Problem Chosen	2022 MCM/ICM Summary Sheet	Team Control Number
C		2227906

Summary

Based on the historical price data of gold and bitcoin, this paper uses the time series model to predict the future price, formulate the investment decision-making standard and provide the daily trading strategy.

Aiming at problem 1, the time series model Arima is applied to predict the data. We calculate the difference of raw data,depending on which to conduct the stationarity test and white noise test on the original data and difference data. Only the data that passed the test will be used for model training and parameter determination. It being sophisticated to redefine parameters erverday,we adopt the automated ARIMA model to obtain the best parameters and start batch model training and model prediction to determine the price data in the next 7 days.After linear regression,the expected rate of return for the next seven days can be figurede out.With expected rate of return and Mean-Variance Model,we set up the Buying standard ,selling standard and repositioning standard.Use this model,the total asset value is about 18000$.

For problem 2, in order to illustrate that the strategy is the best strategy, we introduce a disturbance to display the stability of the model through the change of the final assets. The results show that the model is stable under a certain range of disturbances.

In response to question 3, we adjust the transaction commission ratio to obtain various the final asset data under different commission ratios,and visualize the changes of assests to intuitively show the sensitivity of the strategy to the transaction cost. ARIMA ARIMA 7 7 18000$ MEMO

Keywords: Short-term ArbitrageTwo-risk Asset PortfolioSharpe Ratio;Trading Commission;ARIMA;Average Value-square Difference Model

Huiteng Rong and Yuning Xiao and Jianhui Liu

February 22, 2022

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Contents

1 Introduction

1.1 Background

As personal assets accumulate, more and more people are entering the investment market in order to preserve the value of their existing assets or to make them more valuable. However, we all know that investment products are often highly volatile,in orther words, it is difficult to predict. Among the many investment products, gold and bitcoin are the most popular. Bitcoin, in particular, has seen a rapid expansion in trading since its emergence.But its security and stability have been called into question by the huge price fluctuations.

Obviously, with the gold and bitcoin investment boom, a substantially profitable portfolio for the average trader is difficult to achieve. It is essential to predict future trends in volatile assets based on daily and previous days' updated trading data. Therefore, traders propose to develop a model that uses only the past stream of daily prices to date to determine each day if the trader should buy, hold, or sell their assets in their portfolio. ,

1.2 Problem Statement

According to our understanding,our problem has few key points:

1. Build a model with raw data to analyze the trend of gold and bitcoin values are going.
2. Forecasting future volatile asset movements based on time series models.
3. ,Solving the problem of maximizing benefits using dynamic planning while taking risks into account.
4. Determine the trader's daily trading decisions and trading behavior with trading commissions.
5. Prove that we provide the optimal strategy.
6. Determine how sensitive the strategy is to transaction costs.

1.3 Problem Analysis

After clarifying the problem, we believe that the ARIMA model has a great advantage over the traditional model in the problem of time series analysis. **Our work overview**

- **We pre-process the raw data**,including filtering the data, visualizing the data, and mining the time series.

  This part of the work can greatly improve the efficiency of modeling and analyzing volatile assets.

- **We selected ARIMA for data prediction**

  Provided that ARIMA model is applies, we establish daily buy and sell, position transfer and investment ratios to maximize asset value.

- **to prove the optimality of our strategy,**we set perturbation terms on the three criteria developed for buying and selling, position adjustment and portfolio to determine the optimal parameters.
- Finally, we enumerate a series of results that **test the sensitivity to commissions.**

ARIMA ARIMAARIMA

2 Assumption

1. All cash is consumed at each purchase.
2. The price fluctuations of gold and bitcoin are independent.

3 Data Processing

For the problem we faced, the stability of the data is the basis of our model. Generally speaking, incomplete and abnormal data in the raw data may greatly affect the efficiency of problem analysis and the accuracy of the results. For this reason, it is essential to analyze and pre-process the data.

3.1 Data Screening

We analyzed the raw data in the LBMA-GOLD.csv and BCHAIN-MKPRU.csv files,final data status is as follows:

For the missing data in LBMA-GOLD.csv, we fill in the date according to the average of the day before and the day after.

