Performance of Brownian-Motion-Generated Universal Portfolios during COVID-19 Pandemic

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A project report submitted in partial fulfilment of the requirements for the award of Master of Mathematic

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"Performance of Brownian-Motion-Generated Universal Portfolios during COVID-19 Pandemic"** was prepared by **KHOR WEI SHENGE** has met the required standard for submission in partial fulfilment of the requirements for the award of Master of Mathematics at Universiti Tunku Abdul Rahman.

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ABSTRACT

The universal portfolio is a portfolio investment strategy which aims to maximize the return and it proves to achieve good return. The algorithm introduced by Cover requires memory in order $O(n^m)$ which n is the number of trading day and m is the number stock in the universal portfolio. As the inefficiency for long trading days, some universal portfolios have been proposed to impose a finite order universal portfolio which is able achieve comparable result. Brownian motion is one of the famous stochastic processes which heavily applied in various financial derivative pricing. The goal of this study aims to study the performance of finite order Brownian motion generated universal portfolio using 3 independent Brownian motion. The research will include thress stocks from respective countries, Malaysia, Singapore and Thailand from January 2020 to June 2022. The pool of stocks is selected as such: KLCI index component stock listed in Kuala Lumpur Stock Exchange (KLSE), Straits Time Index component stock listed in Singapore Exchange (SGX), The Bangkok SET Index component stock listed in Stock Exchange of Thailand. This research will benchmark the result against Buy and Hold, Constant Rebalance and other universal portfolios. This study also wants to study the effect of parameters of Brownian motion in forming the Brownian motion generated universal portfolio to provide more insight in parameter selection. According the to result, Brownian motion universal portfolio is performed better than the benchmark (compare with respective listed index within each country), especially in term of Sharpe ratio and Sortino ratio.This research also achieves some fruitful result with dynamic Brownian motion parameter setting according to Follow the Winner and Follow the Loser to avoid forward looking bias and to be practical.

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LIST OF SYMBOLS / ABBREVIATIONS

σ	volatility, standard deviation
b	weight of asset
x	relative return of asset
S	accumulated wealth
$\xi_{i,j}$	normalising constane in time i, asset j
t	time
μ	mean od stochastic brownian motion
X	stochastic brownian motion particle
BMUP	brownian motion generated portfolio
EWP	equally weighted portfolio

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

Portfolio investment is a strategy allocating fund into selected stocks with aim to generate positive return and to diversify idiosyncratic risk. Various portfolio investment theory has been introduced since last decade. A well performed portfolio emphasize selection of stock and allocation of stock. In this research, we study the part of allocation of wealth into a given set of stock.

Modern portfolio theory (MPT) by Markowitz (1952) is the classic in portfolio investment topic, introduce the construction of a portfolio to maximize the mean return given the level of risk. With the input of assets' mean return, volatility and correlation, MPT provides vectors of weight for respective selected asset for investor with different risk appetite and is rebalanced at the beginning of each trading period. The concept of MPT is then widely applied in the portfolio investment. By constructing portfolio in different risk level, one can produce the efficient frontier.

Cover (1991) introduce the concept of universal portfolio which focused on wealth allocation into each asset without mean return, variance and correlation of the assets. The algorithm learns adaptively from historical asset price with objective function of maximize log-optimal growth rate in the long run and rebalance the universal portfolio at the beginning of each trading period. It is shown that the universal portfolio can outperform than buy and hold strategy of single asset. Cover and Ordentlich (1996) extent the study by employ distribution to generate universal portfolio and included side information in the algorithm to increase the universal portfolio return.

Tan (2013) introduced the finite order universal portfolio generated by some probability distribution and it only use most recent of trading days. The result of study is compatible with best constant rebalance strategy. Pang, Liew and Chang (2019) worked the performance of finite order Brownian motion generated universal portfolio in Malaysia stock market from year 2000 to year 2015 with different length of investment period. It shows that with appropriate

parameter of Brownian motion, the Brownian motion generated universal portfolio performed well and obtained good return.

