Problem Chosen	2024	Team Control Number
C	MCM/ICM	2421624
	Summary Sheet	

From Price Prediction and Transaction Determination to Trading Strategy

Summary

Virual currency has become a hit among all ages, and handreds of thousands people keep track of the price of gold and bitcoin every day. In order to find a optimal strategy of transaction, we developed a Strategy Model with **ARIMA Model** and **DP** method, and obtained the final optimal investment worth.

For **Task 1,** We use **ARIMA Model** to develop the **Price Pridiction Model**. For each opening day, we will predict the price of 5 days afterwards with the combination of long-term and short-term predicting results in 61.8% and 38.2% percent respectively. According to the prediction, we reach the final optimal investment worth through the **Transaction Determination Model**. The result of our model is $11110449.80806396008, about 110 times higher than the start-up loan ($1000).

For **Task 2,** we prove that our model is the most appropriate by comparing our prediction-decision model with other models. When proving the optimal prediction model, we compare the prediction accuracy of the two optimal models—ARIMA model and grey prediction model—in all the models we tried. The MRE (Mean Relative Error) of gold and bitcoin price prediction in ARIMA Model prediction are 0.0063 and 0.0281, which are better than 0.0078 and 0.0350 of GP (Grey Prediction) model.

For **Task 3,** we test the holding frequency and trading frequency of each transaction costs rate under different portfolios at a step of 0.002, finding that the DP decision model is very sensitive to the change of transaction costs rate. The specific information is shown in the figures.

For **Task 4,** we write a memo to the trader to share our achivement of trading strategy with this model and its result. Finally, our model find a favorable strategy to achieve a desirable result of gold and bitcoin transaction under the indicated condition.

Keywords: Gold and Bitcoin Transaction; Time Series Analysis; ARIMA model; Dynamic Programming; Robustness

Contents

1 Introduction

1.1 Problem Background

For some time now, market traders have been worried about the uncertain risk of fiat money and losing confidence in modern monetary system step by step. Gold and bitcoin, as they are difficult to control, possess the ability to keep neutral and safe under any circumstances, drawing the whole world's attention.

Considering two types of virtual currency markets—spot gold market and bitcoin market, traders need more technical assistence for better decision. We will start with $1000 on 9/11/2016, and the transaction will last for 5 years till 9/10/2021. We hold a portfolio composed of cash in U.S. dollars, gold in troy ounces, and bitcoin in bitcoins.

As virtual currency market gradually expands its influences on the economy, it is crutial for individual traders to make good prediction of price trend, sound consideration of the commission, and cautious determination of their transaction. On each trading day, traders keep a close eye on the figures and force themselves to estimate and react fast. What if they have a more scientific method and gain more accurate forecast!

1.2 Restatement of the Problem

Combining background information and restricted conditions identified in the problem statement, we need to accomplish the following tasks:

- **Task 1**

  Develop model functioning in providing best trading advice acoording to price data up to the given day and present the value of the initial $1000 on the last day of the whole period.

- **Task 2**

  Offer evidence to prove that our model is the most appropiate.

- **Task 3**

  Evaluate the sensitivity of our strategy in terms of the trasaction costs by stating the impact that the costs make on our strategy and results.

- **Task 4**

  Write a memo to the trader to clarify the rationality of our model and strategy with computed results.

1.3 Our Work

Our work flow of this paper is showned in Figure 1 on Page 4.

