lambda_i - \sum_{i=1}^{n} |x_i - p_i| \lambda_i \alpha_i \geq kM, \quad i = 1, 2, \cdots, n \\ \sum_{i=1}^{n} \{(x_i - p_i)\lambda_i + |x_i - p_i|\lambda_i \alpha_i\} = p_0 - x_0 \\ x_i \geq 0, \quad i = 0, 1, 2, \cdots, n \\ M = p_0 + \sum_{i=1}^{n} p_i \lambda_i \end{cases} \tag{10}$$

We choose Model A because the problem requires the greatest profit. The variables are replaced as in Equation (11) and (12) because the objective equation and constraints both contain absolute values.

$$u_i = \frac{|x_i - p_i| + (x_i - p_i)}{2} \quad v_i = \frac{|x_i - p_i| - (x_i - p_i)}{2} \quad i = 1, 2, \cdots, n \tag{11}$$

$$x_i = u_i - v_i + p_i \quad i = 1, 2, \cdots, n \tag{12}$$

Our final model is listed below.And $\triangle\mathbf{X} = \mathbf{X} - \mathbf{P}$ is **the best daily trading strategy** where gold can be traded.

$$\max F = \sum_{i=1}^{n} (u_i - v_i + p_i) r_i \lambda_i - \sum_{i=1}^{n} (u_i + v_i) \lambda_i \alpha_i$$
$$\text{s.t.} \begin{cases} q_i(u_i - v_i + p_i)\lambda_i \leq kM, \quad i = 1, 2, \cdots, n \\ \sum_{i=1}^{n} \{(u_i - v_i)\lambda_i + |u_i + v_i|\lambda_i \alpha_i\} = p_0 - x_0 \\ u_i, v_i \geq 0, \quad i = 0, 1, 2, \cdots, n \\ x_0 \geq 0 \\ M = p_0 + \sum_{i=1}^{n} p_i \lambda_i \end{cases} \tag{13}$$

When gold cannot be traded and only Bitcoin has the potential to trade, and the model is simpler. As follows:

$$\max F = (u_2 - v_2 + p_2) r_2 \lambda_2 - (u_2 + v_2) \lambda_2 \alpha_2$$
$$\text{s.t.} \begin{cases} q_2(u_2 - v_2 + p_2)\lambda_2 \leq kM \\ (u_2 - v_2)\lambda_2 + |u_2 + v_2|\lambda_2 \alpha_2 = p_0 - x_0 \\ u_2, v_2 \geq 0 \\ x_0 \geq 0 \\ M = p_0 + \sum_{i=1}^{n} p_i \lambda_i \end{cases} \tag{14}$$

Based on this model, we only need to run this model every day from 9/11/2016, make decisions, and then obtain the best daily trading strategy and final result.

4.3.3 Adaptive optimization

Our model has the advantages of self-adaptation, which is reflected in the principle of not buying for small profits, not selling for small losses, and adaptive adjustment to the risks that can be tolerated. The schematic diagram is shown in Figure 11.

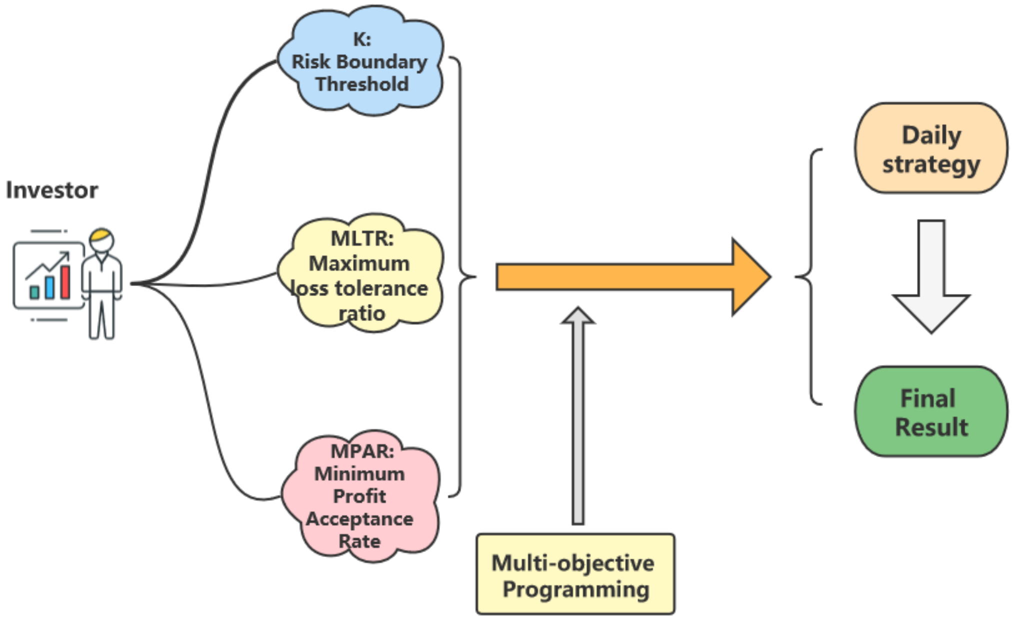

Figure 11: Adaptive Multi-objective Programming

If the strategy is formulated to ensure that it is optimal every day, we often cannot obtain the global optimal value, but will fall into the trap of ultra-short-term investment. In the stock market, we often cannot make the most accurate investment judgment through a single day's profit and loss. And because of commission, the more we trade, the more commission we pay. Thus, we should take a long-term view and follow the principle of not buying for small profits and not selling for small losses, which will not only help us formulate long-term strategies during the investment process, but also help us to save commissions. We create three hyperparameters: Risk Boundary Threshold k, $MLTR$ (Maximum Loss tolerance rate) and $MPAR$ (Minimum Profit Acceptance Rate) to refine the model. If it is within this interval, it is considered to be a small loss and a small gain. In this case, instead of buying and selling, we adopt a strategy of preserving assets.