As the satisfactory result on previous work, we consider the most recent n days in our study and then make use of Brownian motion generate universal portfolio to study its performance during COVID-19 pandemic. Similar research had been done by Pang, Liew and Chang (2019) but the period studied is under normal economic cycle We study the Brownian motion generated universal portfolio using Malaysia, Singapore and Thailand stock marlet. Next, we weill extend to study the parameter of Brownian motion generate universal portfolio.

1.2 Problem Statement

Pervious works on Brownian motion generated universal portfolio focus its performance on normal economy cycle with different holding period. This research will extend the work to several areas:

(i) To study the performance of Brownian motion generated universal portfolio in stock market of Malaysia, Singapore and Thailand during COVID 19 pandemic

(ii) To study the effects of the parameter of Brownian motion generated universal portfolio on the final wealth.

1.3 Aim and Objectives

The aim of this research is to study the performance of Brownian-motion-generated universal portfolios during COVID-19 Pandemic. The research includes performance of Brownian-motion-generated universal portfolio in stock market of Malaysia, Singapore and Thailand. The research also study effects of Brownian motion's parameter on the return by varying the parameter.

1.4 Scope and Limitation of the Study

Portfolio constructed is based on three stocks from the pool and it can lead to bias since small number of stocks within a portfolio introduce overconcentration risk. Besides, the study assumed some level of survivorship bias as this research aims to ensure the portfolio comparability and stocks should be available throughout the sample period.

1.5 Contribution of Study

The goal of this project is to study performance of Brownian motion generated universal portfolio in stock market of Malaysia, Singapore and Thailand during COVID 19 pandemic. Also, the project aims to provide some useful insight in choice of Brownian motion's parameter in generating universal portfolio.

CHAPTER 2

LITERATURE REVIEW

2.1 Literature Review

The universal portfolio is introduced by Cover (1991), a kind of portfolio investment focuses on multi period or sequential portfolio selection, aiming to maximize the portfolio expected growth rate. In Cover's work, there is no assumptions on the stock prices. Before Cover, the mean variance theory had long stood in asset management and portfolio investment, which focuses single period portfolio selection to achieve highest return in any given unit of risk. Markowitz (1952) introduced mean variance theory chooses the optimal portfolio based on risk appetite profile, produce efficient frontier that consist of best combination of assets given the unit of risk assumed.

According to Li and Hoi (2014), there are few categories of algorithms in studying portfolio investment. "Follow the winner" tries to achieve the growth rate in line with the optimal strategy. "Follow the loser" proposed to transfer the wealth allocation from winner to loser which in hope the bounce back of loser can assist the portfolio achieve higher return. "Pattern matching" attempt to predict the next market distribution based on distribution generated from historical data and optimize the portfolio based on the distribution. Above mentioned categories focus on single strategy to achieve the target, however, "Meta-learning strategy" focuses on combines multiple strategy to optimize the portfolio.

Besides, the researchers also expand artificial intelligence into field of portfolio selection. Liang et al. (2021) obtain the weight of assets according to news keyword with the objective of decreasing the CVaR (Conditional Value at Risk) of the portfolio. It shows that relevant risk and return ratio improved significantly during 08's crisis as well as covid-19 period.

Yashawi (2021) extend previous work on reinforcement learning application in portfolio management by taking noise and non-stationary price fluctuation into the agent knowledge domain.

Other that quantitative portfolio selection, He and Yang (2020) employs experts' advices as source of information to perform portfolio selection.

By studying the performance of experts and select the portfolio accordingly. The method proved to be universal and manage to achieve satisfactory results.

To compare the result of portfolio, the most intuitive measurement will be the accumulated wealth. However, different risk appetite may affect the performance of portfolio significantly. There few golden measurement of portfolio measurement in financial markets, is that, CAPM by Willian (1964), Sharpe ratio by Willian (1975), Sortino Ratio by Sortino and Van (1991) are used to measure the portfolio performance relatively in different dimension with different objective. The CAPM is measuring the degree of a portfolio expose to systematic risk. Sharpe ratio focus on the consistency of portfolio performance given a period of time or its risk reward relationship. Sortino ratio consider the downside risk of a portfolio performance. The various measurement provide the risk profile of portfolio but not only the accumulated wealth.