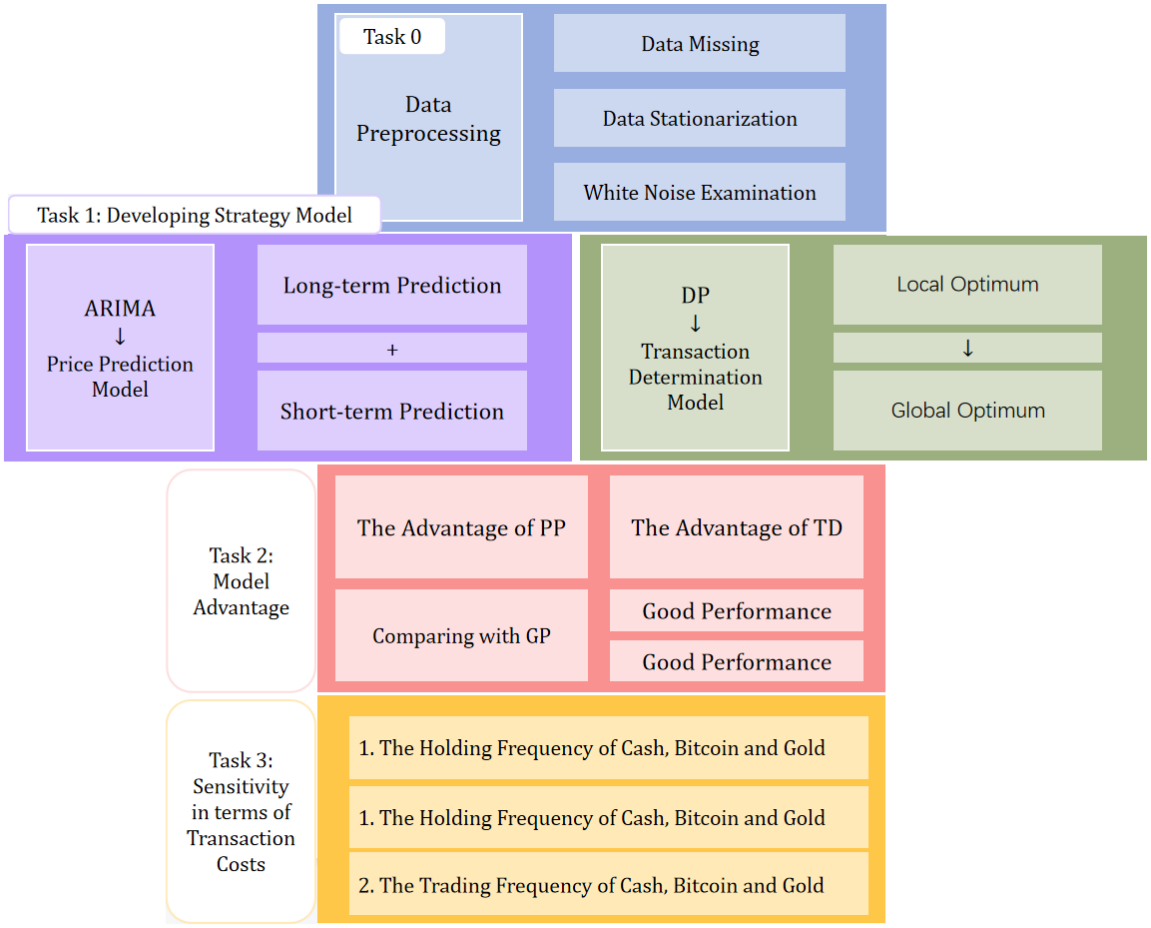


Figure 1: Work Flow

2 Assumptions and Justifications

In order to simplify our model, we made some general assumptions which are listed below corresponding with justifications:

1. **It is assumed that opening price is equal to closing price, and the price of gold and bitcoin is stable in one opening range.**

   On the basis of market trading rules, traders have access to the opening price and real-time price. Therefore, every decision are made on account of known price by the time and pridicted price trend in the future. For the convenience of modeling, we hypothize stable assets price on each opening range. Meanwhile, considering that traders can buy and sell near the closing time, this does not affect the model results.

2. **It is assumed that on each opening range, the trader only makes one transacion with no limitation of transaction amount.**

   Under such assumption, our model will make decisions with more freedom and the transaction process will be more simple. Since the price of each asset is fixed on the same day in Assumption 1, the model does not consider multiple transactions in the same market when making the optimal choice.

3. **It is assumed that trading margin is always sufficient during the whole trading period.**

   This assumption can eliminate the impact of trading margin making on transaction determination.

3 Notations

In this paper, some important notations are listed in Table 1.

Table 1: Notations

Symbol	Desciption
s	the state of assets s_0 = cash s_1 = bitcoin s_2 = gold
F(k,s_i)	the maxmum value of assets on the kth day with the ith type of assets
T(s_j,s_i)	the obtainable amount of assets with the deduction of transaction cost after the transferation from the jth to the ith type of assets
V(k,s_i)	the price of the ith type of assets on the kth day

4 Task 1: Constructing Strategy Model

4.1 Price Pridiction Model Based on ARIMA

4.1.1 Data Preprocessing

1. **Data Missing**

   When processing data, we find that there is some missing data of closing price due to the **business suspended** in advance of gold market in holidays. For the purpose of applying

time series analysis, we use the opening price on the same day in search of the website, which is persistent with our **Assumption 1**.