As benefits and risks coexist, if you want to gain profits, you have to bear the corresponding risks. Therefore, the level of risk tolerance is also a key factor in our strategy. In our model, the risk tolerance is adjustable and traders can determine based on their own relative preferences.

4.4 The Solution of Model

After testing hyperparameters, We obtain the results shown in Figures 12. Using these parameters, we run the program and get the daily asset $[C \quad G \quad B]$ changes as shown in Figure 13 and 14

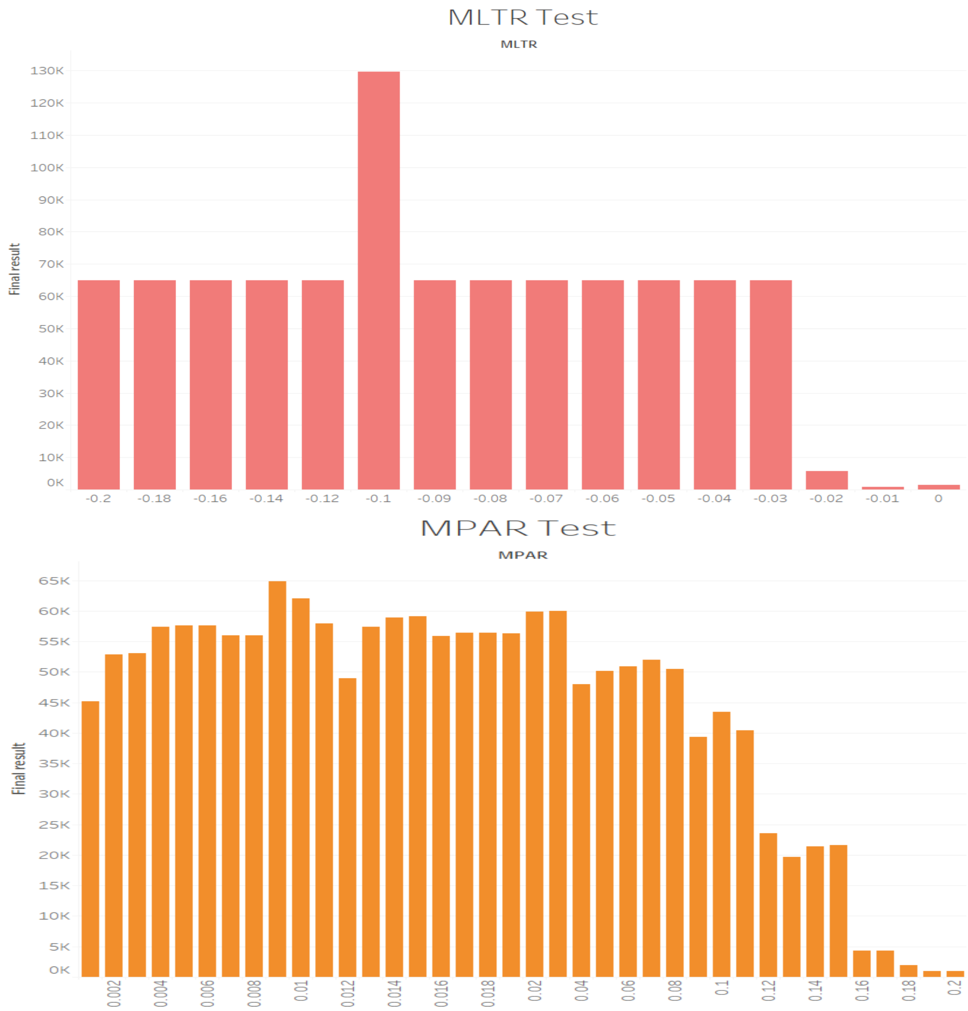

Figure 12: Test Results for MLTR and MPAR

5 Present Evidence for the Best Strategy

5.1 The Result is Reasonable

Just make decisions based on historical data, and we can get considerable returns in the real investment market. The initial $1000 investment has increased by more than 60 times the principal within five years, which proves the rationality of the investment decision and the correctness of the model.

5.2 Data Processing is Correct

Through the differential processing of historical data, it is found that the first-order difference sequence is a stable sequence, which meets the applicable conditions of ARIMA. Therefore, it is reasonable to apply the ARIMA model for data prediction.

And the predicted data obtained by using the ARIMA model is basically the same as the real data trend, and the value is basically the same.The comparison results are shown in the Figure 15 This shows that the results of the forecast data are reasonable and can reflect the real market laws to a certain extent.