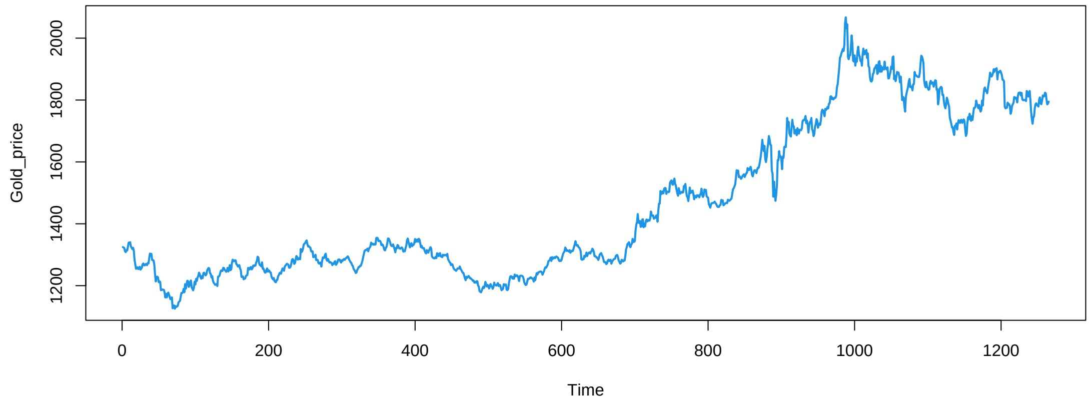
3.2 Data Visualization

To observe the price trends of gold and bitcoin more visually, we visualize the given data and draw figure**??**and**??**

3.3 Mining Time Series

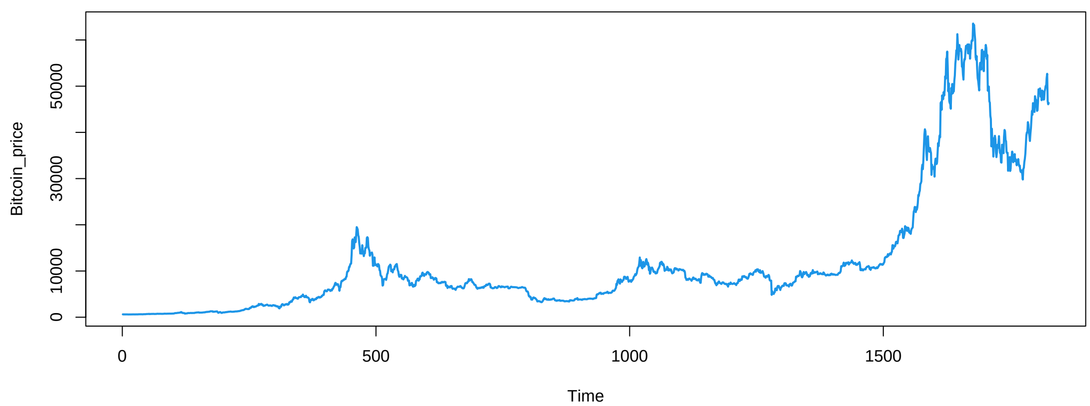
For subsequent data prediction using the time series model ARIMA, We perform stability test and white noise test on the raw data and processed data as a way to mine meaningful time series.

	gold	bitcoin
count	1255	1826
mean	1464.54	12206.06
std	249.29	14043.89
min	1125.7	594.08
max	2067.15	11084.73
missing data	10	0



(a) 1

Figure 1: Gold price tendency



(a) 2

Figure 2: Bitcoin price tendency

3.3.1 Stability Test

First,we test the stability of the original data by comparing two methods, the image observation and the unit root test. Testing unit rootand result is shown below: GoldDickey-Fuller = -2.4368, Lag order = 10, p-value = 0.3934<0.1 BitcoinDickey-Fuller = -1.4395, Lag order = 12, p-value = 0.8156<0.1

The raw data, the image mean varies with time and the unit root test p>0.05, so it is an unstable time series. We then perform first order differencing on the original data to obtain updated data.

Secondly,the first-order difference data is obtained according to the first-order difference of the original data, and the two methods abrove are also used to test.The result is as follows.**??** Visualizing the first order difference data is illustrated in Figure 4

Testing unit rootand result is shown below:

GoldDickey-Fuller = -11.357, Lag order = 10, p-value <0.01 BitcoinDickey-Fuller = -11.633, Lag order = 12, p-value <0.01

It can be concluded that the first-order difference data, with image mean essentially zero and unit root test p<0.05, is a stable time series.

Thirdly,utilizing second order difference we obtained second order difference data with two methods testing The result is shown in**??**.