2.2 Covid – 19 Pandemic and Stock Market

The covid 19 pandemic strikes the global market with no pre-alarm and turn business and market into chaos in short amount of time. The answer of surviving in the market or preserving value portfolio value become an important topic. Cheng et al. (2022) suggest that the outbreak of COVID-19 pandemic has significant connected to the stock market volatility. While the Asian market present a different level of connectedness in different stage of COVID 19 development while the volatility of Europe, U.S. and Australia market show a consistent closely connection to the COVID 19 development. Liu et al. (2020) show that the Asian stock market experienced more negative abnormal compared to the western using event study method. Gamal et al. (2021) confirmed that the negative relationship of daily trading size in Malaysia stock market and both global and domestic market case of coronavirus.

2.3 Universal Portfolio

Cover (1991) introduce universal portfolio which aim to maximize log growth rate of the universal portfolio

To overcome the problem of exponential growth of implementation cost as the number of stock grow, Kalai and Vempala (2002) presented an efficient algorithm based on non-uniform random walks. Tan (2013) also proposed to constraint the order of algorithm of universal portfolio.

Cover and Ordentlich (1996) attempted to include side information into the universal portfolio and came out with moving order universal portfolio, which the implementation time and memory storage grow exponentially as number of stocks increased. Giler (2007) studied the performance of universal portfolio with and without side information and find that not all combination of stocks can prove that the side information does contribute some additional wealth. The limitation also addressed by Cover and Ordentilich, mentioned that the role of side information is arbitrary which cannot be clearly defined in real world market. Bhatt et al.. (2021) further extend the work of Cover and Ordentlich (1996) that assumes single state function to a collection of function of finite Natajaran dimension and the proposed strategy achieve the similar result as the best state-constant rebalanced portfolio.

To setting a good benchmark to compare the performance of universal portfolio, Tavory and Feder (2010) proposed that the performance of a universal portfolio must compare with one that rebalances a stronger portfolio strategy often enough to avoid pathological sequences, but not so frequently that transaction costs dominate rather than CRP strategy.

Recent researchers extend the generation of universal portfolio using vary distributions or functions. Tan et al. (2015) generate a universal portfolio by price relative reciprocal function. Tan and Kuang (2019) apply pseudo f-divergence in generating universal portfolio to study the result of final wealth. An empirical on the performance of universal portfolio generated by Holder inequality ratio based on Malaysia stock market done by Tan and Yap (2019). Pang et al. (2019) studied the performance of Brownian motion generated universal portfolio in Malaysia stock market outperform the constant rebalance portfolio.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The research seeks to study the Brownian motion generated universal portfolio in stock market of Malaysia, Singapore and Thailand. This work will focus on stock data from Bursa Malaysia, Singapore Exchange and Stock Exchange of Thailand. Consider the pandemic still spreading around the world, our study period starts from January 2020 to June 2022. The research compare the performance of Brownian motion generated universal portfolio and that of classic portfolio selection theory in term of return to study the performance of aBrownian motion generated universal portfolio.

3.2 Basic terminology and Review in Universal Portfolio

We let $\boldsymbol{x_n}$ be the vector of stock-price-relative factor ($x_{n1}, x_{n2}, \ldots, x_{nm}$) on the nth trading day of a m stock market. The stock-price-relative factor, x_{ni} is defined as the ratio of closing price to the opening price of stock i on day n. We let $\boldsymbol{x^n}$ represents the sequence of stock-price-relative vectors, $\boldsymbol{x_1, x_2, \ldots, x_n}$. Similarly, we let b_{ni} be the proportion of wealth invested on stock i on day n where $0 \leq b_{ni} \leq 1$. Then, $\boldsymbol{b_n} = (b_{n1}, b_{n2}, \ldots b_{nm}$ be the portfolio strategy on day n and $\sum b_{ni} = 1$.

