Research on Portfolio Management in Financial Markets Against the Background of the Epidemic

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Abstract. Portfolio management serves as an important role in risk management, therefore, the paper intends to study its role in risk hedging and the influence of the COVID-19 pandemic on certain examples, whose data are from Yahoo Finance. The main methodology is to apply mathematical models on collected data and study the effectiveness of portfolio management including portfolio optimization and time series analysis. It can be concluded from the results that different stocks have different similarities according to the clustering results. A fixed portfolio is best suited for real capital assets in pursuit of lower risk level and higher profits under a relatively stable circumstance. And the pandemic has direct impacts on the stock price including higher variance and higher level of volatility. The meaning for this research is give illustrations and models that can be further applied in real financial markets added with the consideration of significant events such as pandemic.

Keywords: Portfolio optimization, COVID-19 pandemic, Black-Litterman Model, Hierarchical Clustering, Time series analysis.

1. Introduction

Portfolio management plays a big part in risk management since it involves the process of choosing, arranging, and managing an organization's projects and programs in conformity with its strategic objectives and ability to deliver [1]. Considering its role for insuring against price movements, the author intends to model certain data from several stocks before 2020, and especially study the impact of the COVID-19 pandemic on the price of Goldman-Sachs stock to see the effectiveness of portfolio management. By adopting useful hedging techniques, one can achieve effective financial decisions and financial risk management [2]. The paper studies the risk-hedging role of portfolio management and the influence of pandemic. In Section 2 is the methodology applied in this paper, and in Section 3.1 is the pre-pandemic period data process and the calculation of results. In Section 3.2, the author especially studies the example of Goldman Sachs during the pandemic. The Section 4 focuses on conclusion and further discussion.

2. Methodology

2.1. Portfolio Optimization

Portfolio optimization is the operation of selecting the optimum portfolio out of all those under consideration, usually with the goal of maximizing certain characteristics like predicted return and minimizing others like risk level [3]. This part contains several implementations for better analyzing and understanding portfolio management.

2.1.1 Markowitz Mean-Variance Optimization

The Markowitz Mean-Variance model seeks to quantify the value of return and risk by treating individual security returns as random variables and using expected value and variance as inputs. Let Edenote the expected value operator, and Vardenote the operator of variance, x_i be the ratio of wealth invested in security i, $\gamma_i$be the random return for the ith security, and α is the minimum investment return, and $\beta$is the maximum risk level investors may accept [4]. So the formula come as follows:

$$\begin{cases} \max E[\gamma_1 x_1 + \gamma_2 x_2 + \cdots + \gamma_n x_n] \\ s.t.Var[\gamma_1 x_1 + \gamma_2 x_2 + \cdots + \gamma_n x_n] \le \beta \\ x_1 + x_2 + \cdots + x_n = 1 \\ x_i \ge 0, i = 1,2,\cdots,n \end{cases} \tag{1}$$

To have the minimum risk level for a given return level, the formula is:

$$\begin{cases} \min Var[\gamma_1 x_1 + \gamma_2 x_2 + \cdots + \gamma_n x_n] \\ s.t.E[\gamma_1 x_1 + \gamma_2 x_2 + \cdots + \gamma_n x_n] \le \alpha \\ x_1 + x_2 + \cdots + x_n = 1 \\ x_i \ge 0, i = 1,2,\cdots,n \end{cases} \tag{2}$$

The Markowitz Mean-Variance model only provides a rudimentary idea on the optimal portfolio option, but the model will meet the majority of financial needs.

2.1.2 Black-Litterman Model

By combining views of investors and market equilibrium, the Black-Litterman model is a mathematical model developed for portfolio allocation, and the model guarantees that a portfolio's asset allocation is maximized while incorporating subjective forecasts using the Bayesian theory [5]. Starting with the expected returns based on market implications, the model then have the said returns get adjusted to reflect the fund managers' or investors' individual opinions. The Black-Litterman formula goes as follows,

$$E[R] = [(\tau\Sigma)^{-1} + P'\Omega P]^{-1}[(\tau\Sigma)^{-1}\prod + P'\Omega Q] \tag{3}$$

where: $E[R]$ is the new combined return vector, an $N \times 1$column vector.$\tau$is a scalar ranging from 0 to 1. $\Sigma$is the covariance matrix of excess returns, an $N \times N$matrix. $P$is a matrix that identifies the assets involved, a $K \times N$matrix. $\Omega$is a $K \times K$diagonal covariance matrix of error terms representing uncertainty in each view. $\prod$is the implied equilibrium return vector, an $N \times 1$column vector. Q is the view vector, a $K \times 1$column vector. In return, the implied equilibrium return is expressed in the following equation:

$$\prod = \lambda\Sigma w_{mkt} \tag{4}$$

where $\lambda$is the risk aversion coefficient and $w_{mkt}$is the market capitalization weight of the assets which is an $N \times 1$column vector [6].

