3.4 Data Analysis

3.4.1 Basic Statistical Characteristics

The basic characteristics of the data are described in Table 1, Table 2, Figure 1 and Figure 2. According to the results in Table 1, the mean and standard deviation of the CHFJPY currency pair is relatively large. This is consistent with the fact that the higher the risk, the higher the return on investment. The USDJPY currency pair has the smallest standard deviation, which means that the currency pair has the smallest volatility in the exchange price. This is related to the fact that the USD and the JPY are both currencies with hedging functions. The return skewness of the seven currency pairs is not 0, among which the skewness of EURJPY, GBPJPY, NZDJPY, AUDJPY and CADJPY is negative, indicating that their return series are left-skewed. The skewness of USDJPY and CHFJPY is positive, implying that their return series are right-skewed. CHFJPY has the largest kurtosis, showing the data characteristics of sharp peaks and thick tails. The correlation between the various currency pairs is depicted in Table 2. It can be seen that currency pairs are positively correlated. As observed in Figure 1, the return time series diagrams of the seven currency pairs all show an obvious growth or decline trend over time. For example, looking the fluctuations in return of the GBPJPY currency pair from 2011 to 2020. It declined slightly from 2011 to 2012, and then continued to rise. The highest point of revenue appeared in the first half of 2014. Over the next half of the year, the GBPJPY began to fall sharply, until 2016 earnings fell to the bottom. Since then, the GBPJPY return had gradually increased, but the exchange rate had not been able to return to the high return range of 2014. Figure 2 represents the volatility. Except for CHFJPY, other currency

pairs fluctuate sharply. The uncertainty of the political event of Brexit in 2016 had caused strong volatility in return.

Table 1: Basic Statistics of Currency Pairs

	USDJPY	EURJPY	GBPJPY	NZDJPY	AUDJPY	CHFJPY	CADJPY
mean	0.000108	0.000082	0.000067	0.000094	0.000014	0.000142	0.000021
std	0.005635	0.006546	0.007215	0.007836	0.00779	0.007125	0.006987
skew	0.191484	-0.11689	-0.88077	-0.29017	-0.29846	5.692605	-0.10298
kurt	4.04357	4.30624	16.98454	2.575605	2.298002	162.7839	2.396409

Table 2: Correlation of Currency Pairs

	USDJPY	EURJPY	GBPJPY	NZDJPY	AUDJPY	CHFJPY	CADJPY
USDJPY	1	0.619226	0.655468	0.523277	0.576606	0.44331	0.743254
EURJPY	0.619226	1	0.724023	0.655831	0.676148	0.638604	0.689794
GBPJPY	0.655468	0.724023	1	0.631216	0.670163	0.498513	0.699714
NZDJPY	0.523277	0.655831	0.631216	1	0.854296	0.446613	0.723815
AUDJPY	0.576606	0.676148	0.670163	0.854296	1	0.448293	0.785105
CHFJPY	0.44331	0.638604	0.498513	0.446613	0.448293	1	0.465794
CADJPY	0.743254	0.689794	0.699714	0.723815	0.785105	0.465794	1

