Construction of Novel Portfolio Based on Modern Portfolio Theory

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Abstract: Modern Portfolio Theory (MPT) suggesting diversifying portfolios to reach an optimal trade-off between returns and risks is the footstone of practical financial investments. Nowadays, portfolio construction has continuously embraced novel types of assets to enhance returns and manage risks rather than solely containing traditional stocks and bonds. This study constructs a novel portfolio under the MPT framework and discusses weight allocation to make the portfolio the most efficient. One hundred thousand Monte Carlo simulations are carried out to discover the Efficient Frontier, and the Solver technique in Excel is used to put constraints on objective functions to draw the Capital Market Line (CML). The allocation of portfolios with the highest Sharpe Ratio, the highest return and the minimum volatility, has been explained and discussed. For results, investors who want to optimize their portfolios and have a certain level of risk tolerance should focus more on cryptocurrency and specific futures. This study may benefit investors interested in novel assets in markets by having a clearer understanding of their weight allocation according to their preferences.

1 INTRODUCTION

Nowadays, with the improvement of economics, increasing people make their own investments to gain returns. In retrospect, the idea of Modern Portfolio Theory was introduced by Markowitz, which is the fundamental footstone of practical financial investments. Modern Portfolio Theory suggests that a diversified portfolio can spread out risk and attain an optimal return through asset allocation (Markowitz, 1952). This idea lets investors no longer focus on sole asset investment as before but start to increase the variety of assets in the portfolio to reduce risk. Also, the correlation between assets is a crucial factor. Investors try to avoid highly correlated securities as this will increase the volatility of investments. In the same year, Roy introduced the Safety-First Portfolio Theory, which minimizes the possibility of returns falling below a specific threshold (Roy, 1952). The Minimum Variance Model was then introduced in 1959 by Markowitz as a result of this theory, minimizing the volatility in the constructed portfolio (Markowitz, 1959). Later, Sharpe introduced the famous Capital Asset Pricing Model, which outlined the method for appropriately determining the prices of securities based on their risks (Sharpe, 1964). The Black-Litterman model by Black and Litterman can deal with real-life investment situations (Black & Litterman, 1990). Meanwhile, Jorion introduced the Value at Risk model to calculate the maximum potential loss of investment (Jorion, 1997). Contemporarily, the portfolio construction theory has been continuously enhanced and applied in many aspects. For example, more customized investment decisions can be made utilizing big data and artificial intelligence, which facilitates more accurate evaluations of market trends (Kearns & Nevmyvaka, 2013). Furthermore, the inclusion of environmental, social, and governance (ESG) factors has become essential in the process of building investment portfolios, making investment choices contributed at social levels to some certainty (Friede et al., 2015). In recent years, with the improvement of portfolio theory, a variety of classes of novel assets, such as cryptocurrencies, exchange-traded commodities (ETCs), green bonds, and new index-tracking ETFs etc., have come out in the market. Baur and Lucey state that cryptocurrencies can be seen as a hedge that is not influenced by market fluctuations (Baur & Lucey, 2010). Therefore, they are not as vulnerable when undergoing a financial crisis as equity investments. This is the characteristic of cryptocurrencies and also the reason why cryptocurrencies tend to have high prices and demand. Gorton and Rouwenhorst claimed that ETCs allow portfolios to protect against inflation by

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granting access to commodities through traditional stock exchanges (Gorton & Rouwenhorst, 2006). The reason is that commodities are independent of the movement of equity under inflation. Therefore, considering long-term influence, investors can allocate weight to ETC to hedge inflation influence. The characteristic of green bonds is that they align investment portfolios with sustainability goals (Baker & McClain, 2019). Investors who prioritize ethical and environmental development prefer allocating weight to it. It shows not only the returns but also the contribution to the social environment. The achieved research on these novel types of assets all shows their unique characteristic influencing the final decision investors make.

In order to further research this concern, this paper will construct a portfolio consisting of five novel assets and see how the portfolio is influenced by the different weight allocations of these securities. The following part will discuss the data and methodology used, evaluate the model performance, explain the empirical results, and propose limitations and prospects for the future. The results presented may shed light on certain investors interested in novel portfolios in the financial markets.