Date	Cash	Gold	Bitcoin	Date	Cash	Gold	Bitcoin	Date	Cash	Gold	Bitcoin	Date	Cash	Gold	Bitcoin	Date	Cash	Gold	Bitcoin
9/11/16	1000	0	0	7/21/17	0	1.38376	0.84058	12/6/17	7485.95	0	0.69624	······	1327.93	8.765	0.41135	4/2/18	0	0	2.02049
······	1000	0	0	7/22/17	749.98448	1.38376	0.568	12/7/17	8289.74	0	0.64654	1/26/18	1327.93	8.765	0.41135	4/3/18	684.904	0	1.92618
10/11/16	1000	0	0	7/23/17	766.90496	1.38376	0.56189	12/8/17	8557.68	0	0.63033	1/27/18	0	8.765	0.52432	4/4/18	0	0	2.01659
10/12/16	0	0	1.5439	7/24/17	0	1.03112	0.99128	12/9/17	8452.97	0	0.63711	1/28/18	334.543	8.765	0.49446	······	0	0	2.01659
······	0	0	1.5439	······	0	1.03112	0.99128	12/10/17	8225.17	0	0.65213	······	334.543	8.765	0.49446	4/10/18	0	0	2.01659
3/12/17	0	0	1.5439	7/28/17	0	0	1.44637	12/11/17	8225.17	0	0.65213	2/7/18	334.543	8.765	0.49446	4/11/18	0	0.44885	1.92638
3/13/17	503.31	0	1.12556	······				12/12/17	5905.5	0	0.78376	2/8/18	7308.19	0	1.02281	4/12/18	0	0	2.00084
3/14/17	670.118	0	0.98889	8/15/17	0	0	1.44637	12/13/17	0	0	1.12821	2/9/18	7690.3	0	0.97552	······	0	0	2.00084
3/15/17	676.431	0	0.98377	8/16/17	437.61512	0	1.33954	12/14/17	0	0	1.12821	2/10/18	4338.76	0	1.37045	11/27/18	0	0	2.00084
3/16/17	0	0.59665	0.93149	8/17/17	588.57309	0	1.30396	12/15/17	2188.21	0	1.00257	2/11/18	0	0	1.88028	11/28/18	1020.85	0	1.74698
···	0	0.59665	0.93149	······	588.57309	0	1.30396	12/16/17	6936.4	0	0.75409	······	0	0	1.88028	11/29/18	990.969	0	1.75386
3/19/17	0	0.59665	0.93149	8/22/17	588.57309	0	1.30396	12/17/17	9118.51	0	0.6386	2/16/18	0	0	1.88028	11/30/18	0	0	1.98092
3/20/17	0	0.59665	0.93149	8/23/17	0	0	1.44217	12/18/17	0	8.45733	0.54984	2/17/18	3829.13	0	1.51989	12/1/18	0	0	1.98092
3/21/17	0	0.50105	1.03448	······	0	0	1.44217	······	0	8.45733	0.54984	2/18/18	6378.55	0	1.28523	12/2/18	525.466	0	1.85226
3/22/17	0	0.53408	0.99628	9/18/17	0	0	1.44217	12/26/17	0	8.45733	0.54984	2/19/18	7198.82	0	1.2099	······	525.466	0	1.85226
······	0	0.53408	0.99628	9/19/17	1435.0378	0	1.07084	12/27/17	0	3.74555	0.92516	2/20/18	8128.35	0	1.12663	12/16/18	525.466	0	1.85226
3/26/17	0	0.53408	0.99628	9/20/17	0	0	1.42454	······	0	3.74555	0.92516	2/21/18	7164.01	0	1.21069	12/17/18	915.977	0	1.73479
3/27/17	0	0	1.62476	······	0	0	1.42454	1/1/18	0	3.74555	0.92516	······	7164.01	0	1.21069	12/18/18	787.515	0	1.77021
3/28/17	70.0593	0	1.55609	11/14/17	0	0	1.42454	1/2/18	0	1.88857	1.08275	2/26/18	7164.01	0	1.21069	12/19/18	0	0.22128	1.90074
3/29/17	0	0	1.62209	11/15/17	4131.71	0	0.84712	1/3/18	0	2.96603	0.98575	2/27/18	0	0	1.89131	12/20/18	0	0.22474	1.89962
······	0	0	1.62209	11/16/17	4040.9604	0	0.8585	1/4/18	0	3.57894	0.93054	······	0	0	1.89131	12/21/18	264.113	0.22474	1.83444
6/9/17	0	0	1.62209	11/17/17	252.59437	0	1.33051	1/5/18	2456.94	3.57894	0.78456	3/2/18	0	0	1.89131	12/22/18	747.349	0.22474	1.70836
6/10/17	403.627	0	1.47735	11/18/17	0	0	1.36219	1/6/18	6957.59	3.57894	0.51939	3/3/18	957.958	0	1.80501	12/23/18	1115.84	0.22474	1.615
6/11/17	0	0	1.61386	······	0	0	1.36219	1/7/18	7014.89	3.57894	0.51598	3/4/18	5323.31	0	1.4153	······	1115.84	0.22474	1.615
······	0	0	1.61386	12/1/17	0	0	1.36219	······	7014.89	3.57894	0.51598	3/5/18	7216.72	0	1.24754	1/1/19	1115.84	0.22474	1.615
7/17/17	0	0	1.61386	12/2/17	3336.6256	0	1.04925	1/14/18	7014.89	3.57894	0.51598	······	7216.72	0	1.24754	1/2/19	0	1.08591	1.615
7/18/17	0	1.57086	0.74808	12/3/17	5808.9461	0	0.82664	1/15/18	0	8.765	0.51598	3/13/18	7216.72	0	1.24754	······	0	1.08591	1.615
7/19/17	0	1.56409	0.75169	12/4/17	5779.6591	0	0.82912	1/19/18	0	8.765	0.51598	3/14/18	0	0	2.02049	1/6/19	0	1.08591	1.615
7/20/17	0	1.47018	0.80153	12/5/17	6118.081	0	0.79932	1/20/18	1327.93	8.765	0.41135	······	0	0	2.02049	1/7/19	0	0	1.95244