2.1.3 Hierarchical Clustering

Hierarchical Clustering is a supervised learning algorithm that connects data points dependent on distance to form a cluster, and the algorithm then links those already clustered points into another cluster, which creates a structure of sub-clusters imbedded in the clusters. Additionally, the Scikit-Learn is equipped with single, average, complete and ward linking methods, thus making hierarchical clustering be easily implemented. Since the data is small and explicability is a major factor, Hierarchial Clustering is enough to solve this problem.

2.2. Time Series Analysis

In statistics, Generalized AutoRegressive Conditional Heteroskedasticity (GARCH) is a model applied in analyzing time-series data in which researchers can consider the variance to be serially autocorrelated and the model presupposes that the error term has the variance and it moves in an autoregressive moving average fashion. GARCH is useful in predicting the volatility of returns on financial assets and evaluating risk level and expected returns of portfolios that possess clustered periods of volatility in returns [7].

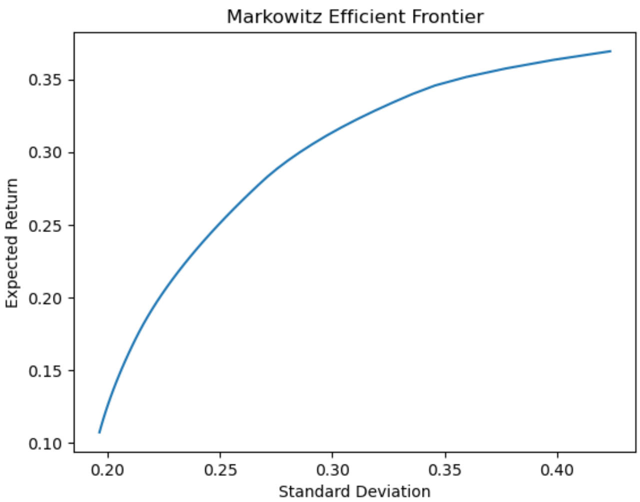
3. Data Process and Results

The data are the prices of stocks drawn from Yahoo Finance, including the stock of AAPL, H, Y, SNE, GS, K, NKE and LEVI. The time period chosen ranges from 2013 to 2019, and the study of which can help reveal the role of portfolio management in practice [8].

3.1. Mathematical Modeling of History Data

3.1.1 Markowitz Efficient Frontier

The Markowitz efficient frontier theory is one of the cornerstones of modern portfolio theory. The graph is composed of Expected Return (x-axis) and Risk/Volatility/Standard Deviation (y-axis). In general, the efficient frontier represents portfolios that maximize returns for the assumed risk in a graphical manner, and the values of returns are related to the investment combination composing the portfolio. A security's standard deviation is synonymous with risk. Theoretically, investors tend to find a portfolio with securities providing extraordinary returns but with much lower combined standard deviation than that of the individual securities. According to the efficient frontier theory, one can picture points standing for different portfolio decisions on the graph and eventually decides on choosing points the closest to the curve, which may potentially generate the highest return with the lowest degree of risk level.



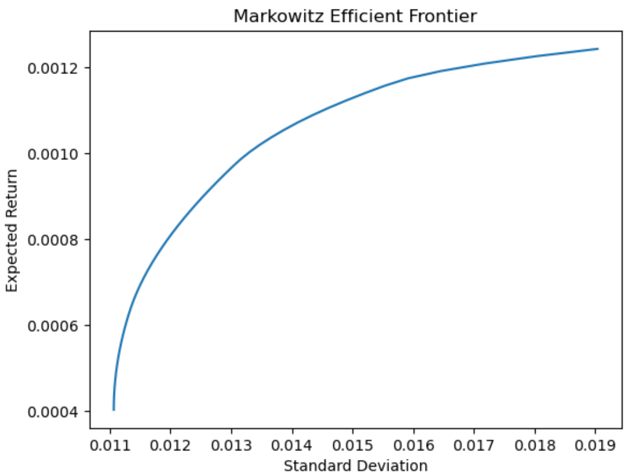


Fig. 1 Efficient Frontier of Annual Returns **Fig. 2** Efficient Frontier of Daily Returns

Another observation obtained from the comparison between the two pictures is the difference in frequency and the similarity in the tendency of the curves. Figure 1 is of longer period with higher value of expected return and standard deviation, while Figure 2 has shorter period with lower expected return and standard deviation, whose value can be converted to one another, resulting the similar trend of the two curves.

3.1.2 Black-Litterman Model

By applying the Black-Litterman model to the data, other two efficient frontier can also be obtained, which checks the feasibility of the portfolio management.