2 DATA AND METHOD

In this paper, datasets were collected from Yahoo Finance (2024). To be specific, the portfolio contains five classes of novel securities, and each class selected a representative company to construct. They are respectively the ETC from SparkChange Physical Carbon EUA (CO2U.L), stock equity from Tesla (TSLA), ETF from iShares ESG Aware MSCI EAFE (ESGD) tracking the performance of the MSCI EAFE ESG Focus Index, cryptocurrency Bitcoin USD (BTC-USD) and Crude Oil Futures (CL=F). In the remaining part of this paper, they are referred to by their tickers. Weekly historical data were chosen from 20 Oct. 2021 to 20 Aug. 2024 to reflect returns. It should be noted that the tracking period is less than three years because the subject CO2U.L is too novel, so its public trading time can only be traced back to 18 Oct. 2021.

This study aims to construct an investment portfolio with the maximum Sharpe Ratio as its objective function optimization. The Sharpe ratio measures the expected excess return divided by the overall portfolio risk. This metric can accurately quantify the efficiency of portfolio returns in relation to the risks undertaken. Therefore, it needs to find the most appropriate weight allocation by maximizing the Sharpe Ratio value. Following are the steps employed to figure out the proper weights for portfolio optimization. First of all, weekly adjusted closing prices are used to calculate the average returns of five securities and then convert them into annualized ones. Then, a covariance matrix of these five securities needs to be shown. Afterwards, Monte Carlo simulations are carried out to generate random variables for each of their weight allocation. Monte Carlo simulations use random variables to calculate results over and over to conduct a quantitative risk analysis (Glasserman, 2003). This forecasting model is innovative and highly adaptable, allowing for adjustments based on changing investment objectives. One hundred thousand Monte Carlo simulations were carried out in this paper to optimize the Sharpe Ratio. Values of random weight variables are all larger than zero and less than one. Besides, constraints were put to avoid some extreme situations. Specifically, the sum of the weights of five securities is always equal to one. Next, the expected portfolio return and portfolio risk can be calculated as follows:

$$E(R_p) = \Sigma_{i=1}^{5} \omega_i E(r_i) \tag{1}$$

$$\sigma_p = \sqrt{\Sigma_{i=1}^{5} \Sigma_{i=1}^{5} \omega_i \omega_i \mathrm{Cov}(\mathrm{r_i}, \mathrm{r_j})} \tag{2}$$

where ω_i represents the security weights, $E(r_i)$ is the expected returns (annualized) and $Cov(r_i, r_j)$ is the covariance of five securities. Then, the standard deviation needs to be converted into the annualized value. Finally, the Sharpe Ratio can be calculated as follows:

$$Sharpe\ Ratio = \frac{R_p - R_f}{\sigma_p} \tag{3}$$

where R_f is the risk-free rate during this 3-year period. Values of 10-year treasury bonds were used to calculate R_f.

3 RESULTS AND DISCUSSION

3.1 Efficient Frontier

The Efficient Frontier was derived by applying Monte Carlo methods to simulate 10,000 portfolio combinations. These combinations were then plotted on a graph, with the expected returns on the y-axis and the standard deviation on the x-axis. The graph (Figure 1) below depicts the trade-off between portfolio risk and expected return, showcasing portfolios on the frontier that optimize returns for a specific level of risk. Figure 1 is the scatter plot of portfolio return and standard deviation consisting of one hundred thousand Monte Carlo simulations. The graph illustrates that most of the portfolio combinations have a 20% to 40% risk and generate 5% to 20% expected returns. Applying portfolio theory and using the Monte Carlo simulations make it possible to figure out the portfolio's efficient frontier. Any portfolios that are just on the line can have the optimal returns under that particular level of risk. In contrast, any investment combinations inside the efficient frontier can be reached whether with a higher return under the same volatility or with lower volatility under the same return.

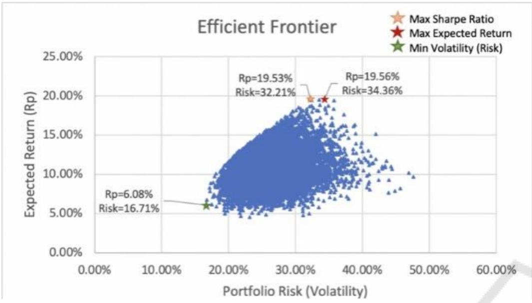

Figure 1: Portfolio Efficient Frontier using Monte Carlo simulations (Photo/Picture credit: Original).