Figure 13: Tabel 1 of Daily strategy

Date	Cash	Gold	Bitcoin	Date	Cash	Gold	Bitcoin	Date	Cash	Gold	Bitcoin	Date	Cash	Gold	Bitcoin	Date	Cash	Gold	Bitcoin
······	0	0	1.95244	······	0	0	1.87364	4/2/20	0	0	1.78038	1/9/21	20561.4	0	0.87629	6/12/21	0	0	1.41129
5/12/19	0	0	1.95244	8/9/19	0	0	1.87364	4/13/20	0	0	1.78038	1/10/21	20465	0	0.87864	6/13/21	0	0	1.41129
5/13/19	1693.28	0	1.70485	8/10/19	1908.3944	0	1.7094	4/14/20	0	6.80098	0	······	20465	0	0.87864	6/14/21	0	0	1.41129
5/14/19	4220.83	0	1.37517	······	1908.3944	0	1.7094	4/15/20	0	6.80098	0	1/14/21	20465	0	0.87864	6/15/21	0	0	1.41129
5/15/19	4344.29	0	1.35941	8/19/19	1908.3944	0	1.7094	4/16/20	0	6.80098	0	1/15/21	0	0	1.39102	6/16/21	623.672	0	1.39545
5/16/19	4558.57	0	1.33276	8/20/19	0	0	1.88078	4/17/20	0	0	1.57087	······	0	0	1.39102	······	623.672	0	1.39545
5/17/19	3225.44	0	1.4985	······	0	0	1.88078	······	0	0	1.57087	2/19/21	0	0	1.39102	6/24/21	623.672	0	1.39545
5/18/19	3225.44	0	1.4985	10/22/19	1050.5091	0	1.75041	5/9/20	0	0	1.57087	2/20/21	9283.51	0	1.2216	6/25/21	749.133	0	1.39176
5/19/19	3225.44	0	1.4985	······	1050.5091	0	1.75041	5/10/20	530.651	0	1.51403	2/21/21	21216.8	0	1.00417	6/26/21	749.133	0	1.39176
5/20/19	0	0	1.88443	10/25/19	1050.5091	0	1.75041	5/11/20	530.651	0	1.51403	2/22/21	0	14.3689	0.91517	6/27/21	749.133	0	1.39176
······	0	0	1.88443	10/26/19	3345.6854	0	1.48018	5/12/20	530.651	0	1.51403	······	0	14.3689	0.91517	6/28/21	0	0	1.41296
6/25/19	0	0	1.88443	10/27/19	3902.9723	0	1.41877	5/13/20	530.651	0	1.51403	3/1/21	0	14.3689	0.91517	······	0	0	1.41296
6/26/19	4411.13	0	1.50189	10/28/19	4003.3046	0	1.40805	5/14/20	0	0.30342	1.51403	3/2/21	3723.77	0	1.32611	7/29/21	0	0	1.41296
6/27/19	7902.24	0	1.22643	10/29/19	2344.4208	0	1.58447	5/15/20	0	0	1.56623	3/3/21	0	0	1.40161	7/30/21	0	1.36362	1.34882
6/28/19	7902.24	0	1.22643	······	421.58035	0	1.7843	······	0	0	1.56623	······	0	0	1.40161	7/31/21	3913.84	1.36362	1.25421
6/29/19	7237.43	0	1.2791	11/3/19	421.58035	0	1.7843	8/4/20	0	0	1.56623	4/26/21	0	0	1.40161	8/1/21	964.59	1.36362	1.32362
······	7237.43	0	1.2791	11/4/19	421.58035	0	1.7843	8/5/20	0	8.30604	0	4/27/21	3179.26	0	1.3416	······	964.59	1.36362	1.32362
7/3/19	7237.43	0	1.2791	11/5/19	0	0	1.82819	······	0	8.30604	0	4/28/21	0	0	1.3982	8/5/21	964.59	1.36362	1.32362
7/4/19	0	0	1.87115	······	0	0	1.82819	9/16/20	0	8.30604	0	······	0	0	1.3982	8/6/21	0	0	1.40382
······	0	0	1.87115	3/19/20	0	0	1.82819	9/17/20	0	0	1.42574	5/8/21	0	0	1.3982	······	0	0	1.40382
7/9/19	0	0	1.87115	3/20/20	4347.3686	0	1.11214	······	0	0	1.42574	5/9/21	439.699	0	1.39058	9/10/21	0	0	1.40382
7/10/19	1771.12	0	1.72756	3/21/20	2556.5312	0	1.39412	12/13/20	489.302	0	1.39918	5/10/21	0	1.05146	1.36406				
7/11/19	2152.35	0	1.69541	3/22/20	0	0	1.79904	12/14/20	1024.53	0	1.37068	······	0	1.05146	1.36406				
······	2152.35	0	1.69541	3/23/20	0	0	1.79904	12/15/20	800.887	0	1.38206	5/26/21	0	1.05146	1.36406				
7/18/19	2152.35	0	1.69541	3/24/20	0	0.30258	1.72203	12/16/20	0	0	1.42245	5/27/21	0	0	1.41322				
7/19/19	0	2.60913	1.53796	3/25/20	0	1.07997	1.53199	······	0	0	1.42245	······	0	0	1.41322				
7/20/19	1366.65	2.60913	1.4056	······	0	1.07997	1.53199	1/6/21	0	0	1.42245	6/9/21	0	0	1.41322				
7/21/19	1372.49	2.60913	1.40504	3/31/20	0	1.07997	1.53199	1/7/21	8302.86	0	1.1926	6/10/21	2107.98	0	1.35561				
7/22/19	0	0	1.87364	4/1/20	1685.5951	0	1.53199	1/8/21	19919.9	0	0.89239	6/11/21	1441.51	0	1.37341				