2. **Data Stationarization**

   Sequence stationarity is a prerequisite for time series analysis. We use **Dickey-Fuller Test** to examine the stationarization of the completed data.

   Firstly, at a certain confidence level, we set a **Null Hypothesis** that the time series data is unstable and the sequence has a unit root. For a stationary time series data, it is necessary to be significant at a given confidence level and reject the null hypothesis. **Secondly,** we put our data into the course of **ADF Test**. Unfortunately, the result is about 0.9042384812941663 and absolutely larger than 0.05, which means we have to accept the hypothesis—our raw data is unstable. **Thirdly,** for the reasonability of model application, we perform **first-order difference** on the data and recalculate its P-value. This time, the ADF result is $9.26971142153572e^{-13}$, smaller than 0.05 and showing that our processed data is already stable.

3. **White Noise Examination**

   If the past behavior has no effect on the future development, there is no need to further analyze. Therefore, when we use time series analysis, we need to ensure that our processed data is not white noise. Through Ljung-Box Examination, the P-value of our data is 0.424308, which means that it can be employed in time series analysis.

4.1.2 Modeling Idea of ARIMA

Using time series analysis reuqires time sequence models. In our solution, we use **ARIMA Model** (Auto Regressive Integrate Moving Average Model). After delay difference, **firstly,** the model establishes a regression equation through the correlation (autocorrelation) between the data in the front part of itself and the data in the back part, so that it can be predicted or analyzed. **Secondly,** we can obtain the moving average equation by weighting the white noise in a time series.

4.1.3 Model Establishment

At the beginning, as we have no data to predict the price trend, we had better wait and collect some information with no decision. From the 50th day, we start training our model to do some prediction and making transaction decisions with the model in the next part.

To reflect the long-term trend and meanwhile probable abnormal data in the short run, we construct a **long-short period hybrid prediction model**. With the average two long periods of 67 and 69 days, our model will present the price trend of future 5 days. For the short-time tendency of price in future 3 days, the model will refer to the average of past 27 and 29 days. As for the final predicting result, our model will combine the 61.8% of long-term result and 38.2% of short-term result when obtaining the data of future 3 days. As the accuracy is gradually declining with the increase of predicted time in the short-term model, we regard the results in the long-term model directly as the predicted price on the 4th and 5th day.

4.2 Transaction Determination Model Based on DP

4.2.1 Modeling Idea of DP

Dynamic Programming is the majorization of plain recursion. The main idea is to break down a long-term problem and find globally optimal solution for each subproblem. Coping with subproblems in a specific order, we can guarantee that the final solusion is the best as a consequence of abundant optimal steps. Whenever we discover a recursive solution requiring repetitive calls for same inputs, Dynamic Programming will exhibit its advantages.

Assuming that our prediction for price is completly correct, due to Greedy Strategy, there is no doubt theoretically that the summit of total interest will spring up under the condition that we transfer our assets into only one optimal form. We name it as **EAI (Extremely Aggressive Investment) Strategy**. Unavoidably, deviation exsists. Nevertheless, concentrating on another indicator–expectation, we all know that the result from ARIMA model is unbiased estimation, which means the estimated expectation has no difference from the real one. Therefore, only when we put all the assets into our predicted optimal choice can the expectation of total interest achieve the peak value.

In the course of transaction determination, we determine each daily optimal though back-tracking the result of dynamic programming in the current phase first, as per the temporary net asset value and the result of relatively precise price prediction for future 5 days. Under the situation of this problem, we make future assets maimization as prior judging criterion. Therefore, our goal is to figure out **today's** best decision to **maximize the assets after 5 days**.

According to our EAI Strategy, there is only one out of states of our assets: cash, bitcoin, and gold. In accordance with Greedy Strategy, we will choose the state that ensures **the highest daily investment worth**. Therefore, we construct system of state transition equations as below:

When gold market is open,

$$F\left(k+1, s_i\right)=\max\left\{F\left(k, s_j\right) \cdot T\left(s_j, s_i\right)\right\} \cdot \frac{V\left(k+1, s_i\right)}{V\left(k, s_i\right)}, \qquad j, i \in\{0,1,2\} \tag{1}$$