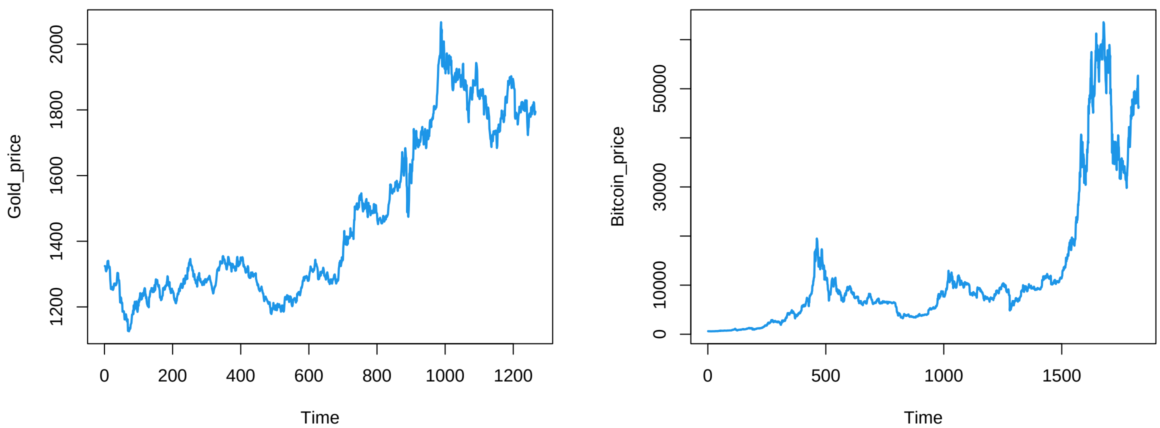


Figure 3: Raw data visualization

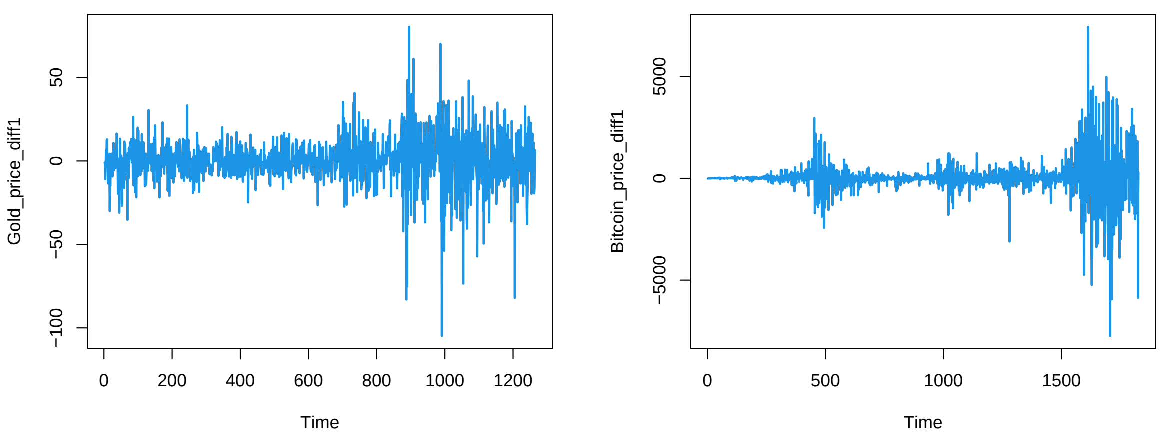


Figure 4: first order difference data

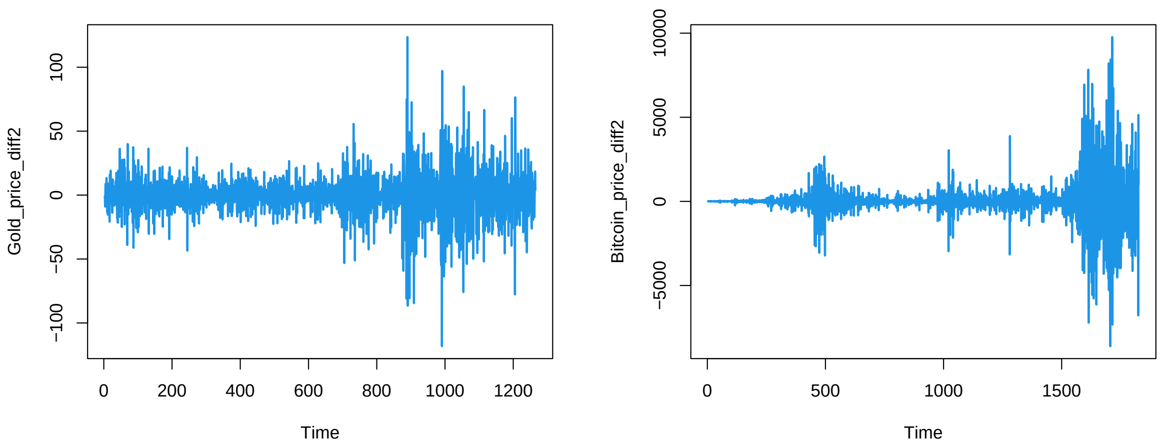


Figure 5: second order difference data

Testing unit rootand result is shown below:

GoldDickey-Fuller = -20.351, Lag order = 10, p-value <0.01 BitcoinDickey-Fuller = -18.999, Lag order = 12, p-value <0.01

It can be seen that the image mean of the second order difference data is basically 0 and the unit root test $p<0.05$, which means it is a stable time series.