The constant rebalanced portfolio is then the portfolio with $\mathbf{b} = (b_1, b_2, \ldots, b_m)$ where the proportion of wealth on each stock is independent on day of trading, $b_{ni} = b_i$. The wealth accumulated by a constant rebalanced portfolio with initial wealth of 1 is then:

$$S_n(b) = \prod_{i=1}^{n} b^T x_i \qquad (1)$$

(Where subscript T refer to transpose of vector)

For all available constant rebalanced portfolio, the best constant rebalanced portfolio (BCRP), $S_n^*(x^n)$ is then the one with highest wealth achieved:

$$S_n(x^n) = \max_b S_n(b) \qquad (2)$$

The proposed universal portfolio strategy in Cover (1991) is the strategy weighted by performance: $b_i = \left(\frac{1}{m}, \frac{1}{m}, \ldots, \frac{1}{m}\right)$,

$$b_{n+1} = \frac{\int bS_n(b)db}{\int S_n(b)db} \tag{3}$$

where

$$S_n(b) = \prod_{i=1}^{n} b^t x_i$$

Later, Cover and Ordentlich (1996) redefined the universal portfolio to the following:

$$b_{n+1} = \frac{\int bS_n(b)d\mu(b)}{\int S_n(b)d\mu(b)} \tag{4}$$

$$S_n = \int S_n(b)d\mu(b) \tag{5}$$

where μ is a given distribution in the space of portfolios (Li and Hoi 2012) and:

$$S_n(b) = \prod_{i=1}^{n} b^t x_i$$

Since μ is a given distribution, we can let **Y** = (Y_1, …, Y_m) be a random vector with m-dimensions and $0 \leq Y_i \leq 1$, $\sum Y_i = 1$ with probability distribution of f(**Y**). Using Wackerly et al.. (2000)'s notations of expected value, μ can be replaced with **Y** and the portfolio strategy can be redefined as:

X = price relative to the previous day

Y is the pdf vector

$$\mathbf{b_{n+1}} = \frac{E(\mathbf{Y}\prod_{j=1}^{n}\mathbf{Y^t}\mathrm{x}_j)}{E(\prod_{j=1}^{n}\mathbf{Y^t}\mathrm{x}_j)} = \frac{E[\mathbf{Y}(\mathbf{Y^t}\mathrm{x}_n)(\mathbf{Y^t}\mathrm{x}_{n-1})\ldots(\mathbf{Y^t}\mathrm{x}_1)]}{E[(\mathbf{Y^t}\mathrm{x}_n)(\mathbf{Y^t}\mathrm{x}_{n-1})\ldots(\mathbf{Y^t}\mathrm{x}_1)]} \tag{6}$$

The *k* component of vector $\mathbf{b_{n+1}}$ will be:

$$b_{n+1,k} = \frac{E(\mathrm{Y}_k\prod_{j=1}^{n}\mathbf{Y^t}\mathrm{x}_j)}{E(\prod_{j=1}^{n}\mathbf{Y^t}\mathrm{x}_j)} = \frac{E[\mathrm{Y}_k(\mathbf{Y^t}\mathrm{x}_n)(\mathbf{Y^t}\mathrm{x}_{n-1})\ldots(\mathbf{Y^t}\mathrm{x}_1)]}{E[(\mathbf{Y^t}\mathrm{x}_n)(\mathbf{Y^t}\mathrm{x}_{n-1})\ldots(\mathbf{Y^t}\mathrm{x}_1)]} \tag{7}$$

3.2.1 Finite Order Universal Portfolio

Tan (2013) adopted the approach of universal portfolio generated by probability distribution and introduced the finite moving order universal portfolio generated by probability distribution. In contrast to Cover and Ordentlich (1996)'s moving

order universal portfolio, which the computation time and memory storage grow exponentially fast when number of stocks increased, Tan (2013)'s proposed finite order universal portfolio tackled this problem by improving the time and memory storage performance. Hence, it is more practical to use Tan (2013)'s universal portfolio in investment strategy than the Cover and Ordentlich (1996)'s.

The order ν of universal portfolio is the number of days of stock data used in computing the portfolio strategy in the following day. For small order ν (i.e. ν =1,2,3), computational time and memory storage requirement to compute the portfolio will be reduced significantly.