Figure 1: Cumulative Daily Return of Currency Pairs

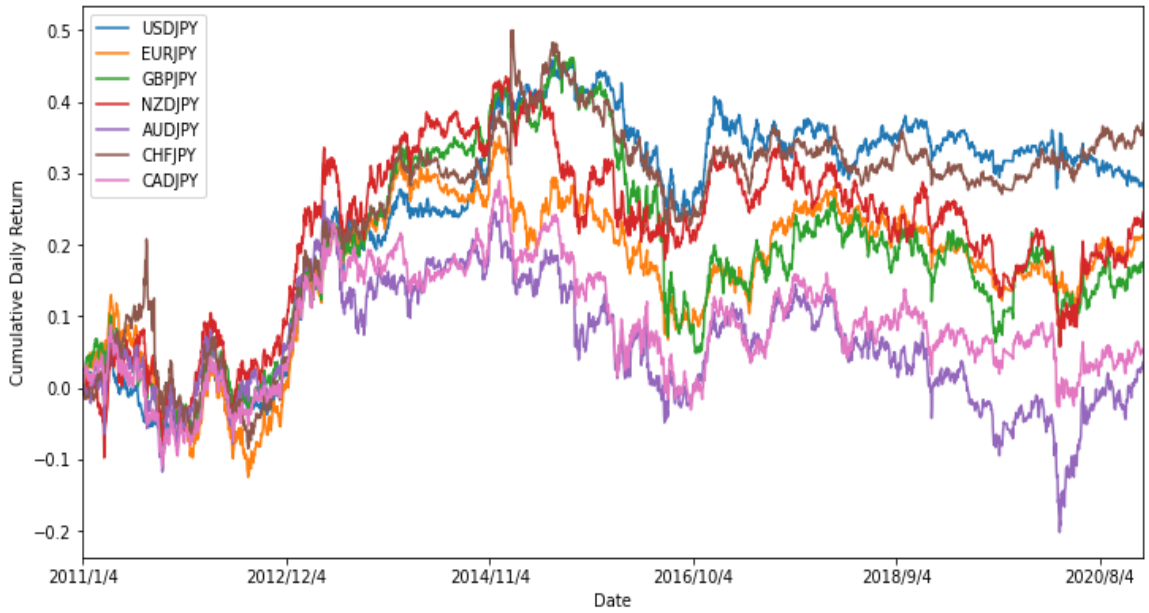
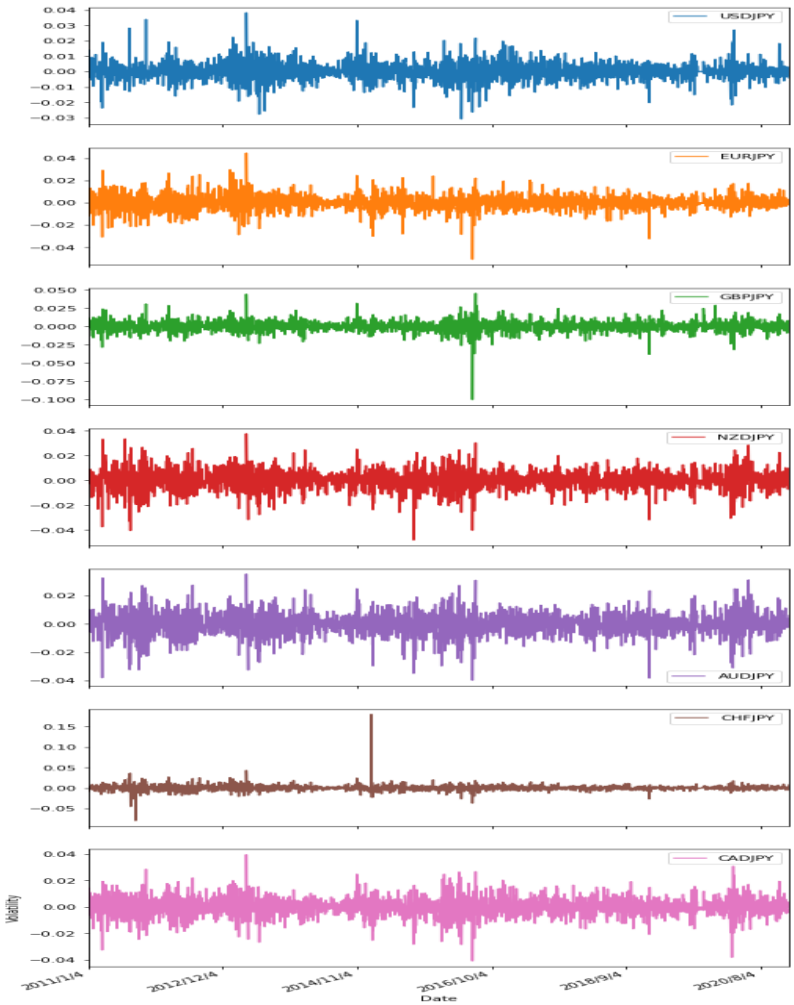


Figure 2: Volatility of Currency Pairs



3.4.2 Portfolio Weight Determination

Table 3 contains the portfolio weights calculated by python. The proportion of the equal weighted portfolio is 1/7. The investment portfolio constructed according to the Kelly criterion has all the weights allocated to CHFJPY. The return of CHFJPY started to rise in 2011 and became the highest in 2020. The Kelly criterion seeks to maximize the logarithm expected return, which is the most direct reason why it invests all the weight in CHFJPY. For more specific reasons, we need to pay attention to factors such as the policies and national economy of Switzerland and Japan. The line chart of Swiss GDP is presented in Figure 3. It can be inferred that the Swiss economy was in a stable state from 2010 to 2019. Swiss watches have been exported to Asia in large numbers. The Swiss National Bank has great independence in formulating monetary policy, so Switzerland's exchange rate is relatively stable. In addition, Switzerland also pursues a policy of neutrality and non-alignment, so it also has the characteristics of a traditional safe-haven currency. Japan's domestic market is narrow, so the export has become a major factor in its economic growth. The Japanese government intervened in the foreign exchange market to prevent the yen exchange rate from being too high, which maintained their export competitiveness.