Final conclusion: we cannot use the original data directly for time series modeling because it is unstable, and need to use its first-order difference or second-order difference data for time series model.

3.3.2 White Noise Test

We need to evaluate whether the data is white noise or not, and will discard the one that is white noise because it has no research significance. So We chose Ljung-Box test to meet the demands.

The first step is to examine the raw data,The test yielded the following graph

GoldX-squared = 7495.2, df = 6, p-value < 2.2e-16 X-squared = 14834, df = 12, p-value < 2.2e-16 X-squared = 22018, df = 18, p-value < 2.2e-16 BitcoinX-squared = 10716, df = 6, p-value < 2.2e-16 X-squared = 20966, df = 12, p-value < 2.2e-16 X-squared = 30765, df = 18, p-value < 2.2e-16

Raw data $p<0.05$, not white noise

The second step,we test first order difference data,result can be seen below:

GoldX-squared = 35.268, df = 6, p-value = 3.824e-06 X-squared = 47.324, df = 12, p-value = 4.097e-06 X-squared = 56.106, df = 18, p-value = 8.576e-06 BitcoinX-squared = 21.896, df = 6, p-value = 0.001265 X-squared = 63.942, df = 12, p-value = 4.275e-09 X-squared = 71.685, df = 18, p-value = 2.339e-08

First order differential data p<0.05, not white noise

Third,we test second order difference data,result is shown below

Second-order differential data p<0.05, not white noise **Final conclusion:** The data come from a professional data statistics center and should not be white noise, and the test results prove it. They are not white noise.

4 PartModel Development

4.1 Time Series Model ARIMA - Data Forecasting

4.1.1 Model Theory

AutoregressiveăIntegratedăMovingăAverage model is the differential integrated moving average autoregressive model, also known as the integrated moving(or slilding)average autoregressive model, is one of the time series forecasting analysis methods. In ARIMA(p, d, q),AR is "autoregressive", p is the number of autoregressive terms; MA is "sliding average ",q is the number of sliding average terms, and d is the number of differences (order) made to make it a smooth series. Although the word "difference" does not appear in the English name of ARIMA, it is a key step to analyse time series.

«««< HEAD «««< HEAD «««< HEAD $\left(1-\sum_{i=1}^{p} L^{i}\right)(1-L)^{d} X_{t}=\left(1+\sum_{i=1}^{q} \theta_{i} L^{i}\right) \varepsilon_{t}$

======= »»»> e0d6d6aa972c268925f53c491cc6a08ca18daf0e ======= »»»> e0d6d6aa972c268925f53c491 ======= »»»> e0d6d6aa972c268925f53c491cc6a08ca18daf0e

4.1.2 Determining the parameters p, q

We take advantage of the autocorrelation and partial autocorrelation plots to find out the parameters p, q. The following figures show the the format of autocorrelation and partial autocorrelation plots.

In theory Tail-dragging: always have non-zero values, not constant equal to zero after k is greater than some constant (or fluctuate randomly around 0).

Truncated tail: After greater than a constant k, it quickly tends to 0 as a k-order truncated tail when both autocorrelation and partial.

By figure **??**and **??**, it can be seen that the first order difference data and the second order difference data are meaningful time series. Therefore,we use the same methods in the subsequent section.The analysis charts are as follows.

4.1.3 R Language Determines the Optimal Parameters p, d, q

Given that only the price data as of the day can be used each day, i.e., the training data used each day are inconsistent, it is not practical to determine the optimal parameters for the model through autocorrelation and partial autocorrelation plots, so we use the auto.arima function in R language to automate the parameter determination.

The best model information was obtained after using the auto.arima function with all given data.