When gold market is closed,

$$\begin{cases} F\left(k+1, s_i\right)=\max\left\{F\left(k, s_j\right) \cdot T\left(s_j, s_i\right)\right\} \cdot \dfrac{V\left(k+1, s_i i\right)}{V\left(k, s_i\right)}, & j, i \in\{0,1\} \quad (2) \\ F\left(k+1, s_i\right)=\max\left\{F\left(k, s_j\right) \cdot T\left(s_j, s_i\right)\right\} \cdot \dfrac{V\left(k+1, i\right)}{V\left(k, s_i\right)}, & j, i \in\{2\} \quad (3) \end{cases}$$

Therein, **Equation 3** can be simplified as:

$$F\left(k+1, s_i\right)=F\left(k, s_i\right) \cdot \frac{V\left(k+1, s_i\right)}{V\left(k, s_i\right)}, \qquad i=2 \tag{4}$$

In the system, $\boldsymbol{s_0}$, $\boldsymbol{s_1}$ and $\boldsymbol{s_2}$ are respectively prescribed as cash, bitcoin and gold. $\boldsymbol{F(k, s_i)}$ is the symbol of the maxmum value of assets on the kth day with the ith type of assets. $\boldsymbol{T(s_j, s_i)}$ represents the percentage of the obtainable assets amount with the deduction of transaction cost after the transferation form the $\boldsymbol{j}$th to the $\boldsymbol{i}$th type of assets. For instance, $\boldsymbol{T(s_0, s_1) = 1 - 0.01 = 0.99}$. $\boldsymbol{V(k, s_i)}$ symbolized the price of the ith type of assets on the kth day.

Prescribing that,

$$\begin{cases} \boldsymbol{V\left(k, 0\right) = 1} & (5) \\ \boldsymbol{F\left(0, 0\right) = 1000} & (6) \end{cases}$$

Through state transition equations, we can compute the highest one of all the three types of assets and record the path of each state with the daily price estimation of bitcoin and gold. Recursing this process, we can work out the highest investment worth after 5 days, from which we can backtrack to the current optimal. Then, combining each choice can apparently lead to the final decision.

The pseudo-code of concrete algorithm is listed as follows:

[H] **Algorithm 1** Dynamic Programming State Transition

```
for each_day in [initial_time, end_time] do
```

```
    is_gold_market_open_today ← check_if_market_open(gold_date, current_day)
    end_state[current_day] ← [0.0, 0.0, 0.0]
    next_type[current_day + 1] ← [0, 0, 0]
    if is_gold_market_open_today then
        compute_max_profit_and_optimal_type
    else
        compute_max_profit_and_optimal_type                ▷ Gold investment profit is −1
    end if
                                                                          ▷ update_state
    today_gold_price, next_gold_price, today_bitcoin_price, next_bitcoin_price
                                                    ← get_prices(current_day)
    end_state[current_day + 1] ← [computed_profit]
end for
```

4.3 The result of Strategy Model

According to our Strategy Model, we can finally get an investment worth of $110449.80806396008 with the initial $1000, which is about 110 times higher than the beginning. **Figure 2** can show the daily investment worth increase under ARIMA-based decision.

Figure 2: Daily Investment Worth Increase under Model-based Decision

5 Task 2: Strategy Model Selection Analysis

5.1 The Advantage of Price Pridiction Model

Before we determined our basic model for price prediction, we apply both GP (Grey Prediction) Model and ARIMA Model. After s series of examinations, ARIMA Model exhibited better properties.

1. **The imitative effect of Predicted Bitcoin and gold Price in 5 Years from GP fails to meet expectation,** which means that most of the prediction values are lagging behind their corresponding real values in the prediction curve of both bitcoin and gold price.

Figure 3: The Assemble of Predicted Bitcoin Price in 5 Years from Grey Prediction