Weights of the minimum-variance portfolio are mainly assigned to USDJPY, EURJPY, NZDJPY and CHFJPY. The ratios are 0.605, 0.098, 0.065 and 0.232 respectively. The minimum-variance portfolio reduces risk by diversifying investment. The returns of USDJPY, EURJPY, NZDJPY and CHFJPY are the top four of all currency pairs. The minimum-variance method decreases the risk while also maximizing the return of the portfolio. It puts 60.5% of the weight on USDJPY. USD is the most traded currency in the foreign exchange market. USD is also a reserve currency, which can be held by almost all central banks and investment institutions in

the world. This is determined by the political and economic status of the United States. Figure 4 provides the yield trend of US Treasury bonds. Comparing Figure 2 and Figure 4, It can be seen that the rise or fall of the yield of US Treasury bonds has a great impact on the exchange rate of the USD. If US Treasury bond yields rise, it will attract capital inflows and support the exchange rate rise. Conversely, if the yield of Treasury bonds falls, the exchange rate will fall. Hence, investors can refer to the yield of treasury bonds to make foreign exchange investment decisions. The EUR has a relatively high value. The Central Bank of the United Kingdom controls interest rates. Changes in interest rates usually have a large impact on the pound. Therefore, the EUR is highly volatile. The monetary policy implemented by the Central Bank of New Zealand aims to maintain the consumer price index at 1.5%. If banks fail to achieve this goal, they need to adjust their policies. The minimum-variance investment portfolio allocates 16.3% of the weight to EURJPY and NZDJPY, achieving the consequent of reducing risk.

Maximum-Sharpe ratio portfolio invested in USDJPY and CHFJPY, with weights of 53.4% and 46.6%. As it can be observed in Figure 1, the returns of GBPJPY, AUDJPY and CADJPY are the lowest three currency pairs in all investment portfolios. Figure 2 depicts their volatility is also relatively strong. Among them, Canada focuses on major commodities, such as crude oil, non-ferrous metals and basic raw materials for the mineral industry. Canada is a major exporter of such commodities, and its basic price fluctuates very sharply, especially the price of crude oil. The volatility of the Australian dollar is also related to oil. Therefore, the Kelly portfolio, the minimum-variance portfolio and the Maximum-Sharpe ratio portfolio have not invested in these currency pairs. The positions of the minimum-variance and maximum-Sharpe ratio portfolios are presented in Figure 5. The red and orange stars respectively represent portfolios with the smallest variance and the largest Sharpe ratio.

Table 3: Weights of Different Portfolios

	USDJPY	EURJPY	GBPJPY	NZDJPY	AUDJPY	CHFJPY	CADJPY
Equal-weighted portfolio	1/7	1/7	1/7	1/7	1/7	1/7	1/7
Kelly portfolio	0	0	0	0	0	1	0
Minimum-variance portfolio	0.605	0.098	0	0.065	0	0.232	0
Maximum-Sharpe ratio portfolio	0.534	0	0	0	0	0.466	0