Following the formula for portfolio strategy with proportion $b_{n+1,k}$ for stock h on trading day $n+1$:

$$b_{n+1,k} = \frac{E(\mathrm{Y}_k \prod_{j=1}^{n} \mathbf{Y}^t \mathrm{x}_j)}{E(\prod_{j=1}^{n} \mathbf{Y}^t \mathrm{x}_j)} = \frac{E[\mathrm{Y}_k (\mathbf{Y}^t \mathrm{x}_n)(\mathbf{Y}^t \mathrm{x}_{n-1}) \dots (\mathbf{Y}^t \mathrm{x}_1)]}{E[(\mathbf{Y}^t \mathrm{x}_n)(\mathbf{Y}^t \mathrm{x}_{n-1}) \dots (\mathbf{Y}^t \mathrm{x}_1)]}$$

Using the derivations from Lim (2013) and Pang (2017) on order 1, 2, 3 universal portfolios, we get the following formula for the portfolio strategy. Note that the independence of $Y_1, Y_2, \dots, Y_m$ is assumed for the following formulas.

For an order 1 universal portfolio will be:

M = number of asset, from i… to m

$$b_{n+1,k} = \xi_{n,1} \left(\sum_{i=1}^{m} x_{n,i} E[Y_k Y_i] \right) \tag{8}$$

for k = 1, 2, …, m and the normalizing constant, $\xi_{n,1}$ is:

$$\xi_{n,1} = \left[\sum_{k=1}^{m} \left(\sum_{i=1}^{m} x_{n,i} E[Y_k Y_i] \right) \right]^{-1} \tag{9}$$

For order 2 universal portfolio:

$$b_{n+1,k} = \xi_{n,2} \left(\sum_{i_1=1}^{m} \sum_{i_2=1}^{m} x_{n,i_1} x_{n-1,i_2} E\left[Y_k Y_{i_1} Y_{i_2} \right] \right) \tag{10}$$

for k = 1, 2, …, m and the normalizing constant $\xi_{n,2}$ is:

$$\xi_{n,2} = \left[\sum_{k=1}^{m} \left(\sum_{i_1=1}^{m} \sum_{i_2=1}^{m} x_{n,i_1} x_{n-1,i_2} E\left[Y_k Y_{i_1} Y_{i_2} \right] \right) \right]^{-1} \tag{11}$$

For order 3 universal portfolio:

$$b_{n+1,k} = \xi_{n,3}\left(\sum_{i_1=1}^{m}\sum_{i_2=1}^{m}\sum_{i_3=1}^{m} x_{n,i_1}\, x_{n-1,i_2} x_{n-2,i_3} E\left[Y_k Y_{i_1} Y_{i_2} Y_{i_3}\right]\right) \qquad (12)$$

for k = 1, 2, …, m and the normalizing constant $\xi_{n,2}$ is:

$$\xi_{n,3} = \left[\sum_{k=1}^{m}\left(\sum_{i_1=1}^{m}\sum_{i_2=1}^{m}\sum_{i_3=1}^{m} x_{n,i_1} x_{n-1,i_2} x_{n-2,i_3} E\left[Y_k Y_{i_1} Y_{i_2} Y_{i_3}\right]\right)\right]^{-1} \qquad (13)$$

Expanding the equation 12 and letting $v = 3$, we can get:

$$\frac{\sum_{i_1=1}^{m}\sum_{i_2=1}^{m}\sum_{i_v=1}^{m}\left(x_{ni_1} x_{n-1,i_2} \dots x_{n-v+1,i_v}\right) E\left[Y_{nk} Y_{ni_1} Y_{n-1,i_2} \dots Y_{n-v+i,i_v}\right]}{\sum_{j=1}^{m}\sum_{i_1=1}^{m}\sum_{i_2=1}^{m}\sum_{i_v=1}^{m}\left(x_{ni_1} x_{n-1,i_2} \dots x_{n-v+1,i_v}\right) E\left[Y_{nk} Y_{ni_1} Y_{n-1,i_2} \dots Y_{n-v+i,i_v}\right]} \qquad (14)$$

3.3 Brownian Motion

Definition 1.0: A stochastic process $\{X(t), t \geq 0\}$ is a Brownian motion process with drift of μ and variance parameter σ^2 if.

1. $X(0) = 0$,

2. $\{X(t), t \geq 0\}$ has stationary and independent increments.

3. for every $t > 0$, $X(t)$ is normally distributed with mean μt and variance $\sigma^2 t$, i.e., $X(t) \sim N(ut, \sigma^{2t})$.