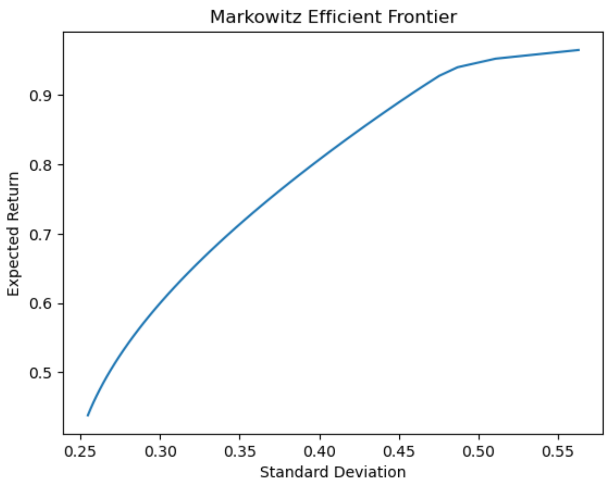


Fig. 3 Efficient Frontier of Annual Returns

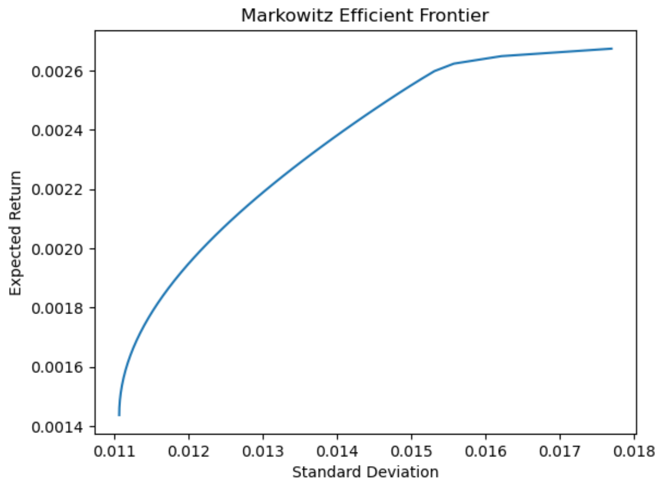


Fig. 4 Efficient Frontier of Daily Returns

Figure 3 and 4 are similar to Figure 1 and 2 respectively, which means that in the case of the selected eight stocks, the portfolio optimization is relatively fixed. The slight difference between the two sets of figures lies in the shape of the curve: in Markowitz Mean-Variance model, that is Figure 1 and Figure 2, the graphs increase in a rounder way, and has a more obvious tendency of increasing even when the slope is lower; while in the case of Black-Litterman model, the graph increases in the way more like a line, and has a relatively more obvious turning point and flatter tendency after the turning point.

The above differences can be explained by the differences of the two model. The Markowitz Mean-Variance model is the foundation of Black-Litterman model, but it also has two significant limitations: firstly, the estimates of risk and return are prone to estimation error; secondly, Markowitz model is more unstable if the inputs change slightly and is not sensitive enough in practice. Therefore, the Black-Litterman was invented later to tackle the above two problems in Markowitz model and the Black-Litterman model suits the financial market better, offering better portfolio optimization.

3.1.3 Hierarchical Clustering

Denoting the stocks of AAPL, H, Y, SNE, GS, K, NKE and LEVI as 0 to 7 respectively, the paper employs the Hierarchical Clustering from Scikit-Learn to determine the similarity between different assets for more information about given portfolio choices.

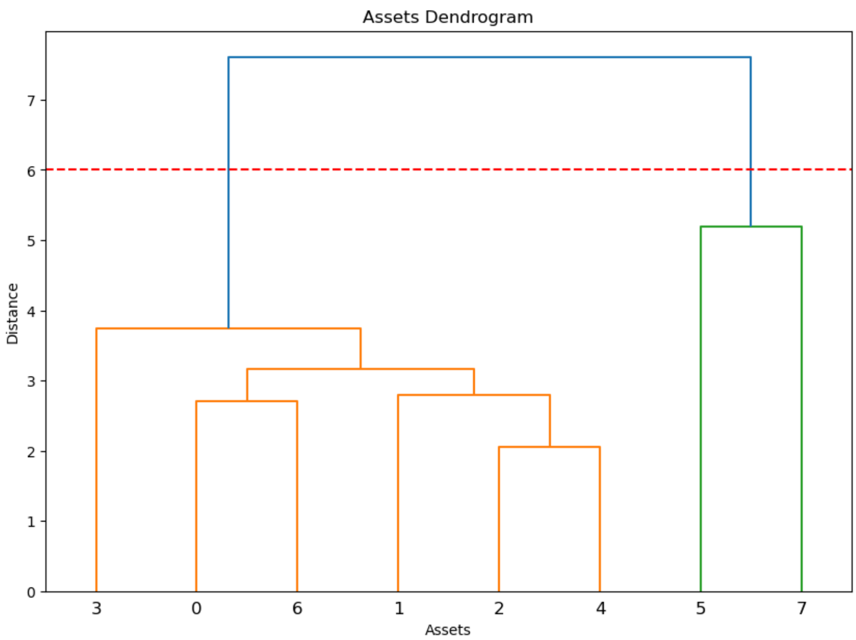


Fig. 5 Dendrogram of the eight stocks

Since the clades are arranged according to how similar they are, the greater the difference in height, the more dissimilarity. The dendrogram in Figure 5 is used to visualize clusters in hierarchical clustering, which helps with a better interpretation of results through meaningful taxonomies. Moreover, by visualizing on the 2-dimensional plot formed by any two stocks selected, the Hierarchical Clustering can be applied to interpret the relationship between individual data points in an unsupervised learning method.