Figure 14: Tabel 2 of Daily strategy

5.3 Markowitz's Model Calculation Parameters is Reliable

The rate of return and risk are calculated using the Markowitz's mean-variance model, which fully considers the expected return and risk in investment, and is reliable.

5.4 Fully Consider the Benefits and Risks in Multi-objective Optimization

In multi-objective programming, the goal is to maximize benefit and minimize risk. Give the risk tolerance k such that $\max q_i x_i \lambda_i < k$,where the risk rate q_i has been calculated by Markowitz's mean-variance theory. Taking $\max q_i x_i \lambda_i$ as the total risk of an investment reflects the reality that risk losses generally do not occur simultaneously, and is also consistent with that adopted in some literature (eg [1]). And, in order to find the best value k, we traverse k, and the result is as shown in Figure 18 above. In this way, we turn the multi-objective optimization into a multi-objective optimization that considers both benefits and risks, and provides adjustable parameters to determine the

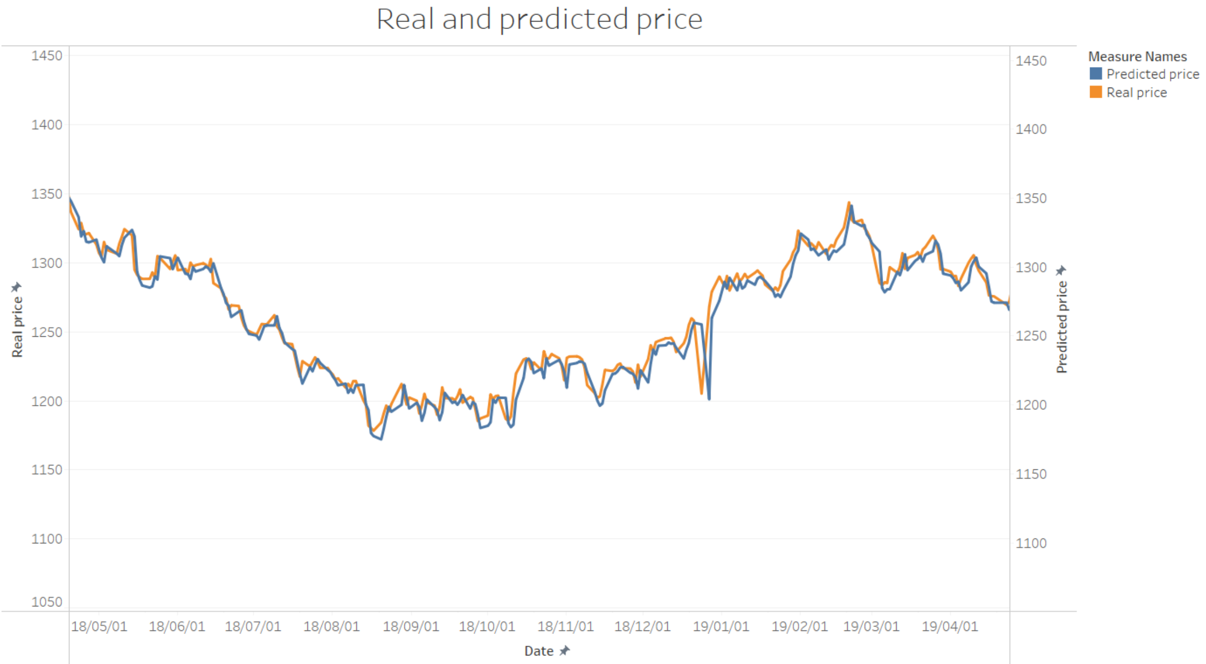

Figure 15: Real and Predicted price for Gold

proportion of risk in decision-making.

6 Sensitivity Analysis

6.1 Qualitative Analysis Sensitivity

In our model, transaction commissions as the coefficient of the objective function and the coefficient of the constraint term in the linear programming model, so when the transaction commission change, it may have an impact on the transaction process.