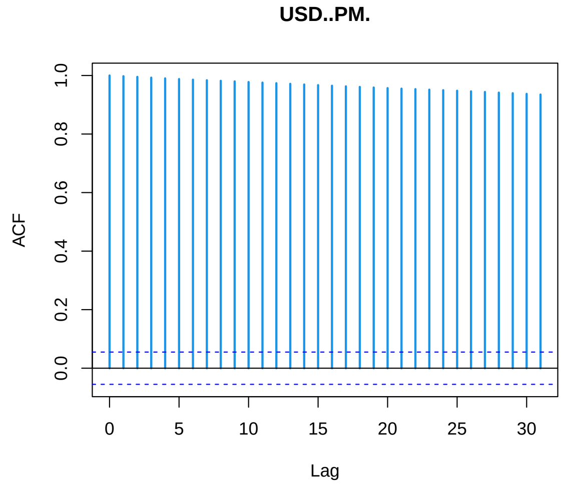


Figure 6: Autocorrelation diagram

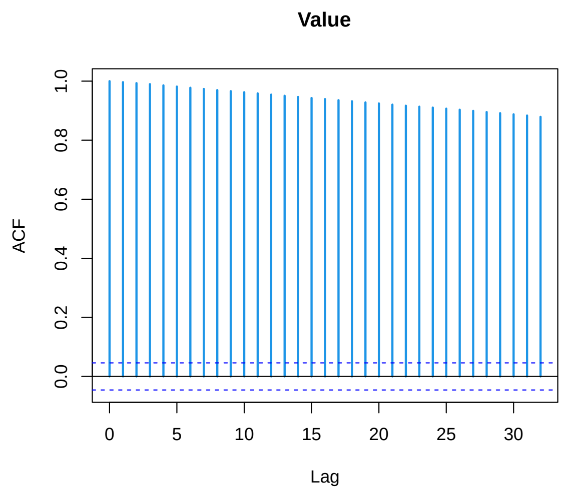


Figure 7: Partial autocorrelation diagram

And the model is as follows: Gold:p=4d=1q=5;ARIMA(4,1,5) Bitcoin:p=2d=1q=1;ARIMA(2,1,1)

4.1.4 White noise test for model residuals

It is usually assumed that the model residuals of a reasonable model should be white noise. logically we conducted a white noise test on the residuals of the resulting model. The results are as follows.

GoldX-squared = 4.9084, df = 7.1428, p-value = 0.6862 BitcoinX-squared = 1.3484, df = 7.5099, p-value = 0.9919 We can see model residuals p>0.05, is white noise.Our model is valid.

4.1.5 Model Prediction and Visualization

To make the results more intuitive,we use the model to calculate and predict the historical data. And the visualization results are shown in the figure

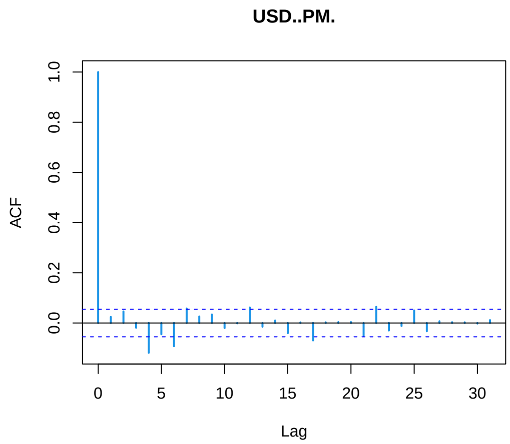


Figure 8: First order differential autocorrelation diagram-gold

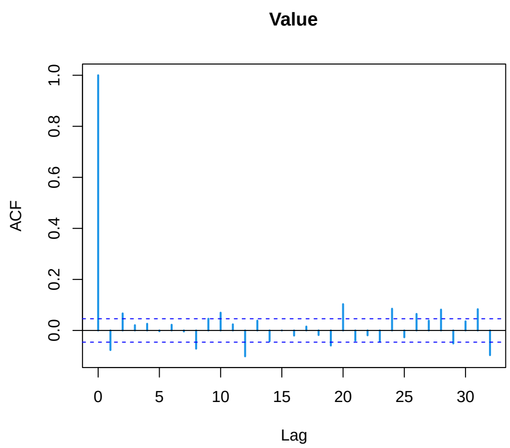


Figure 9: First order differential partial autocorrelation diagram-bitcoin

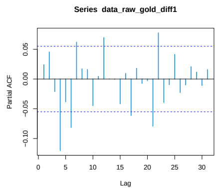


Figure 10: First order differential autocorrelation diagram-gold

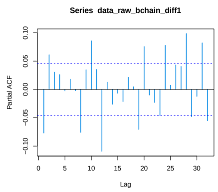


Figure 11: First order differential partial autocorrelation diagram-bitcoin

The reason for the large overlap of lines in Figure 6 is that the data sample is too large. So we choose 100 of these samples and make graph7. The model fits well apparently from the images.

4.1.6 Batch prediction of data

Based on the price data as of the day,we predicted gold and bitcoin price for the next 7 days and the same automated arima modeling is performed using the auto.arima function to obtain the price data for the next 7 days. By analyzing the forecast data, we observed a roughly linear variation. Then,we integrated these data using linear regression to clarity the future price trend and fitted slope quantifies the trend to make the better investment decisions.