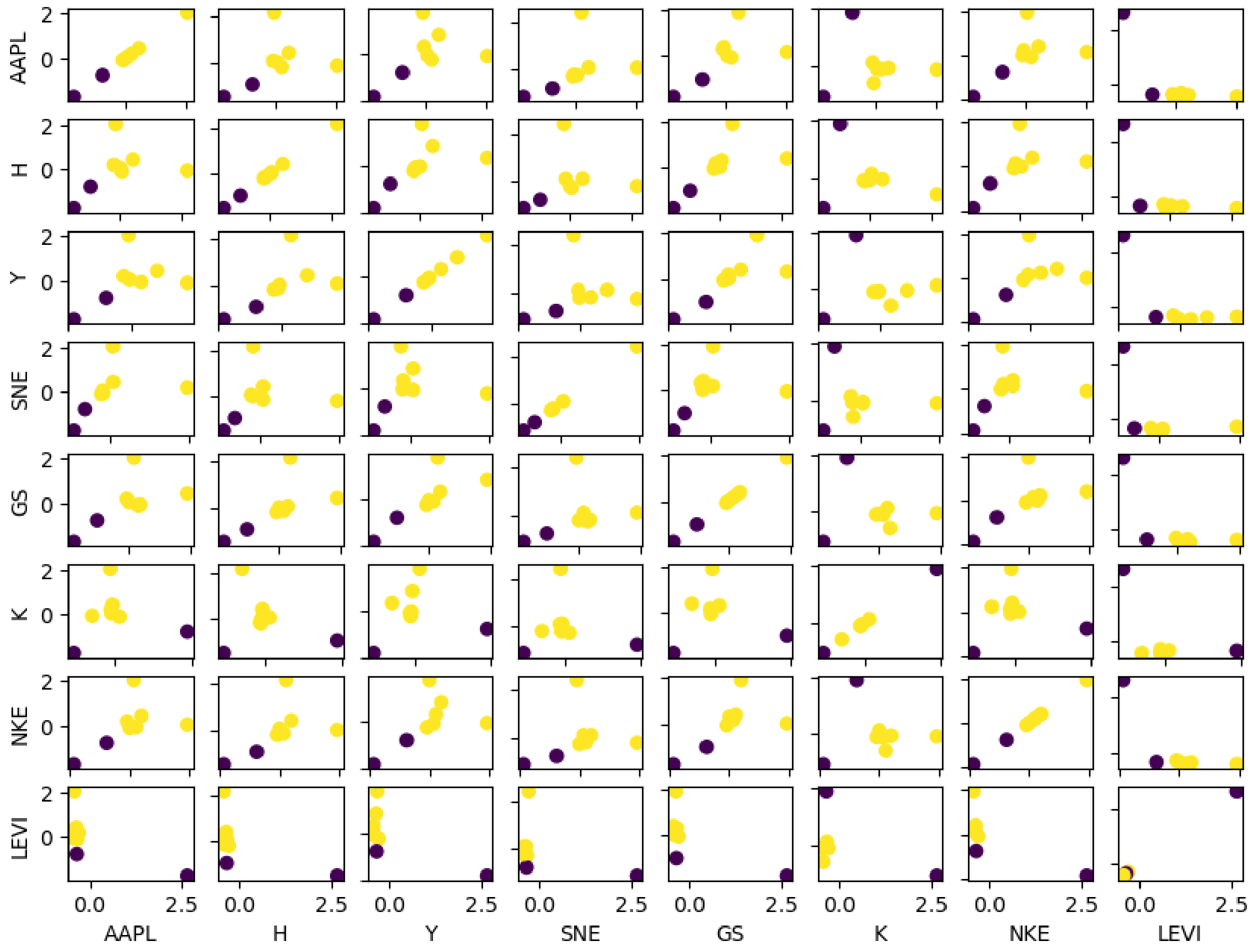


Fig. 6 Scatter plot of the selected stocks

Figure 6 is the scatter plot of the eight stocks, and it reveals the relations between any given two stocks. It can be concluded that most two stocks have an increasing relation formed by scatter point, but the stock K generally has flatter tendencies in the scatter plots while the stock LEVI also has peculiarities in its relations with other stocks.