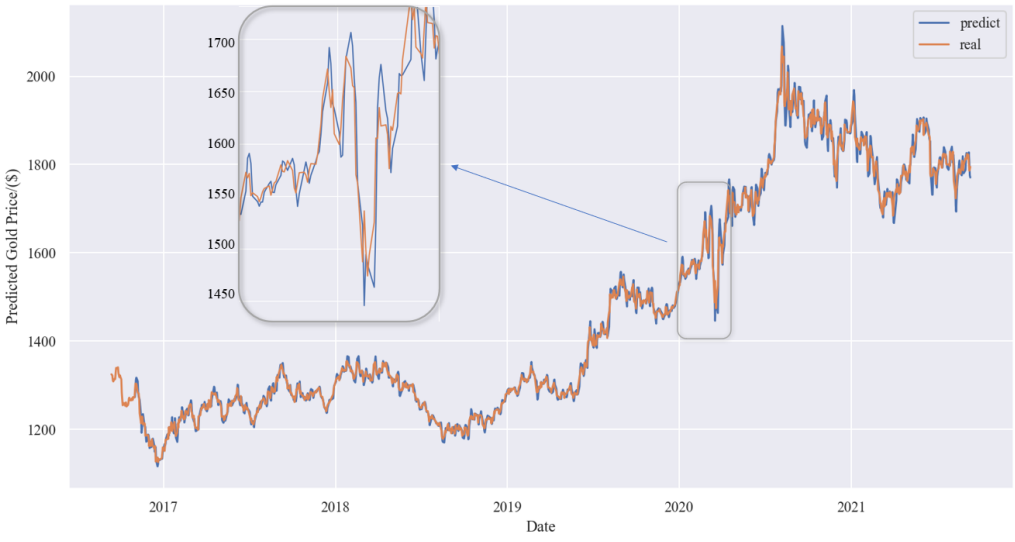
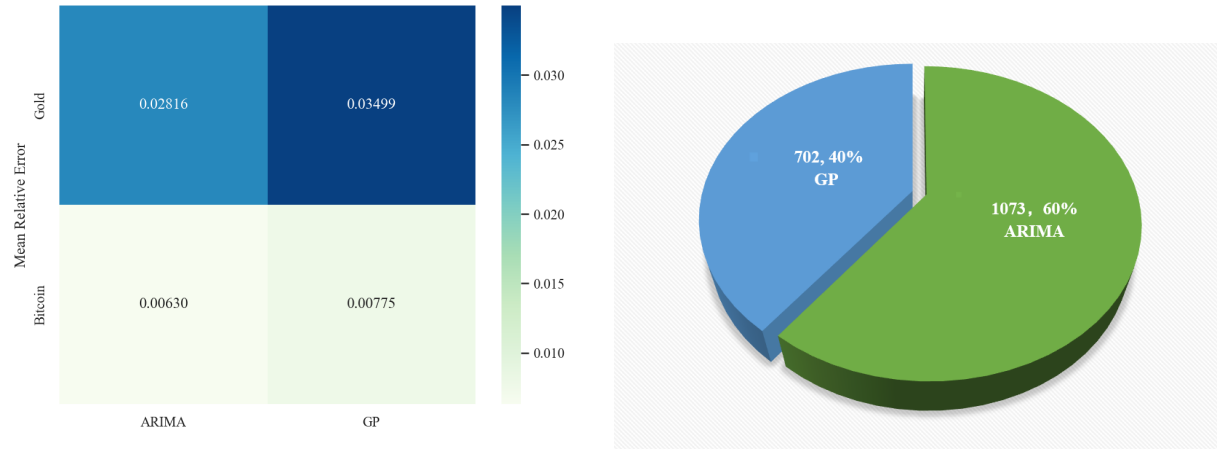


Figure 4: The Assemble of Predicted Gold Price in 5 Years from Grey Prediction

2. **The MRE (Mean Relative Error) of ARIMA is smaller than GP.**



(a) The MRE of ARIMA and GP (b) The Number of Days ARIMA or GP Predicting Better

Figure 5

3. **The Number of Days ARIMA or GP Predicting Better**

5.2 The Advantage of Transaction Determination Model

1. **Effectiveness**

   Compared with ordinary programming problems such as linear programming, dynamic programming aims at the highest profit in the future. Considering the value within a few days as a whole can more comprehensively assess the impact of each day 's trading decisions on the future and help to formulate more effective trading strategies.

2. **Good Performance**

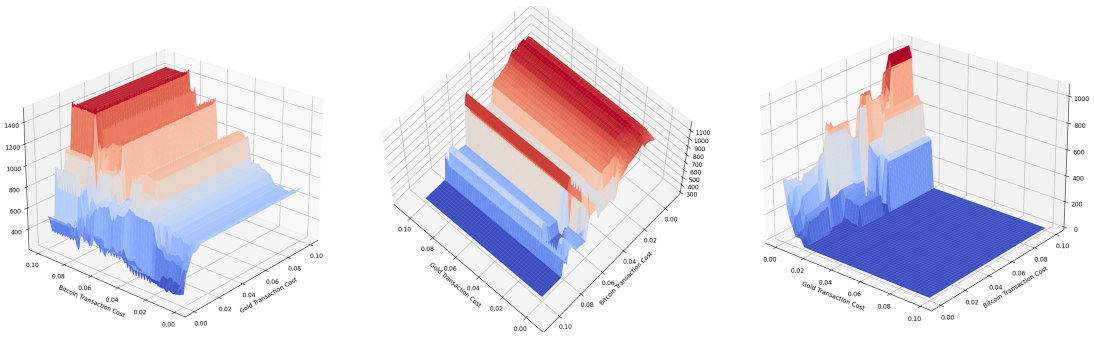
   Compared with the violent algorithm to search all the solution space, dynamic programming avoids repeated calculation and useless calculation. It has relatively low time complexity and space complexity, and consumes less time and space. Therefore, it is a computing framework with good performance.