4.2 Trading Strategy Model - Dynamic Programming

Notation:

w_G:Gold holding ratio

w_B:Bitcoin holding ratio

r_G:Gold expected return

r_B:Bitcoin expected return

α_G:Commission ratio of gold transaction

α_B:commission ratio of bitcoin transaction

σ_G:Gold lower semi-variance of historical yield

σ_B:Bitcoin lower semi-variance of historical yield

β:Risk aversion coefficient of trader

T:The average number of days holding an asset after each purchase

4.2.1 Expected return on assets

Traders pay a percentage of commission when they buy and sell assets, in other words, there is hidden cost to holding assets every day. We use$\alpha \div T$ to represent such costs.

We determine trading behavior by comparing the expected benefit with the size of that cost. When expected revenue is large enough to offset this cost,model decide to buy; When the expected return is less than the negative cost, it represents maintaining; When the asset is about to lose more than commission cost,model needs to sold Holding share immediately to stop loss.

If$r > (1+\beta)\alpha \div T$,it means that the asset will appreciation in the future,so trader can be buy in.

If$r < -(1-\beta)\alpha \div T$,it represents that the asset will depreciation in upcoming period,so trader must sell them out .

If$-(1-\beta)\alpha \div T < r < (1+\beta)\alpha \div T$,it indicates that recent prices are stable,trader can either buy or sell.

moreover,due to the difference in investors and investment products, We introduceβ to characterize the diffrent degree of risk aversion.

The larger the β,refers to the more conservative the investors is,stricter restrictions on buying and more lenient restrictions on selling. On the contrary,thr smaller β indicates that the more aggressive the investor is, who has a higher standard of purchusing and a lower standard of selling.

Additionally,we have to consider the following two situations when purchasing: ,

1. If only one of gold and bitcoin meets the upside condition, then we simply buy all of our currently available funds into that asset.
2. Whereas if gold and bitcoin rise at the same time,there is a need to consider how to allocate the available funds. In this case, we use the Sharpe ratio to measure the different proportional investment groups

$$Sharpe\ Ratio = \frac{w_G \times r_G + w_B \times r_B}{\sqrt{w_G^2\sigma_G^2 + w_B^2\sigma_B^2 + 2Cov_{w_B w_G}}}$$

We use the lower semi-variance as a quantitative index of risk, as the portion of the standard deviation that represents fluctuations less than the mean. which is more indicative of the risk of asset losses. We divide the expected return by the following half standard deviation yields the Sharpe ratio,which implies the magnitude of the return per unit of risk of the current portfolio. When the Sharpe ratio is maximum, it undoubtedly means that the current proportion of the portfolio is optimal

Based on the assumptions that "All cash is consumed at each purchase" and "The price fluctuations of gold and bitcoin are independent", We simplify the problem of solving the optimal investment ratio as an optimization problem. And we can use the computer to find its numerical solution.

$$\begin{aligned} max \quad & \frac{w_G \times r_G + w_B \times r_B}{\sqrt{w_G^2\sigma_G^2 + w_B^2\sigma_B^2}} \\ s.t. \quad & w_G + w_B = 1 \\ & 0 \le w_G \le 1 \end{aligned}$$

4.2.2 Current Asset Holding

After determining the return on the assets, we also consider the current asset allocation in order to determine what and how much assets we will eventually buy or sell. With the assumption that "All cash is consumed at each purchase",it is impossible to hold cash, gold, bitcoin or no assets at the same time. So there are a total of $2^3 - 2 = 6$ possible scenarios, to be specific: (solid circles indicate that the asset is held, hollow circles indicate that the asset is not held)

cash	gold	bitcoin
●	○	○
●	○	●
●	●	○
○	○	●
○	●	○
○	●	●

4.2.3 Determination of the final act of transaction

Daily expected returns for gold and bitcoin are up, down, and stable. 9So,there are 9 cases when they are combined together. 6And the initial state of the daily assets, as pointed out in the previous subsection, has six profiles. 54Thus, the final trading behavior totals 54 scenarios. 546Fortunately, we can summarize this into the following six situations:

1. **one maintain,the other appreciate:**In this case, if cash is available trader uses it all to buy appreciating assets. If no cash is available do not make the purchase.
2. **one maintain,the other depreciate:**Under such circumstances, trader sells all the devalued asset if they hold.
3. **one appreciate,the other depreciate:**In this case, the trader first sells the depreciating asset in full and then buys the appreciating asset with all the cash gained.
4. **both maintain:**Trader does not make any transactions
5. **both appreciate:** 4.2.1 As mentioned in 4.2.1, when the expected returns of two assets rise simultaneously, we need to determine the optimal asset mix based on the Sharpe ratio. If we only hold cash as an asset, then we can simply buy two assets based on the optimal ratio. However, if we hold either gold, bitcoin or both, we have to decide if we still need to adjust the ratio to the optimal ratio.After all, each adjustment requires a significant commission. 10To simplify the model, we define the criteria for transferring positions: If the proportion of simultaneous changes in both assets exceeds 10 percent when the position is transferred, it will be adjusted to the optimal proportion, otherwise it will remain unchanged.
6. **both depreciate:**After selling two assets at the same time, we only have one asset in cash

4.2.4 Additional Explanation

- 4.2.14
- 77

4.2.5

$\beta = 0.2$

5 Part:Strategy Evaluation

5.1 Set Perturbation Terms

To demonstrate strategy optimality,firstly we add small perturbations to the buy and sell criteria.