Figure 3: GDP of Switzerland

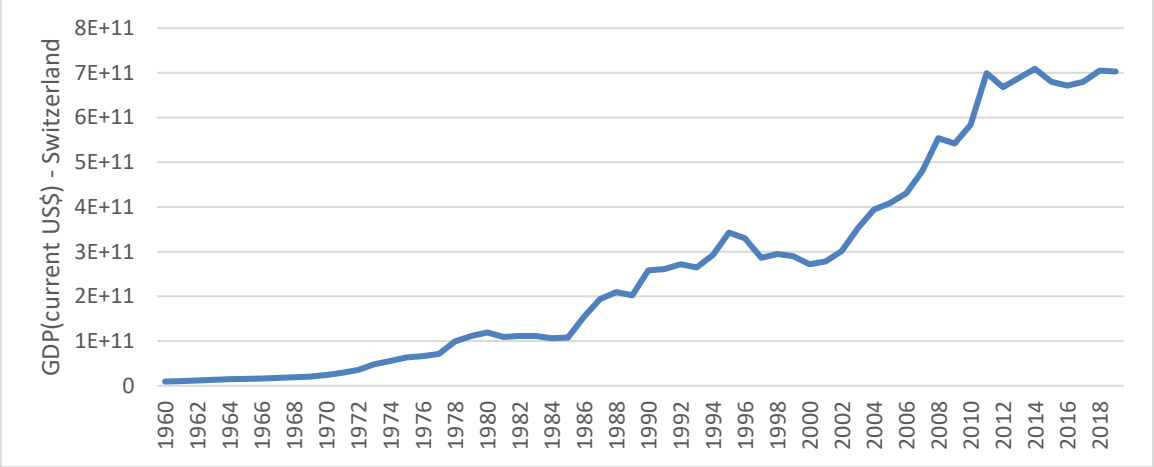


Figure 4: Yield of US Treasury

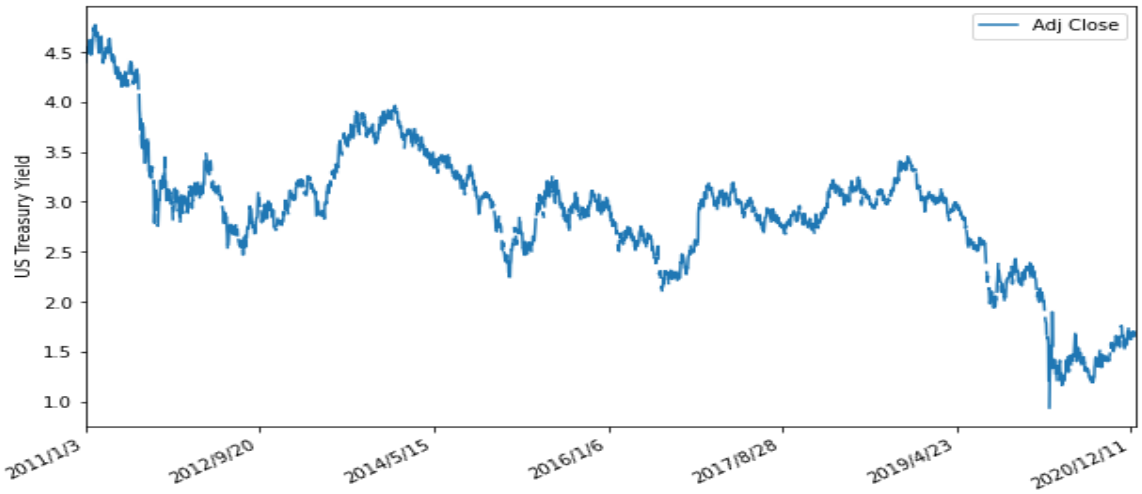
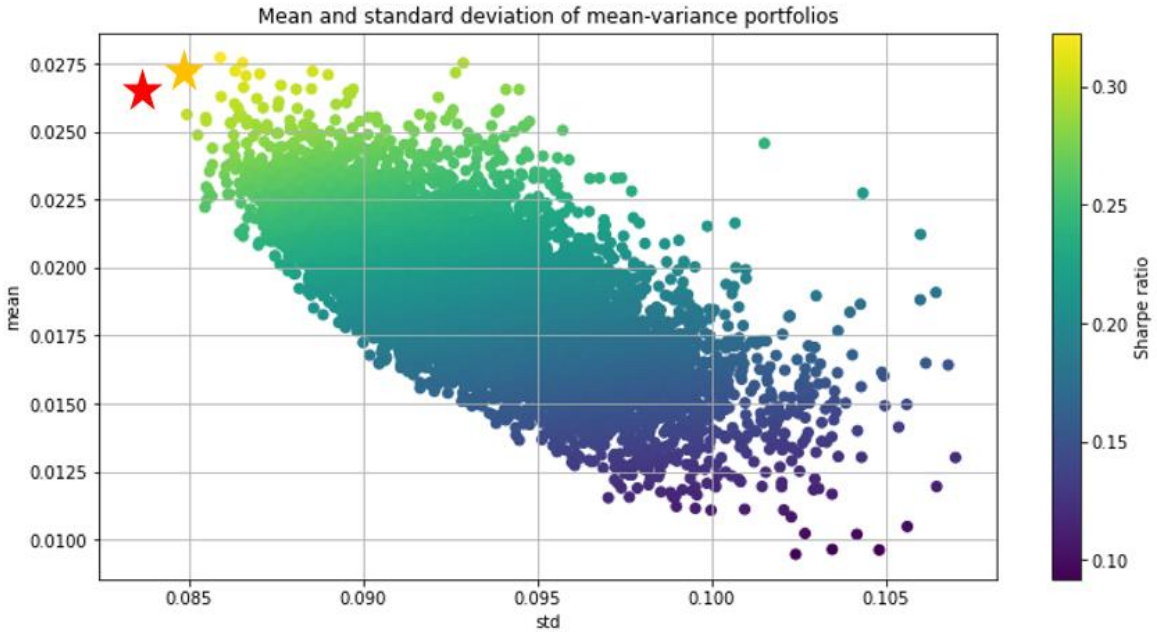