Three portfolio combinations marked with stars in Figure 1 are noticeable. The combination with the highest expected return is 19.56% and a 34.36% volatility. Compared to the highest expected return (19.56%), the investment with the highest sharp ratio (48.90%) is on the efficient frontier and its expected return and volatility are 19.53% and 32.21%, respectively. The nearly identical return value and more minor volatility optimize this portfolio and make it more efficient than the one with the highest expected return under a certain risk level. Another combination has the lowest volatility (16.71%) and a 6.08% return.

3.2 Model Perofopmances

The Monte Carlo simulations were utilized to depict the efficient frontier, providing a macroscopic view of portfolio investment performance across different risk levels through a large number of randomly generated portfolio combinations. Then, in Section 3.2, the Solver tool in Excel will be used to fine-tune the investment. Specifically, 20% of the weight is assumed to be equally allocated to each security. Then the maximum Sharpe Ratio, maximum returns, and minimum volatility will be seen as the objective functions in discussing the portfolio, ensuring the portfolio aligns with the Capital Market Line (CML). This method provides a microscopic view of the portfolio and enhances its practicality. It is worth mentioning that a restriction will be put in place: the weight of each asset is between -1 and 1, but the total weight of the total five assets is always 100%. Unlike Monte Carlo random variables where the value is 0 to 1, the weight can be a negative value here. Its specific meaning will be explained in the next section.

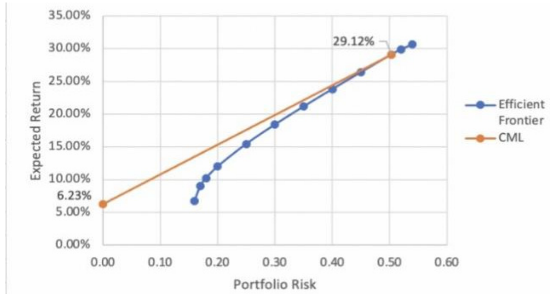

Figure 2: CML and Efficient Frontier using the Solver (Photo/Picture credit: Original).

As depicted in Figure 2, the blue line is the efficient frontier showing portfolios with the highest expected return possible for a given level of risk under the Solver technique. The orange line is the CML, which is tangent to the efficient frontier at the highest Sharpe Ratio point. The point with the highest Sharpe Ratio is just lying on the efficient frontier, which is the portfolio optimization point, with a 29.12% expected return and a 50.32% volatility. The following section is going to use Portfolio A to refer to the one with the highest Sharpe Ratio.

Table 1: Portfolio Combination A with Maximum Sharpe Ratio.

Expected Rerturn		Sharpe Ratio		Portfolio Risk
29.12%		50.36%		50.32%
Coefficients				
CO2U.L	TSLA	ESGD	BTC-USD	CL=F
100%	-5.74%	-43.25%	49.82%	-0.83%

Table 2: Portfolio Combination B with Maximum Expected Return.

Expected Rerturn		Sharpe Ratio		Portfolio Risk
38.64%		33.37%		104.45%
Coefficients				
CO2U.L	TSLA	ESGD	BTC-USD	CL=F
100%	100%	-100%	100%	-100%

Table 3: Portfolio Combination C with Minimum Volatility.

Expected Rerturn		Sharpe Ratio		Portfolio Risk
6.23%		15.96%		15.38%
Coefficients				
CO2U.L	TSLA	ESGD	BTC-USD	CL=F
5.74%	-3.62%	77.91%	4.43%	15.54%

As listed in Table 1, the Sharpe Ratio of Portfolio A is 50.36%, showing its different weight allocation on five assets in the portfolio. It shows a high concentration of CO2U.l, which is 100% fully invested. Also, the cryptocurrency is worth nearly half (49.82%) weight. The other three securities are considered to have a pessimistic expectation for the future, so short selling can be taken as a measure to provide a hedge for portfolio A. ESGD accounts for the largest negative weight (-43.25%) among these.

Similar to Portfolio A, Portfolio B and Portfolio C are also special combinations that represent the one with the maximum expected return and the one with the minimum standard deviation. As shown in Table 2, the highest expected return can be achieved is 38.63% and has a 33.37% Sharpe Ratio. If investors mindlessly pursue high returns and do not take risks into account, there will be an extreme situation. 100% Fully investing and short selling these five securities result in a significant volatility of up to 104.45%, meaning the return range can be from a negative 65.82% to 143.08%. Compared to Portfolio B, Portfolio C shows the smallest volatility. In this combination, ESGD is heavily invested in up to 77.91%, ETC, cryptocurrency and futures are also allocated with appropriate proportions respectively. TSLA stock equity is again shorted (-3.62%). This weight allocation generates a relatively low expected return (6.23%) and a 15.38% Sharpe Ratio, which seems not to be an efficient choice as given in Table 3.