6 Task 3: Sensitivity Analysis of Transaction Cost

1. **The Holding Frequency of Cash, Bitcoin and Gold under the Influenced of Transaction Costs Rate**

   When the fee increases, the holding frequency of gold decreases significantly, which is more obvious when the transaction costs rate of bitcoin is lower. The overall holding

frequency of bitcoin shows a downward trend, but it is not stable and there is a sudden change. A reasonable explanation is that bitcoin has a higher growth rate, and it is possible to purchase bitcoin at higher transaction costs. However, the number of transactions is reduced, and it is not easy to trade due to small changes, resulting in long-term holding or non-holding of bitcoin and serious fluctuations.

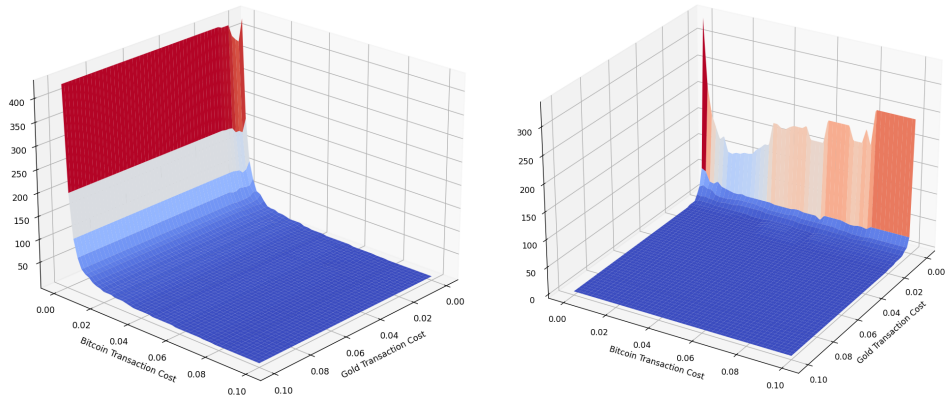


(a) The Holding Frequency of Cash (b) The Holding Frequency of Bitcoin (c) The Holding Frequency of Gold coin

Figure 6: The Holding Frequency under the Influenced of Transaction Costs Rate

2. **The Trading Frequency of Cash, Bitcoin and Gold under the Influenced of Transaction Costs Rate**

When the transaction costs rate of bitcoin is changing, or when the transaction costs rate of gold is slightly higher, there is no abnormal situation. When the transaction costs rate of gold is negligible, the transaction costs rate of bitcoin has a great impact on the frequency of gold transactions. The specific explanation is that when the transaction costs rate of bitcoin is high, the transaction frequency increases due to the increase of gold transaction. When the transaction costs rate of bitcoin is very low, the model will hold gold for a short period of time during the small decline of real bitcoin price, resulting in an increase in transaction frequency.



(a) The Trading Frequency of Bitcoin (b) The Trading Frequency of Gold

Figure 7: The Trading Frequency under the Influenced of Transaction Costs Rate

Our model is sensitive when we changed the rate of transaction costs, mainly because it shows a certain degree of over-fitting in the initial parameters of ARIMA Model.

7 Robustness Analysis

Analysis proves that our model features good robustness.

We added Gaussian error to the input price data. For the avoidance of influencing the initial and final price, we selected two relatively long periods, such as the 1300th to 1500th day of bitcoin price prediction and the 500th to 800th day of gold price prediction. The mean value of the Gaussion error of both prediction model is 0 and for the standard deviation is 10 for gold price and 100 for bitcoin. Putting the new data into our prediction model, we found that the new final investment worth is $110507.36378518504, less than 1‰ higher than the original one (110449.80806396008). Hereafter, we conducted repetitive examination with diverse location and length of the error section. As all the test results are similar, therefore, our model is characterized by good robustness.