First of all, qualitatively analyze the impact of the transaction commission on the results. When the transaction commissions are high, they will lead to excessive consumption in the transaction process, which will reduce the profit or even lose money in the transaction process, so they will reduce transactions when making trading decisions. When the transaction commission is low, the loss in the transaction process is low, and the profit of the transaction is high, so it will promote the conclusion of the transaction and make the transaction more frequent.

6.2 Analyze Results with Different Commissions

First, when we vary the commissions for gold and bitcoin trades by a wide margin from 0% to 10%, the results are shown in figure 16:

Changing commission from 0% to 10%

	Bitcoin commission										
Gold com..	0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1
0	127,304	102,644	94,803	61,998	11,889	11,651	10,840	11,403	11,770	14,233	16,384
0.01	130,352	79,253	61,025	58,703	6,189	7,462	7,045	6,933	8,334	9,816	12,014
0.02	89,349	68,219	57,927	64,572	3,495	4,768	4,130	6,435	7,958	9,044	11,330
0.03	62,914	65,189	61,581	54,306	5,119	8,132	6,416	4,480	4,947	6,315	8,312
0.04	18,594	6,419	4,219	2,400	982	1,379	702	441	393	585	702
0.05	2,268	1,698	1,061	788	519	1,004	399	307	257	412	381
0.06	908	1,170	1,272	1,820	406	1,178	442	498	415	648	491
0.07	746	2,001	2,722	3,133	865	1,295	455	643	655	955	730
0.08	951	1,975	3,735	5,300	1,354	2,220	884	447	376	583	459
0.09	3,640	3,231	4,908	7,691	2,164	943	1,110	522	750	1,139	1,035
0.1	1,062	2,038	4,324	7,664	1,100	998	878	488	716	1,096	1,075

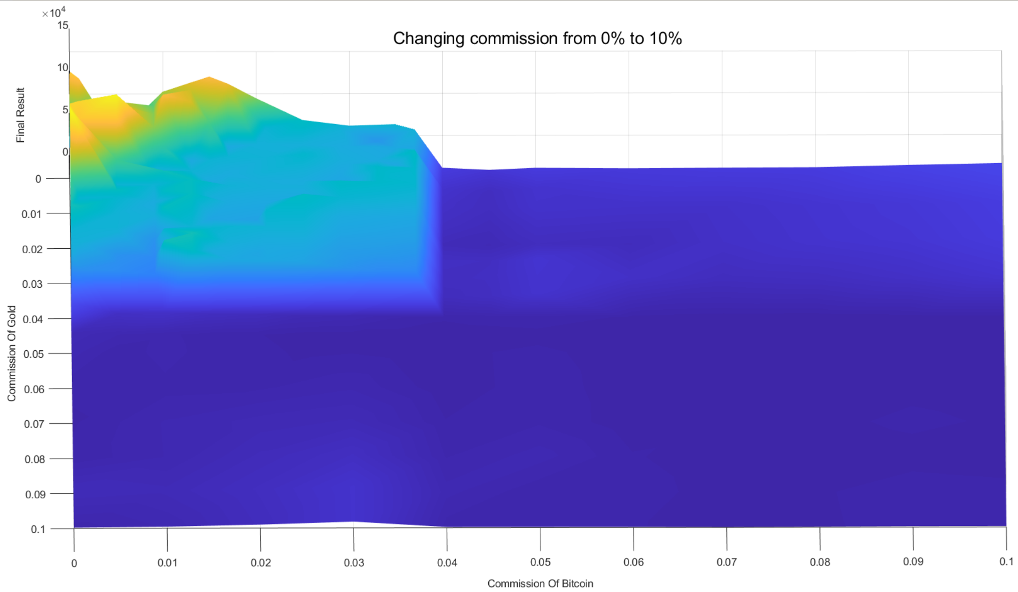

Figure 16: Changing Commission from 0% to 10%

From the figures, we can conclude that when the commissions are lower, the general income is higher. When both gold and bitcoin trading commissions are lower than 4%, the income increases significantly and changes rapidly with the reduction of the commissions, and the general income is significantly larger. When the commission ratio of gold or bitcoin is higher than 4%, the income changes slowly and the overall income is obviously small. When the commission ratio is too high, there is even a loss of assets.

Also, take a closer look at the results when the trading commission ratios for gold and Bitcoin vary in small increments between 0.1% and 3.7% in figure 17. The general trend still satisfies that when the commission ratio of the two goods transactions is smaller, the income is higher, and the income is more sensitive to the change of the commission rate. But not when the commission rate is the smallest, the profit is the highest. This shows that more frequent transactions do not necessarily lead to higher returns. In the data obtained from the experiment, when the transaction commission rate of Bitcoin is 0.1%, and the commission rate of gold is 1.7%, the highest profit is obtained, which is $131,829.