Then,we make minor adjustments to the buy and sell criteria, invoking the model (at this point the risk appetite indicator is 0.2) to calculate the final asset size,.

Finallyobserve the asset stability.We found In the range of -0.25 to 0.25, the final asset is basically smooth and there is no sudden drop, which shows that the model stability is relatively reliable. result shown in the figure.

6 Part:Sensitivity Analysis

6.1 Assuming Changes In Commission

We set the commission percentage of gold as a, the commission percentage of bitcoin as b, and the final asset as f USD. After we kept adjusting the commission rate, we obtained the final assets under different commission rates, and the results are shown in the figure.

Final conclusion Both the gold commission ratio a and the bitcoin commission ratio b will significantly affect the final asset f dollars when they changes. According to the analysis,f is essentially negatively correlated with b and f will be more sensitive to changes in b compared to a. Our model is not very good at grasping the price of gold because it changes so frequently. So it is not true that if the transaction cost is low, trader will benefit more. But for bitcoin, the changes are large and infrequent, the model is easier to make a correct judgment, and when the transaction cost is very low or even 0, we can arbitrage and protect the value easily.

In summary, it can be seen that the model is sensitive to trading commissions.

7 Evaluate of the Model

7.1 Strengths and weaknesses

Strengths

1. By using the time series model ARIMA to forecast the data, the prediction is effective and can be applied as a future price reference for decision making.
2. Our trade model extends the generalizability of the model by fully considering return and risk factors and introducing risk appetite indicators.
3. The model is more stable than the conventional model, and the variation of the model results is small for minor perturbations.
4. The model grasp bitcoin price fluctuations well, for fully capturing the ups and downs of bitcoin. and with traders only having historical data from before that day, the final asset can reach around 20,000USD, which is already very impressive.

Weaknesses

1. The model forecast of gold changes needs to be improved and the profitability level is relatively low.
2. The model performs well when the risk appetite indicator is 0.05-0.45 and can be considered an average risk taker, but otherwise the model underperforms.

8 A Memo

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Dear Traders,

It's a great pleasure to have a connection with you the other day,when we had a constructive discussion on prospect of your investment.In order to maximize your interests,we built a model to meet your investment need.

Having made some suverys on investment in Bitcoin and Gold, we found it is difficult to accurately predict the movements. So we employed ARIMA model for the problem.I have summarized the key points of how our model was built:

1. Time series model ARIMA predicts future seven-day data
2. The future price trend is obtained by linearly fitting the data for the next seven days and quantified by the slope k.
3. Determine the trading commission ratios a and b, risk appetite indicators, etc. based on the slope k.

   and specify buy criteria, sell criteria and position adjustment standard.
4. Determine the daily trading strategy based on each criterion and perform simulation trading to calculate the final asset.

After testing,we can make sure our model is very reliable. In addition,simulation results prove that the model can achieve quite objective profitability.

Every trader can operate our model at their disposal,because it only needs historical price data and does not require any additional data to work. You no longer need to be tormented by obsessing about how to trade every day.Our model will tell you exactly what to do with your daily investments, including guidance on whether to buy or sell assets and what percentage of gold and bitcoin to buy. It is profitable for you to arbitrage and preserve value.

In brief, the advantages of our model are as follows:

1. By using the time series model ARIMA to forecast the data, the prediction is effective and can be applied as a future price reference for decision making.
2. Our trade model extends the generalizability of the model by fully considering return and risk factors and introducing risk appetite indicators.
3. The model is more stable than the conventional model, and the variation of the model results is small for minor perturbations.
4. The model grasp bitcoin price fluctuations well, for fully capturing the ups and downs of bitcoin.

Every coin has two sides,and our model is no exception. **Weaknesses**

1. The model forecast of gold changes needs to be improved and the profitability level is relatively low.

2. The model performs well when the risk appetite indicator is 0.05-0.45 and can be considered an average risk taker, but otherwise the model underperforms.

   According to different risk aversion for each individual,you may get different investment results.You can see the results visually in the table below.

   To sum up,you can profit more at the expense of stability of your investment. And you need to be aware that our predictions are not necessarily accurate,no conclusion should be drawn before the real price is announced.

   Best wishes!