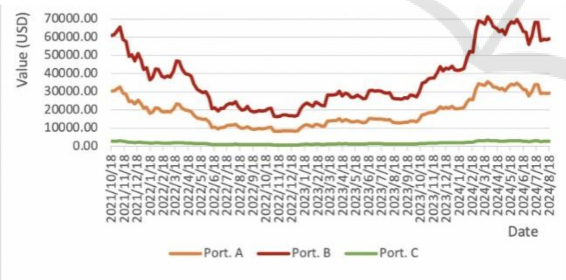

Figure 3: Net Asset Value (NAV) Curve of three Portfolios (Photo/Picture credit: Original).

The Net Asset Value (NAV) curve of the three portfolios is shown below. It depicts the portfolio's performance over the period from Oct. 2021 to Aug. 2024. The assumption is that the investing proportion stays the same for three years. From Figure 3, all these three portfolios exhibit a trend of falling sharply first and then recovering and even rising until now, showcasing their resilience. Comparatively, the three portfolios show different volatility. Portfolio B is more volatile, ranging from $16403 to $71411, showing portfolio B is capable of earning higher gains but facing higher downside risks. In contrast, portfolio C generates the lowest value ($1000 to $3000) and volatility, suitable for risk advisors who prefer steady returns.

3.3 Explanation and Implications

Refocusing on Portfolio A, the reason that having a maximized Sharpe Ratio may be due to it investing heavily in securities such as cryptocurrency, which are more profitable, and it also short other classes of securities to provide a hedge to avoid significant potential losses that high-growth assets bring. Investors who want to optimize their portfolio can take the weight allocation of the Sharpe Ratio point as a reference.

From the above analysis, some insights and investment implications can be given. The CML and efficient frontier help investors reach a balance between returns and risks. Investors can pay more attention to the carbon EUA ETC and the bitcoins when constructing portfolios, meanwhile focusing on volatility. In addition to this, risk tolerance also matters. Risk advisors such as seniors may prefer lower risk and steady returns, so they may choose Portfolio C over Portfolio A. In comparison, risk seekers may be willing to accept the largest volatility for higher returns, such as Portfolio B. Therefore, when constructing portfolios, investors should not only be concerned about the efficiency of diversified securities but also consider personal preferences and market conditions before making investment decisions.

3.4 Limitations and Prospects

In this part, the limitations of the portfolio optimization model and methods will be discussed, as well as the future prospects will be mentioned for further research. The most significant problem is that the model uses historical data to forecast. However, historical data cannot be representative of future results as future results will be affected by the market moment-by-moment. Using historical prices can generate inaccurate returns, standard deviation, and covariance matrix. Additionally, the subject of this paper is a novel portfolio, thus some securities do not have enough data, such as the crude oil futures, which only have public trading prices that are less than three years. The limited period cannot reflect the trend well compared to a long-lasting period (more than ten years). Also, not all types of risks can be included in the model when calculating the Sharpe Ratio. Risks include credit risk, urgent financial crisis and so forth. It takes time to transmit market information to have a reflection on prices in a semi-strong efficient market. Future research can explore the model to have the ability to capture some information and events influencing market dynamics and consider some economic factors. Moreover, new models such as price prediction and risk evaluation that can forecast future results more accurately should be enhanced.

4 CONCLUSIONS

In conclusion, this paper investigates a portfolio based on five novel assets, including ETC, new-energy stock, ETF, cryptocurrency, and futures. First, previous literature is reviewed to illustrate the history of portfolio development and current situations. For investigation, all weekly price data are collected from Yahoo Finance (2024). Then, one hundred thousand returns and risks are generated using Monte Carlo simulations, and all these statistics are plotted to draw an Efficient Frontier. Moreover, the portfolio combinations with the highest Sharpe Ratio, highest return and lowest volatility are specially marked on the figure. Next, the portfolio is focused on a micro view, using the Solver technique in Excel to achieve the objective function. CML and Efficient Frontier are plotted, and the tangent point was found to figure out the weight allocation of the portfolio with the maximum Sharpe Ratio. Tables and the NAV curve are provided with explanations, and some investing insights are given to different investors according to their personal preferences. The lack of long-term data and too much reliance on historical data are the limitations of this paper. Further progress in forecasting more reliable and accurate predictions could be made as prospects on novel portfolios.

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