Figure 5: Position of Minimum-Variance and Maximum-Sharpe Ratio Portfolio



3.4.3 Portfolio Performance Comparison

Table 4 shows the performance indicators of these portfolios. This article takes the investment portfolio with equal weights as the benchmark. It can be seen that the methods of Kelly and Markowitz have played a certain degree of optimization. The annual return and cumulative returns of the investment portfolio constructed based on the Kelly criterion is the most. They are 3.0% and 35.7% respectively. However, while increasing returns, risks are also increasing. The volatility of Kelly portfolio is the most severe. The Maximum drawdown of Kelly portfolio is 26.4%. Maximum drawdown indicates the largest (expressed in %) drop between a peak and a valley. Intuitively speaking, it refers to the losses the strategy has experienced from the base amount of capital which it had at the peak. Therefore, the smaller the maximum drawdown, the better. Sharpe ratio is a very popular risk metric. It indicates the amount of excess return (over the risk-free rate) per unit of risk (measured by

standard deviation). The Sharpe ratio of Kelly portfolio is 0.32, which is 0.11 higher than the equal-weighted portfolio. Table 5 presents top 5 worst drawdowns of Kelly portfolio, together with information such as peak, valley date and the duration. From this chart, people can see that the maximum drawdown in Kelly portfolio occurred from August 10, 2011 to July 25, 2012. The recovery date was April 11, 2013, and it went through 437 duration. The second largest drawdown occurred from January 19, 2015 to July 11, 2016. However, it did not recover to the peak until the end of the sample interval. The minimum-variance portfolio has the smallest annual variance and maximum drawdown. At the same time, its annualized and cumulative returns are 1% and 12.9% higher than the equal-weighted portfolio. Its Sharpe ratio ranks second among all portfolios. Maximum-Sharpe ratio portfolio has the largest Sharpe ratio. The risk and maximum drawdown are 0.9% and 4.4% smaller than the equal-weighted portfolio. Investors can choose the appropriate investment portfolio based on their expected return and risk appetite.

In addition, there are some plots which help to visualize a variety of the performance metrics. The backtest performance graphs of the three optimized portfolios is presented in Figure 6, from left to right represent Kelly, minimum-variance and maximum-Sharpe ratio portfolios respectively. Since they are similar, this article takes Kelly portfolio as an example to analyze. With the annual and monthly return plots, people can see which years and months the algorithm performed the best in. For instance, the monthly heatmap plot in Figure 7 depicts this algorithm performed the best in February 2012 (shaded in dark green). In a backtest with a longer period of time, these plots will reveal more information. Furthermore, the distribution of the monthly returns is also instructive in gauging how the algorithm performs in different periods throughout the year and if it is affected by seasonal patterns. However, it can be seen

from the data in Figure 7 that the exchange rate is not related to the season. Figure 8 shows the rolling Sharpe ratio, which provides more insight into the stability of the portfolio. It is calculated using rolling 6 months of data, not entire sample. As it can be observed in Figure 9, due to the unexpected removal of exchange rate restrictions by the Swiss National Bank in 2015, rolling volatility fluctuates fiercely. People can use the drawdown plots in Figure 10 to quickly pinpoint the time periods in which the strategy performed the worst. As it can be observed that, returns recovered to the peak in April 2013 after falling in August 2011. Figure 11 shows the underwater plot. It depicts drawdowns and shows how long it took for the portfolio's value to recover to the previous peak, after suffering a loss. It can be inferred that the portfolio is difficult to run after 2015.

Table 4: Performance Metrics of Different Portfolios

	Annual return	Cumulative returns	Annual volatility	Sharpe ratio	Max drawdown
Equal-weighted portfolio	1.50%	16.50%	9.20%	0.21	-24.90%
Kelly portfolio	3.00%	35.70%	11.30%	0.32	-26.40%
Minimum-variance portfolio	2.50%	29.40%	8.30%	0.34	-20.50%
Maximum-Sharpe ratio portfolio	2.80%	33.00%	8.50%	0.37	-21.40%

Table 5: Top 5 Worst Drawdowns of Kelly Portfolio

Worst drawdown periods	Net drawdown in %	Peak date	Valley date	Recovery date	Duration
0	26.41	2011/8/10	2012/7/25	2013/4/11	437
1	25.22	2015/1/19	2016/7/11	NaN	NaN
2	7.29	2014/12/8	2015/1/15	2015/1/16	30
3	5.13	2013/12/31	2014/2/4	2014/11/5	222
4	4.54	2013/4/12	2013/6/17	2013/8/26	97