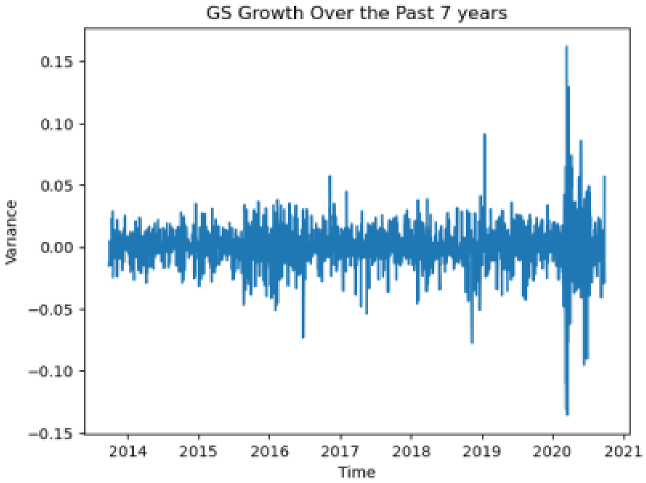
In conclusion, the portfolio management exerts risk hedging capability and high expected returns, and in normal circumstances the investors could choose a fixed portfolio when faced with relatively stable financial market.

3.2. Goldman Sachs

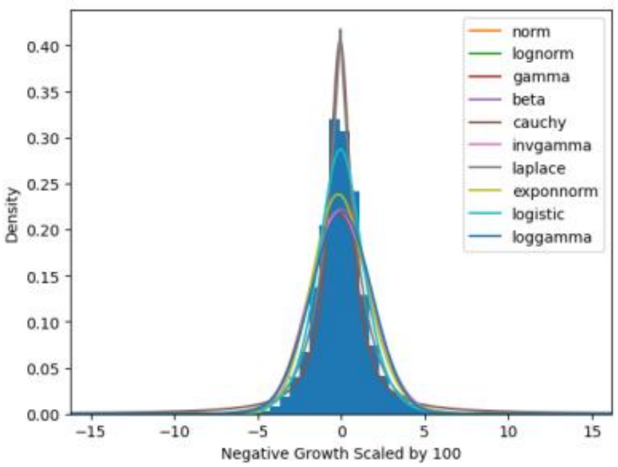
In the last section, the paper has reviewed the portfolio management during 2013-2019, however, with the breakout of COVID-19 pandemic, many fields were heavily impacted and the market was much more volatile. Therefore, in this section, the paper uses the example of Goldman Sachs to explore the influence of pandemic by visualizing the differences before and after the epidemic.

3.2.1 Bayesian Inference

Bayesian Inference is a way of making statistical inferences in which one can attribute subjective probabilities to distributions that could have produced the data, and these subjective probabilities makes up of the so-called prior distribution. After observing the data, one can use Bayes' rule to update the prior, which exactly means to amend the probabilities assigned to the possible data generating distributions, and these revised probabilities compose the named posterior distribution. By applying the Bayesian inference, the results are illustrated as follows:



(1)



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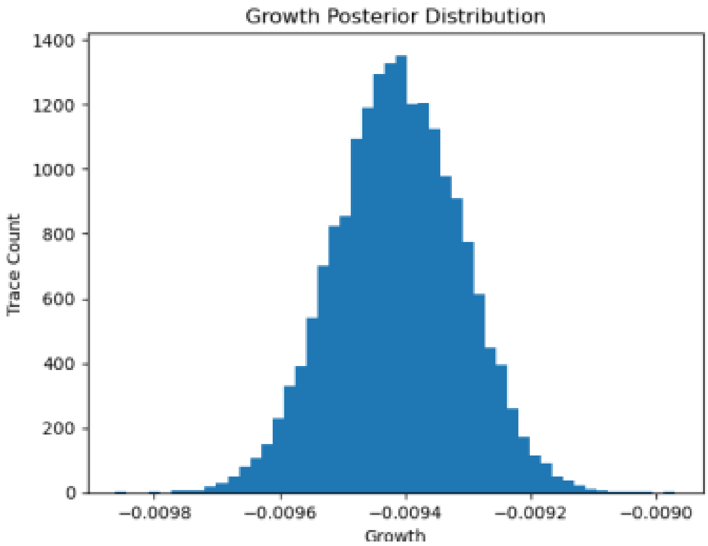


(3)

Fig. 7 Goldman Sachs Stock

The sub-figure 7 (1) shows that the pandemic has caused more volatility in the growth of its stock price, and the highest variance appeared in the first half year of 2020 which corresponds to the very height of the pandemic. With the recovery of all walks of life since 2021, the variance decreased and returned to the approximately same level before the pandemic. The sub-figure 7 (2) and sub-figure 7 (3) are the prior and posterior distribution respectively, which is not the typical norm distribution, indicating the volatility caused by the pandemic.