Changing commission from 0% to 10%

	Bitcoin commission										
Gold com..	0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.1
0	127,304	102,644	94,803	61,998	11,889	11,651	10,840	11,403	11,770	14,233	16,384
0.01	130,352	79,253	61,025	58,703	6,189	7,462	7,045	6,933	8,334	9,816	12,014
0.02	89,349	68,219	57,927	64,572	3,495	4,768	4,130	6,435	7,958	9,044	11,330
0.03	62,914	65,189	61,581	54,306	5,119	8,132	6,416	4,480	4,947	6,315	8,312
0.04	18,594	6,419	4,219	2,400	982	1,379	702	441	393	585	702
0.05	2,268	1,698	1,061	788	519	1,004	399	307	257	412	381
0.06	908	1,170	1,272	1,820	406	1,178	442	498	415	648	491
0.07	746	2,001	2,722	3,133	865	1,295	455	643	655	955	730
0.08	951	1,975	3,735	5,300	1,354	2,220	884	447	376	583	459
0.09	3,640	3,231	4,908	7,691	2,164	943	1,110	522	750	1,139	1,035
0.1	1,062	2,038	4,324	7,664	1,100	998	878	488	716	1,096	1,075

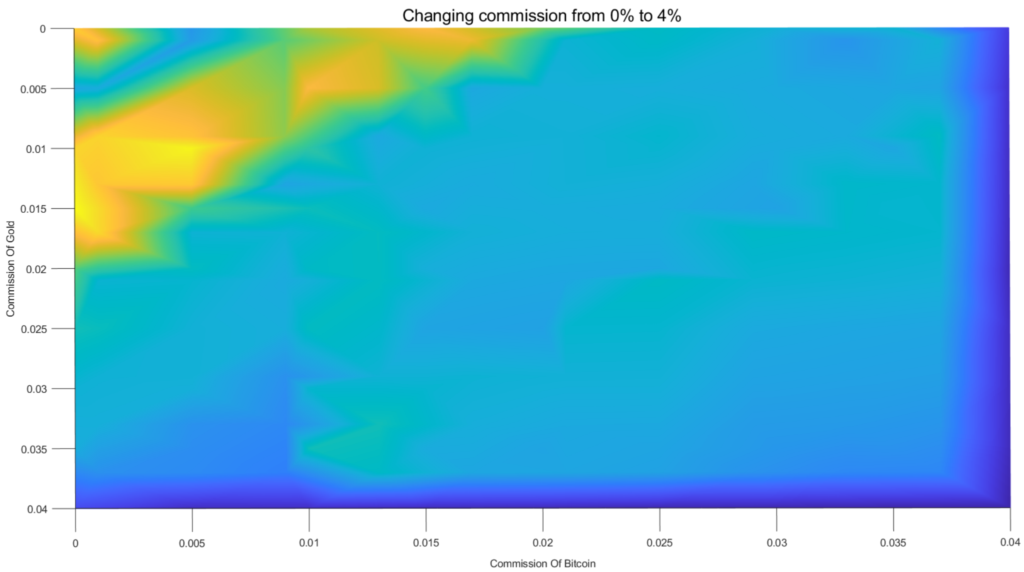

Figure 17: Changing Commission from 0% to 4%

7 Model Evaluation and Further Discussion

7.1 Strengths

Time Series Model

- It can more accurately predict the overall trend of the data and play an important role in investment decisions.
- The model is simple, only endogenous variables are needed and no other exogenous variables are needed.
- The model runs efficiently.

Multi-Objective Programming Model

- Model balances benefits and risks at the same time.
- Model runs fast with low complexity.
- It is easy to expand and can be applied to a variety of asset investment situations.
- It is self-adaptive, with multiple adjustable parameters to be used in many different investment scenarios.

7.2 Weaknesses

Time Series Model

- There may be lags in time series forecast results.
- It can predict trends, but not inflection points.
- The time series data is required to be stable, or stable after being differentiated; in essence, only linear relationships can be captured, and nonlinear relationships cannot be captured.

Multi-Objective Programming Model

- It is greatly affected by the objective equation and constraints. When the coefficients in the equation change, the results change significantly and the reliability of the model decreases.

7.3 Further Discussion

There are three aspects for improving our model:

- For the lag of our forecasting model, increasing the amount of data and using economic knowledge to dig deeper laws of the stock market may overcome this shortcoming.
- For metrics of our optimization models, expanding more indicators to better improve the strategy formulation algorithm.
- When turning multi-objective programming to linear programming, we can redefine objective function by quantifying the weights of the two objectives.

Extend our model:

- Feasibility: The prediction, computation, optimization, and solving parts of the model vastly majority rely on mathematical theoretical derivation rather than relying on difficult-to-explain methods such as neural networks to achieve.
- Practicality: We tend to have more data in practical applications. With more data, our model pre-dicts better and plan better, which further lead to a better daily strategy that can be applied in real life.
- Self-adaptation: Our model generates different investment models according to the risk preferences of different investors.

8 Conclusion

The central idea of this paper is to predict the future price data only through the known prices of the current day and the past, and then use this as a guide to design a multi-objective programming model to provide the daily optimal investment strategy.

The goal of the model is to obtain the maximum daily return with an acceptable level of risk.In order to avoid the trap of ultra-short-term investment and improve the rate of return, we also set the corresponding parameters in the model and adjust them to the optimal.