Figure 6: Performance Graphs of Three Optimized Portfolios

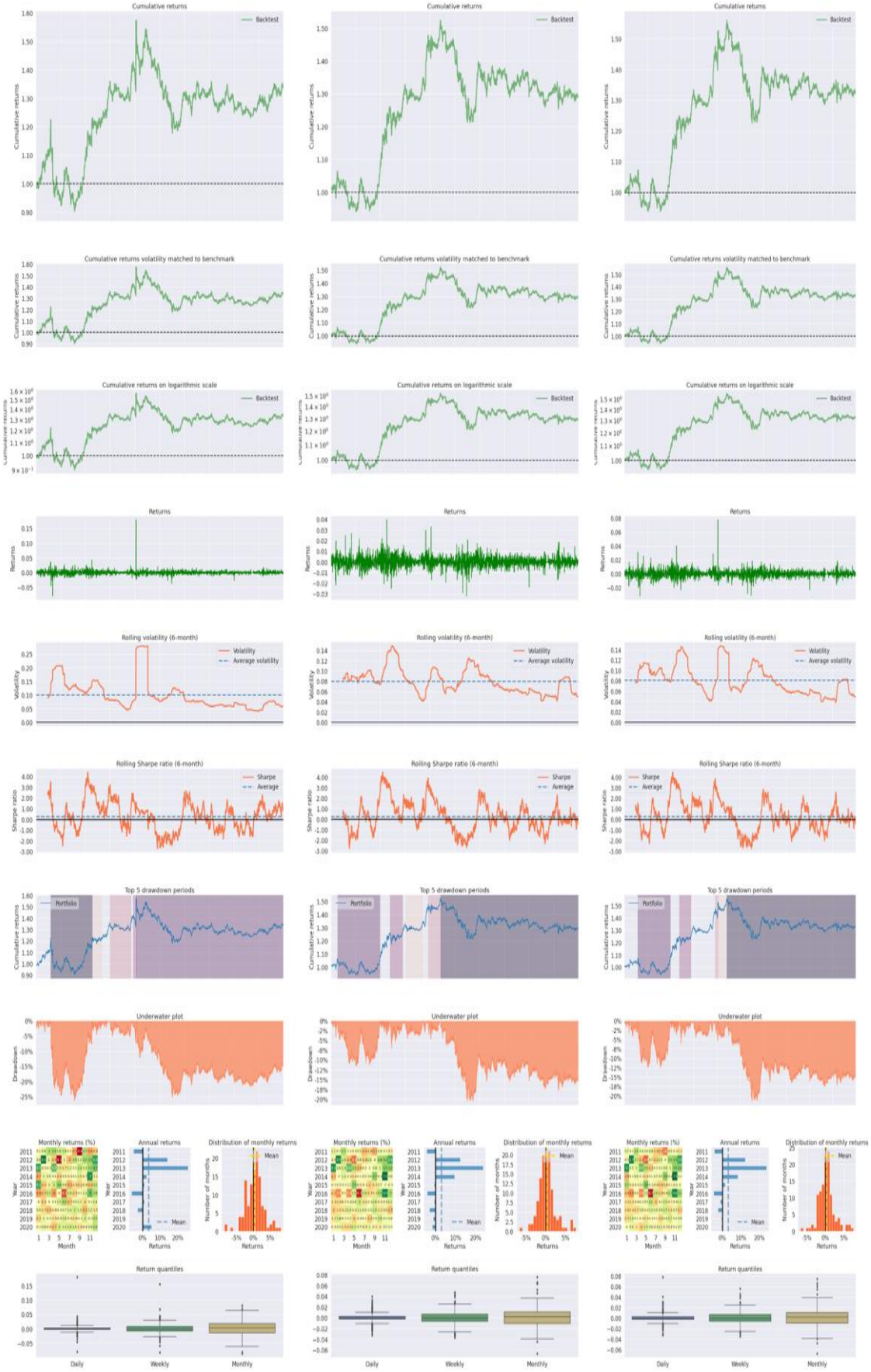


Figure 7: Monthly Heatmap Plot

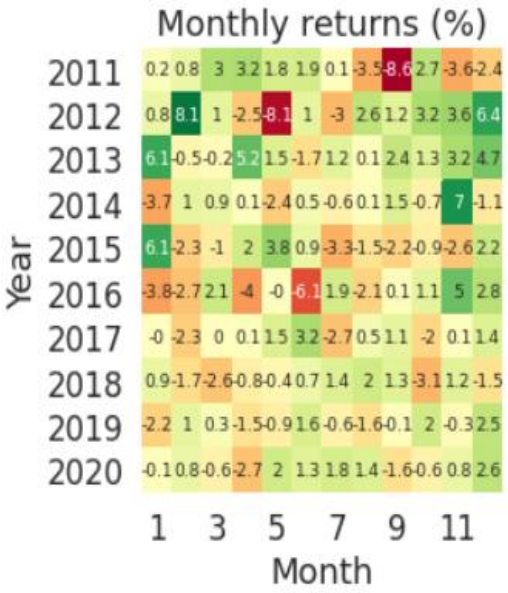


Figure 8: Rolling Sharpe Ratio

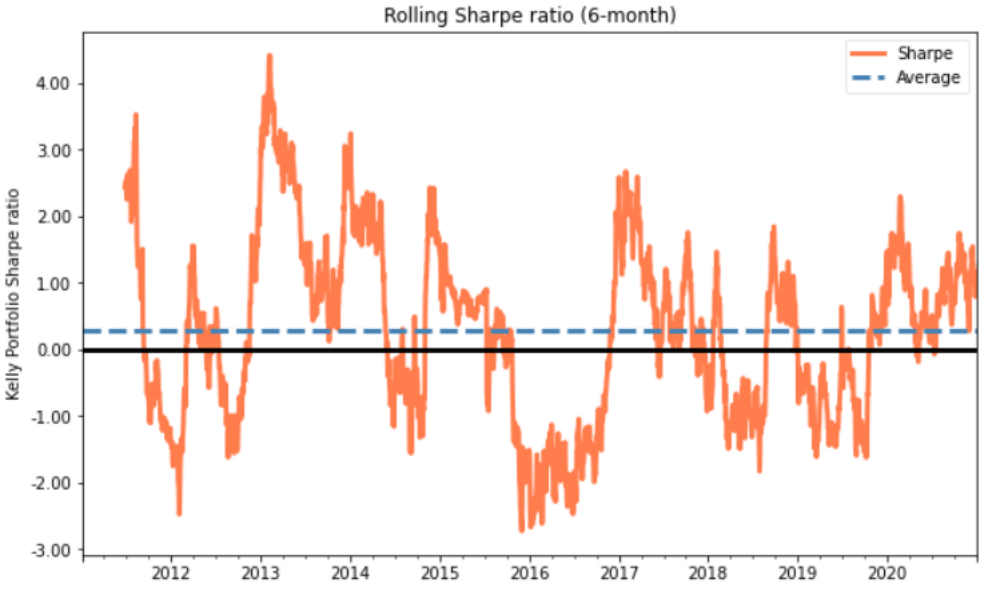


Figure 9: Rolling Volatility

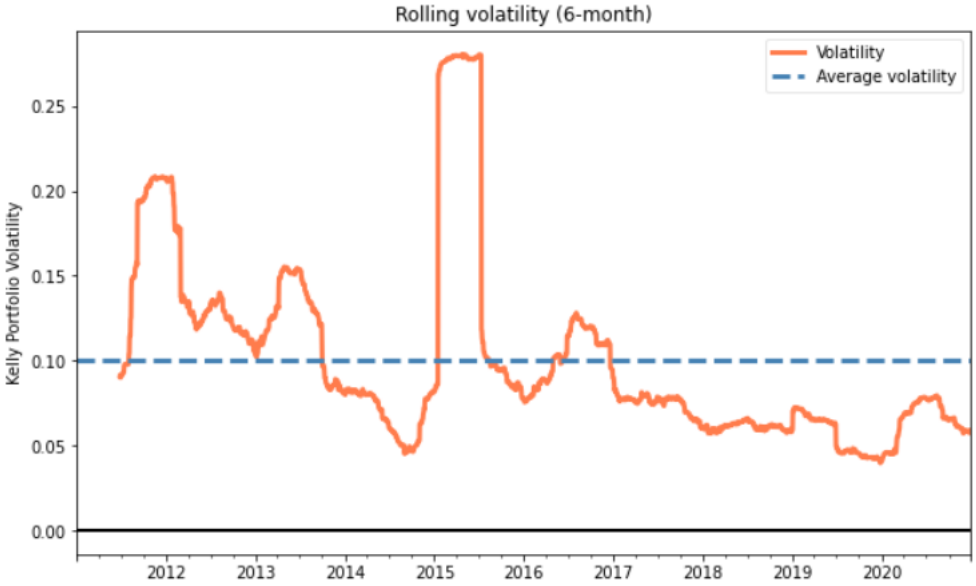


Figure 10: Top 10 Drawdown Plots

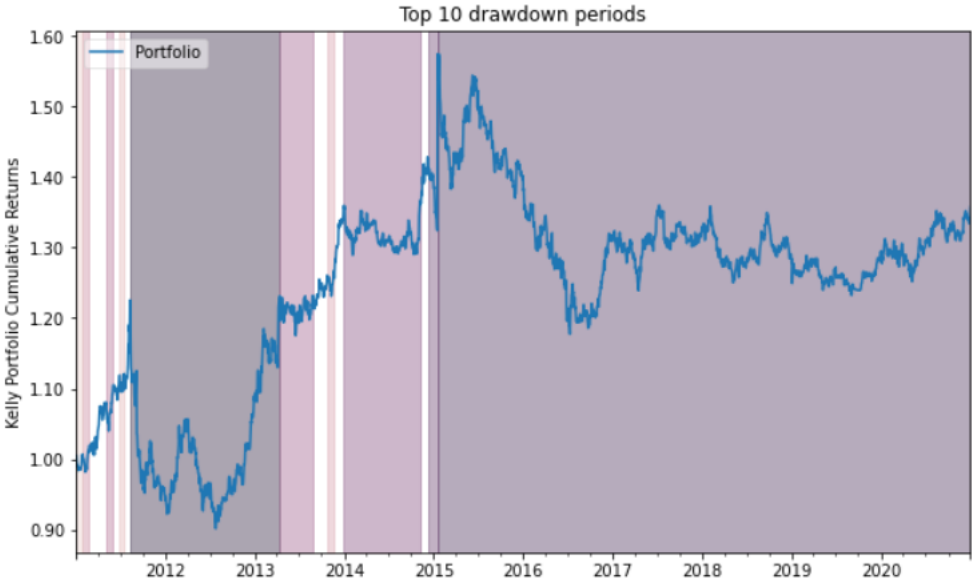
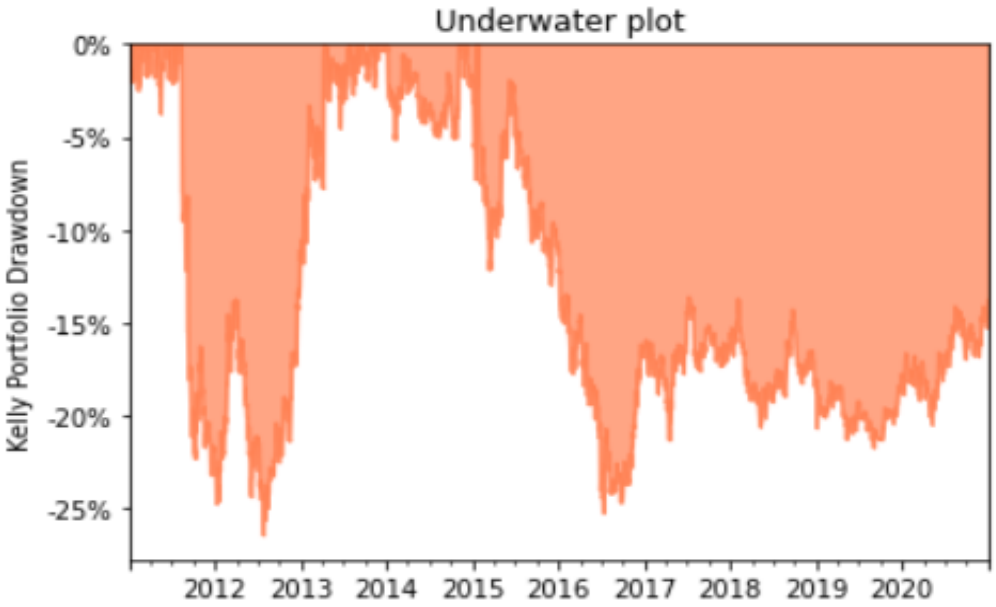


Figure 11: Underwater Plot



CHAPTER 4

CONCLUSION

The major achievement of this study was the construction of portfolios having steadily profitable performance in the foreign exchange market. In order to achieve this target, Kelly criterion and Markowitz portfolio theory was developed first. Then this article constructed an equal-weighted portfolio and used it as a benchmark. By comparing with the benchmark, the returns of the Kelly portfolio, minimum-variance portfolio and maximum-Sharpe ratio portfolio had increased. There are some conclusions can be drawn through the article analysis above. First, Kelly portfolio pursued to maximize the logarithmic rate of return. it tended to allocate a very small investment ratio to relatively low-yield currency pairs, while allocating a larger proportion of funds to relatively high-yield currency pairs, which is not conducive to better diversification of risks. Second, the minimum-variance portfolio overcame the shortcomings of Kelly model of assigning zero weight to low-yield assets. It can reduce the impact of foreign exchange market fluctuations. However, this investment portfolio also sacrificed some returns in order to control risk. Third, the maximum-Sharp ratio portfolio coordinated both returns and risks balancing them at an appropriate point. Therefore, investors need to combine the foundation of the investment model with their own risk preferences, which can obtain a more balanced and optimized portfolio.

The portfolios proposed in this article can help investors optimize their asset allocation strategies. However, the analysis and research work of this article still has some shortcomings, such as the calculation of solving Markowitz portfolio is too large, and the results obtained are not very accurate. In addition, there is still a lot of work to be completed regarding the application of these portfolios in actual foreign exchange

investment decision-making. In order to solve these limitations, machine learning should be more fully applied in the future.