Since in hierarchical clustering, the stocks have been divided into different levels of similarities, the Multi-Level model can be applied, which is a statistical analysis method under hierarchical structure of data, and the process and trace plot are as follows [9]:

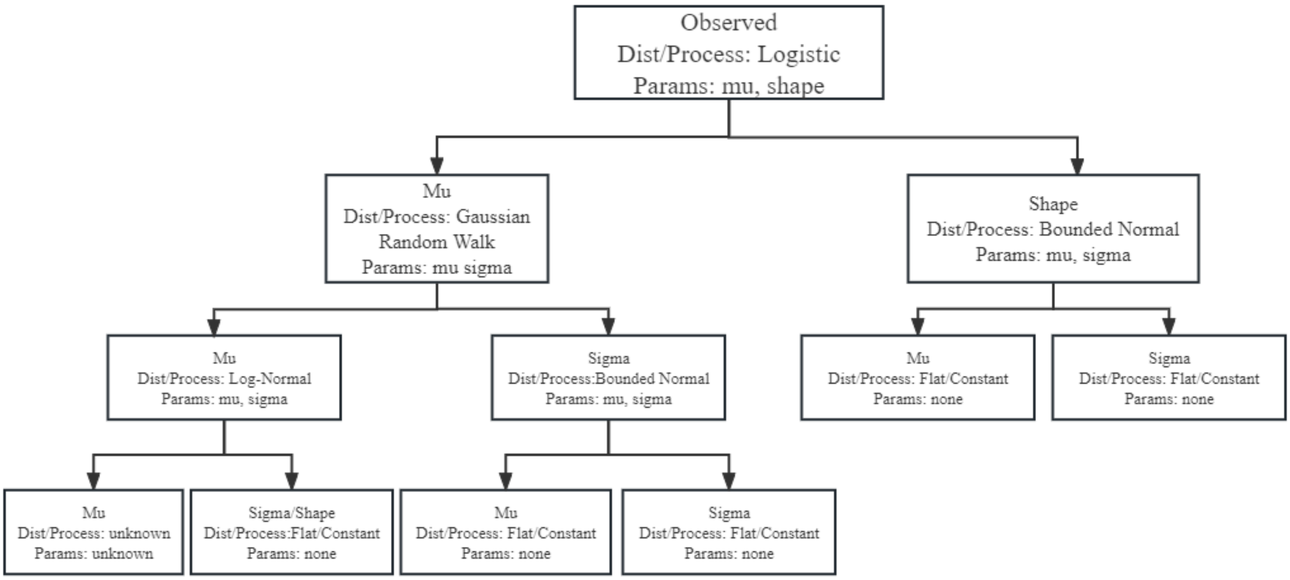


Fig. 8 The principles of multi-level mode

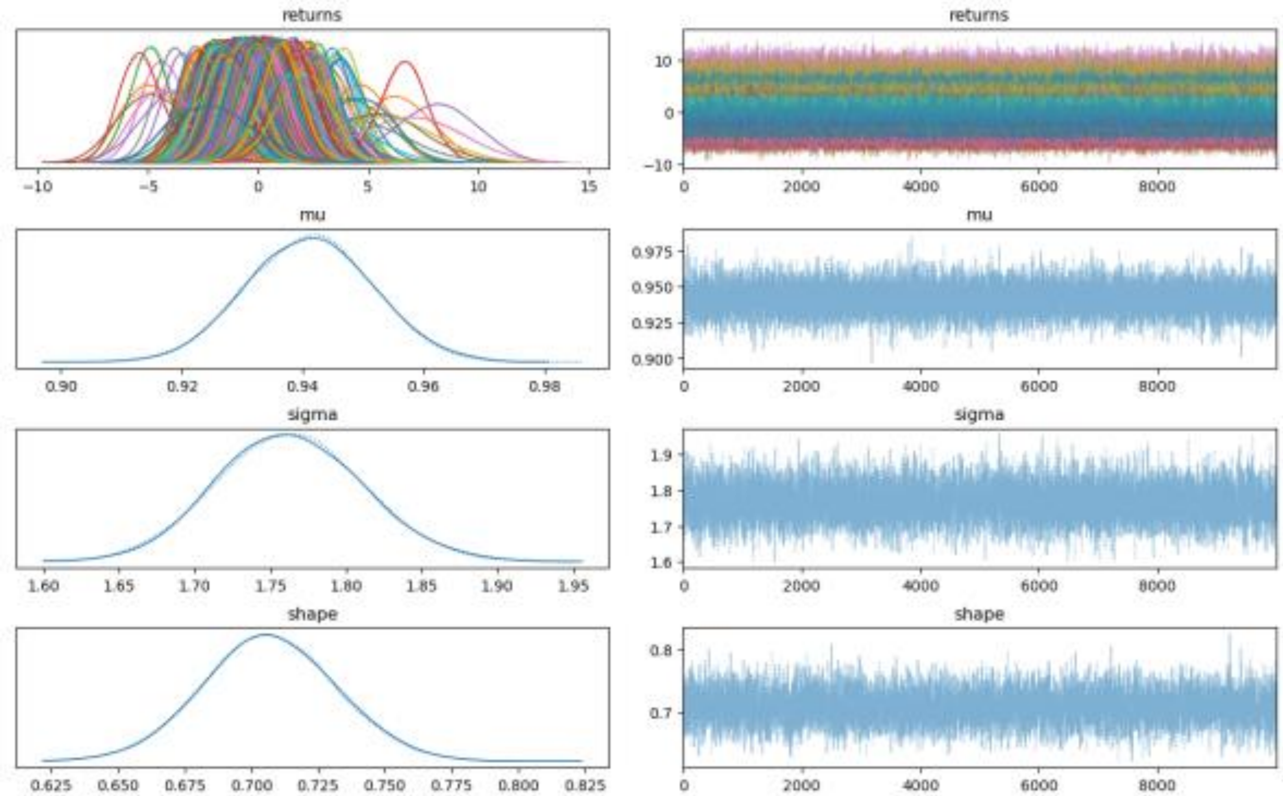
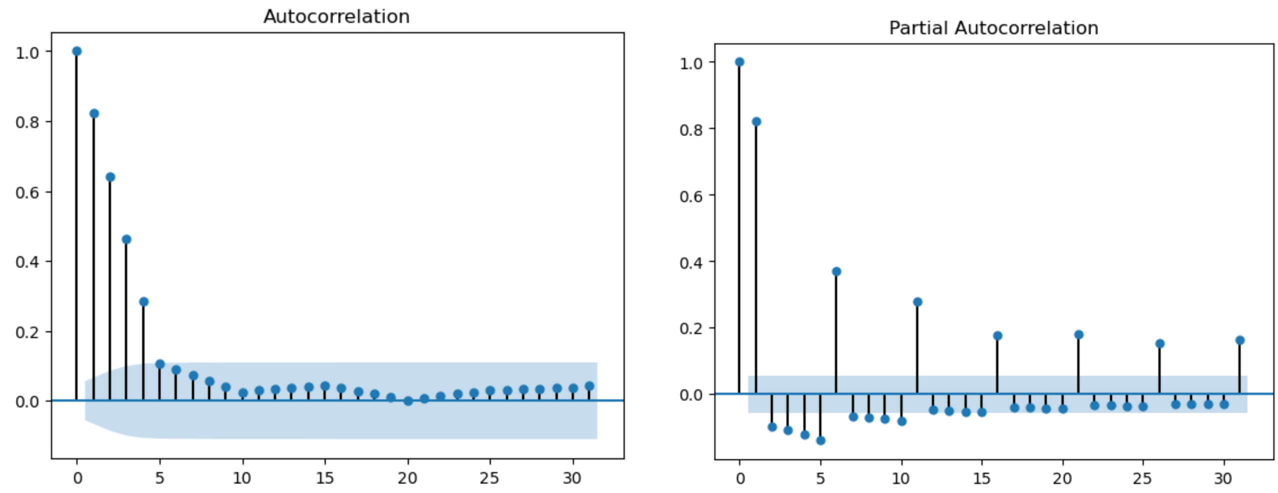


Fig. 9 Multi-Level Model

The Figure 8 illustrates the principles of multi-level model. By further having the Figure 9 of the trace plot, here comes the conclusion that the pandemic has resulted in more instability of the stock price and more uncertainty in prediction based on history data.

3.2.2 Time Series Analysis

To have more quantitative analysis of the influence of pandemic, the time series analysis featured in GARCH model will be applied in this part, in which the focus is time period after 2019.



(1) ACF (2) PACF

Fig. 10 ACF and PACF in GARCH

Figure 10 contains the ACF and PACF in GARCH. ACF graph shows that the correlation is decreasing and eventually reaches nearly zero, meaning there's nearly no autocorrelation. And PACF graph shows that the partial autocorrelation basically non-exists in the time series. With GARCH model, prediction based on time series data and discussion of volatility can be further illustrated by figures, beginning with test set of GARCH model.