Finally, our result is shown in Figure 13 and 14, and the final asset value is $65093.46684. Through this problem, it is possible to show that big data stocks are also possible. But be sure to develop a good investment strategy and not fall into an investment trap. In general, the stock market is risky, and investment needs to be cautious

9 Memorandum

To: Market trader
From: Team # 2204227
Subject: Best Daily Trading Strategies
Date: Sunday, Feb.20, 2022

Dear Market trader:

According to your requirements, we have established a multi-objective optimization model that can formulate a daily optimal strategy for you according to your risk tolerance level.We first predicted the next price of gold and bitcoin on the current trading day, based on the price data of gold and bitcoin from all previous days.Because the price fluctuation is uncertain, we choose to predict the price for multiple days and use the average value as the price for the next day. This will help you avoid the pitfalls of short-term investing.Next, with the forecast data, we can determine the rate of return and risk for the day.Because the benefits and risks coexist, you can choose to trade within the risk you can afford.Through the rate of return and risk rate, we have established a multi-objective optimization model, which follows the basic principle of not buying small profits and not selling small losses, aiming at maximizing long-term returns and helping you get the most.After repeated parameter screening, we calculated that when Minimum Profit Acceptance Rate is 0.9%, Maximum Loss tolerance rate is 10%, and Risk Tolerance rate is 6.66%, it can help you get the maximum profit on the date you specify. At that point, the total value of your \$1000 invested is approximately \$65093.4668.

The curve of total return versus risk tolerance ratio k is shown in the following figure 18:

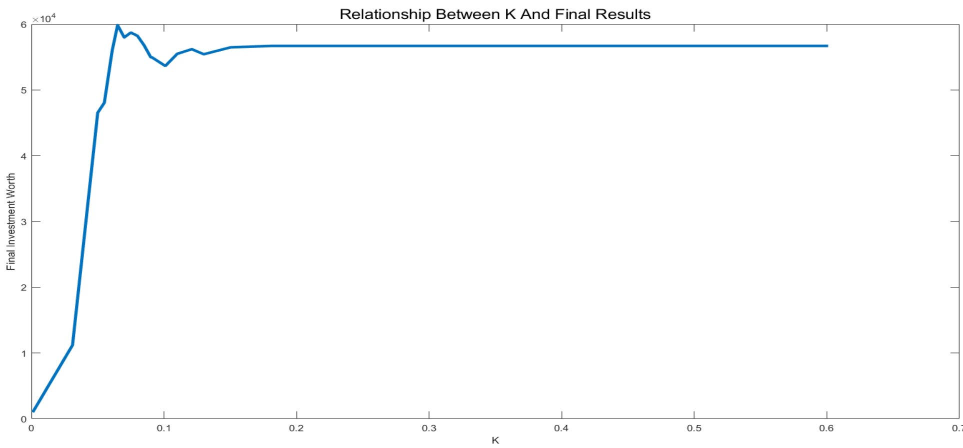

Figure 18: Test Results for hyperparameter k

We recommend your investment plan as shown below.

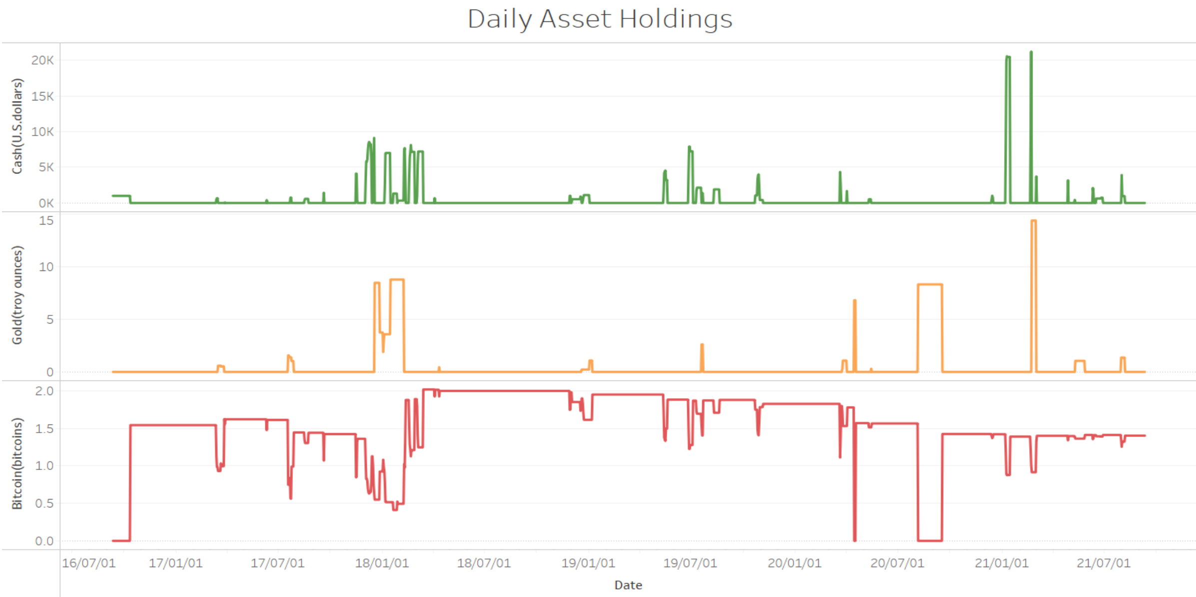

Figure 19: Daily Asset Holdings

The variables in the figure are the holdings after the investment on the day.You can get the specific scheme in Figure 13 and 14 .

If you have different ideas, you can get in touch with us, thank you.

Yours sincerely
Team # 2204227

References

[1] Cai X, Teo K L, Yang X, et al. Portfolio optimization under a minimax rule[J]. Management Science, 2000, 46(7): 957-972.