   Your Sincerely, Team 2227906

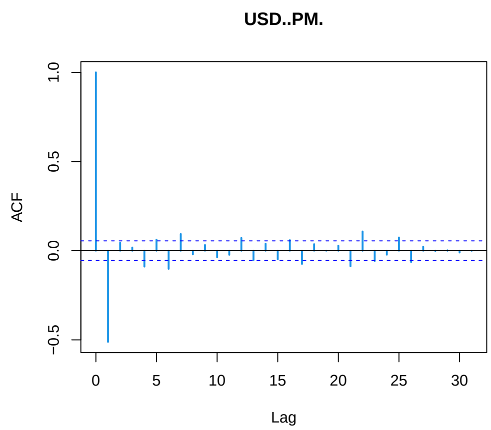


Figure 12: Second order differential autocorrelation diagram-gold

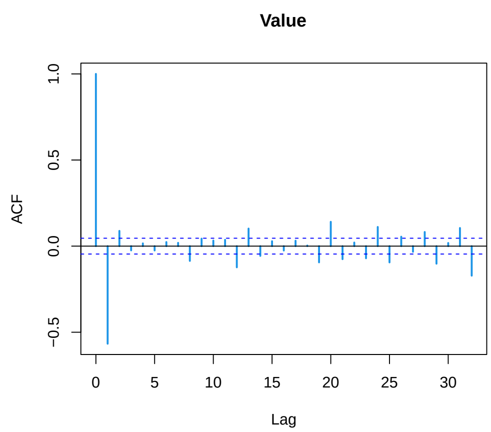


Figure 13: Second order differential partial autocorrelation diagram-bitcoin

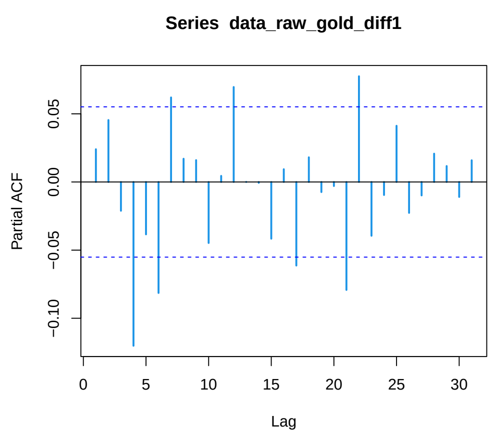
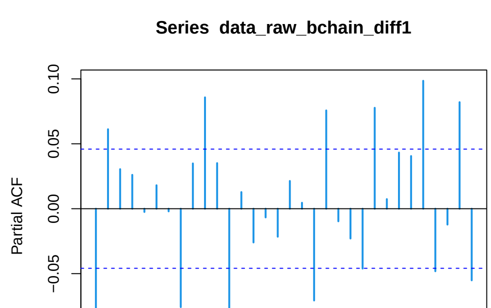
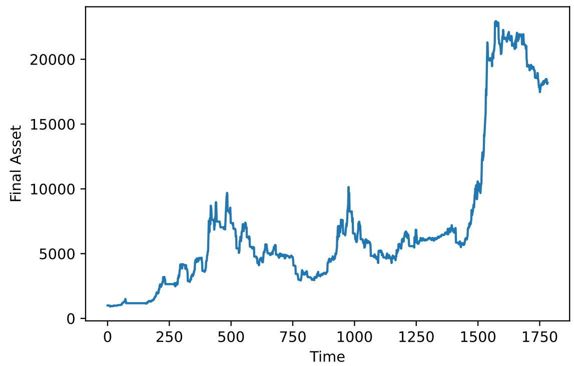


Figure 14: Second order differential autocorrelation diagram-gold




Final Asset
Time
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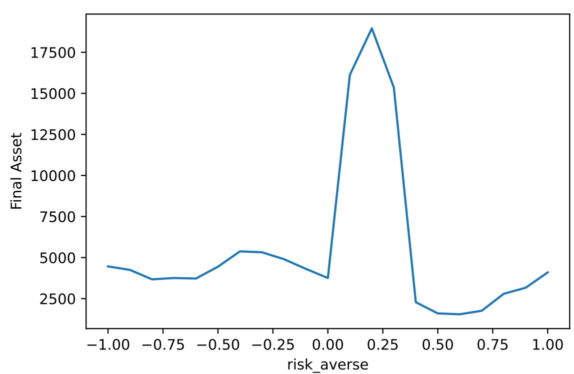
5000
10000
15000
20000
0
250
500
750
1000
1250
1500
1750


Final Asset
risk_averse
2500
5000
7500
10000
12500
15000
17500
−1.00
−0.75
−0.50
−0.25
0.00
0.25
0.50
0.75
1.00

i