8 Model Evaluation and Further Discussion

8.1 Strengths and Weaknesses

8.1.1 Strengths

1. **Stability**

   Our prediction model is insensitive to the time span of predicted price, bacause we take the average of two day's prediction in both long-term and short-term prediction, promoting

its stability.

2. **Universality**

   Our prediction model can be used in similar decision-making process, such as stock price prediction.

3. **Globality**

   Because the Pynamic Programming method reflects the relationship and characteristics of the dynamic process evolution, we will acquire global optimal solution in each transaction determination.

8.1.2 Weaknesses

1. **Unstable Accuracy**

   For data with large changes in the short term, the prediction accuracy of our model will slightly decrease.

2. **Aggressive Strategy**

   In the transaction model, the setted strategy is a little aggressive, which may have conflict with the trader's common methods.

8.1.3 Possible Future Improvement

1. Change the parameters of our model to be adaptive and dynamically adjusted.

2. Enrich related decition-making model to apply multiple decision methods.

9 Conclusions

In this paper, combining the given data and our data cleaning, we use ARIMA Model to create a Price Prediction Model and DP method to find a transaction determination. With the comparison with Model, we prove that our prediction model is the best among all the mentioned model for the reason that our model own better imitive effect with real price model. As for the decision-making model, only DP can determine a local optimum with the global optimum. From these two dimensions, our model's advantage is evident.

Overall, we find a more accurate model for price prediction and a optimal method for transaction determination. When it comes to transaction costs rate, our model shows a good sensitivity, which means that our model take good consideration of transaction costs.

References

[1] Roy, Shaily, Samiha Nanjiba, and Amitabha Chakrabarty. "Bitcoin price forecasting using time series analysis," in *2018 21st International Conference of Computer and Information Technology (ICCIT), IEEE,* 2018.

[2] Guha, Banhi, and Gautam Bandyopadhyay. "Gold price forecasting using ARIMA model," *Journal of Advanced Management Science,* 2016.

[3] Mariani, FrancescaPolinesi, Gloria,and Recchioni, Maria Cristina. "A tail-revisited Markowitz mean-variance approach and a portfolio network centrality," *Computational Management Science,* 2022, pp. 1-31.

[4] Liu, Chengjun, et al. "Application of Grey-Markov Composite Model in Forecasting Gold Price," *Nonferrous Metals(Mining Section),* 2013, pp. 7-11.

[5] Song, Ce. "Prediction of Gold Futures Price Based on BP Neural Network," *Journal of Shanghai University of Engineering Science,* 2017, pp. 90-94.

[6] Xi, Jing. "Prediction of Gold Price Based on Time Series Mode," *Modern Computer,* 2017, pp. 9-14.

Memorandum

To: the trader our friend

From: Team #2421624

Subject: A Trading Strategy and Results Based on Our Created Model

Date: Monday, December 30, 2013

Dear trader,

We cannot resist our urge to share with you that we created a model to assist the trading process. Our model consist of two parts: the price pridiction part with ARIMA Model and the transaction determination with DP method. We examined our model with the star-up loan of $1000, and finally we got an investment worth of $110449.80806396008, about 110 times of the initial value.

We would like to tell you why we choose these two model. Firstly, according to the given condition, we can only use the real price data from the problem so that the time series analysis is the most suitable for our price prediction model.

Then, we prove that our model is the most appropriate by comparing our prediction-decision model with other models. When proving the optimal prediction model, we compare the prediction accuracy of the two optimal models—ARIMA model and grey prediction model—in all the models we tried. The MRE (Mean Relative Error) of gold and bitcoin price prediction in ARIMA Model prediction are 0.0063 and 0.0281, which are better than 0.0078 and 0.0350 of GP (Grey Prediction) model.

In addition, we tested the holding frequency and trading frequency of each asset under different portfolios at a rate of 0.002, finding that the DP decision model is very sensitive to the change of transaction costs rate. The specific information is shown in the figures. In general, the trading frequency and holding frequency of an asset decrease after the transaction costs rate increases, and when its own transaction costs rate is low, the transaction costs rate of another asset will also have a greater influence on it.

Overall, we find a more accurate model for price prediction and a optimal method for

transaction determination. We know that it may be a little bit aggressive, but sometimes we can be more brave.

What is your idea of our model? Please send your feedback of our model to us. Hope you perform well with our strategy model!