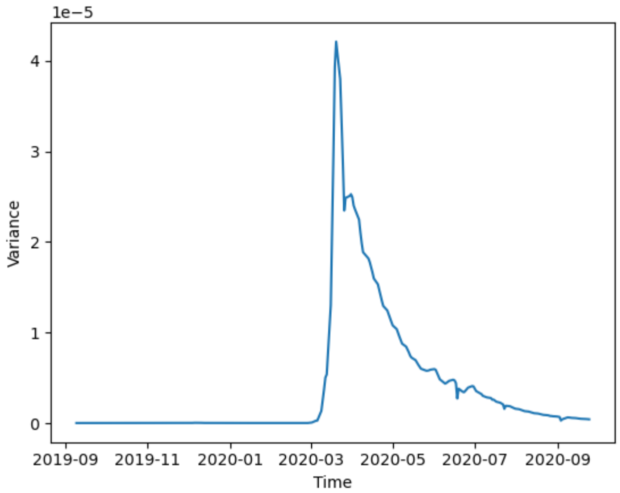


Fig. 11 Test set forecast

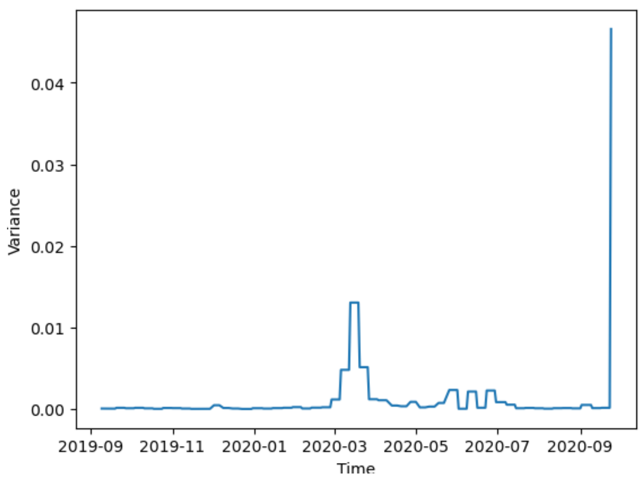


Fig. 12 Test set volatility

In the forecast of test set volatility, the variance is predicted to appear in the March of 2020 and will decline as time goes by [10]. The volatility of data in reality indeed reflects a peak in the March of 2020, but shows another lower peaks in the following months and a dramatic change in the September of 2020, which slightly contradicts the prediction (in Figure 11). The similarity as a whole reveals the feasibility of the model and prediction, while the slight difference can be attributed to the volatility of stock price during the pandemic (in Figure 12).

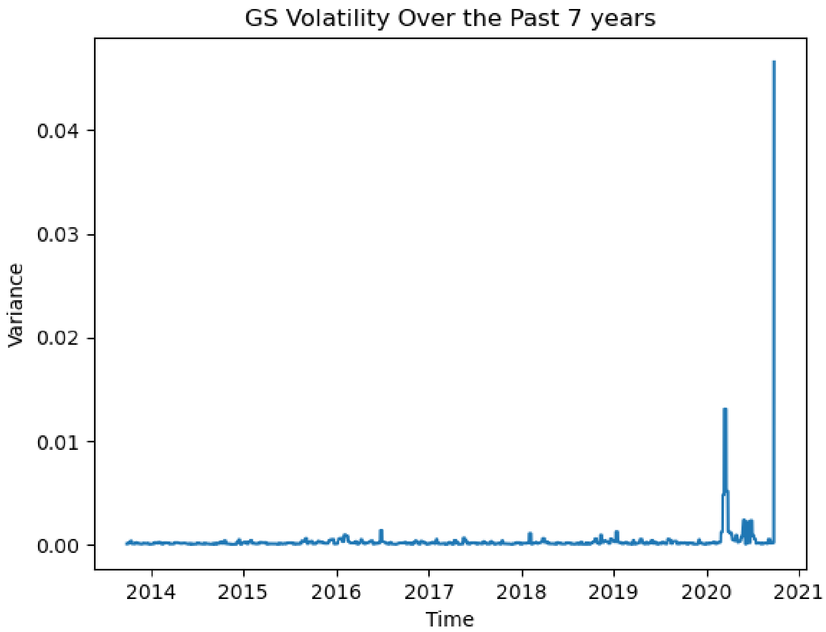


Fig. 13 Goldman Sachs Stock Volatility

It's worth noting that the variance has experienced a peak in 2020 and a higher variance peak in 2021. Since the drastic change starting from 2020, the volatility has changed more frequently due to the instability in financial market, which eventually resulted in the higher peak in 2021 (in Figure 13).

4. Conclusions

This paper intends to apply various mathematical models to time series data to check the feasibility of portfolio optimization under certain circumstances of given stocks and given environments, which can be further applied in practice. The main methodology includes Markowitz Mean-Variance model, Black-Litterman model, hierarchical clustering and GARCH model. And the author notices that when applying hierarchical clustering method, the similarities of given stocks can be obtained thus indicating the deeper connection of different stocks and the choice of portfolio. In the next section, with the consideration of pandemic, the paper further studies the influence of pandemic on stock price and the volatility caused by epidemic. It can be concluded that the changing points correspond to the severity of the pandemic, and the volatility during the pandemic also results in the high variance and more instability after pandemic since the history data during the pandemic is less correlated. The paper will be helpful in modelling given history data to decide on the best-suited portfolio optimization in real financial market. Also, the paper reminds of the importance of considering significant events and applying practical methods to acquire less risk and more profits. Therefore, the paper intends for people of investors or asset managers who need to optimize their portfolio, and other scholars in relevant field.

Indeed, the paper also has drawbacks including that the sample data are small which only have 8 stocks in consideration, and that the author mainly considers typical models and time series analysis. The future studies can be about experimenting the feasibility of portfolio optimization in the face of pandemic, or more deeply understanding the correlation between different assets.

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