When μ= 0, σ= 1, $\{X(t), t \geq 0\}$ is it called standard Brownian motion with $E\big(X(t)\big) = 0\ and\ V\big(X(t)\big) = t$.

Definition 1.1: A stochastic process $X(t), t \geq 0$ is called a normal process or a Gaussian process. or if $X(0), \dots,\ X(t)$ has a multivariate normal distribution for all $t_1, \dots, t_n$ where t is time.

Definition 1.2: A stochastic process $X(t), t \geq 0$ is a stationary process if for all $n, s,\ and\ t_1, \dots t_n$, the random vector $X(t_1), \dots,\ X(t_n)$ and $X(t_1 + s), \dots,\ X(t_n + s)$ have the same joint distribution.

Definition 1.3: A stochastic process $\{Y_{r1}\}_{r=1}^{\infty}$ is said to be weakly stationary if $E(Y_r) = \mu$, independent of the r and $cov\ (\mathrm{Y_r}, \mathrm{Y}_{r+s})$ does not depend on the r but depends on the time difference s only.

3.3.1 Brownian-motion Process Generated Universal Portfolio (BMUP)

From expansion of $b_{n+1,k}$, $E[Y_{s_1,i_1}Y_{s_2,i_2},\dots,Y_{s_ui_u}] = E[Y_{s_1,i_1}]E[Y_{s_2,i_2}],\dots,E[Y_{s_ui_u}]$ if the u integers $i_1,i_2,\dots,i_u$ are distinct. Otherwise $E[Y_{s_1,i_1}Y_{s_2,i_2},\dots,Y_{s_ui_u}]$ is determined by using the moment-generating function of $Y_{s_1,j}Y_{s_2,j},\dots,Y_{s_uj}$.

Since each Brownian is independent,

$$E\left[\left(Y_{s_1j}Y_{s_2j}\cdots Y_{s_uj}\right)\left(Y_{r_1k}Y_{r_2k}\cdots Y_{r_pk}\right)\right] = E\left[Y_{s_1j}Y_{s_2j}\cdots Y_{s_uj}\right]\times E\left[Y_{r_1k}Y_{r_2k}\ \cdots Y_{r_pk}\right] \quad (15)$$

for $j \neq k$.

We have

$$E\left[\prod_{i=1}^{q}\left(Y_{s_{i_1}j_i}Y_{s_{i_2}j_i}\cdots Y_{s_{i_{u_i}}j_i}\right)\right] = \prod_{i=1}^{q}E\left(Y_{s_{i_1}j_i}Y_{s_{i_2}j_i}\cdots Y_{s_{i_{u_i}}j_i}\right) \quad (16)$$

for any set of distinct integers $j_1,j_2,\dots,j_q$.

When $\{Y_{n1}\}_{n=1}^{\infty},\{Y_{n2}\}_{n=1}^{\infty},\cdots,\{Y_{nm}\}_{n=1}^{\infty}$, are independent Brownian motion (Winner process) with positive drift coefficients $\mu_1,\mu_2,\cdots,\mu_m$ and variance parameters $\sigma_1^2,\sigma_2^2,\dots,\sigma_m^2$. Ross (2007) suggested that the process$\{Y_{nl}\}$ has stationary and independent increments, where Y_{nl}has a gaussian distribution with mean $n\mu_l$ and variance $n\sigma_l^2$ $for\ l = 1,2,\dots,m$ and $n = 1,2,\dots$. The covariance of $Y_{\mathrm{n}_1 l}$ and $Y_{\mathrm{n}_2 l}$ is given by.

$$Cov\left(Y_{n_1l},Y_{n_2l}\right) = n_1\sigma_l^2 \text{ for } 0 < n_1 < n_2 \quad (17)$$

Furthermore, the random variables $Y_{n-\nu+1,l},Y_{n-\nu+2,l},\dots,Y_{n,l}$ have a joint multivariate normal distribution with mean vector $\mu l =$ and $\nu\times\nu$ covariance matrix.

$$K_l = \sigma_l^2 L = \sigma_l^2\left(\lambda_{ij}\right) \text{ for } l = 1,2,\dots,m \quad (18)$$

Where

$$\mu_{ik} = (n-\nu+k)\mu_i \text{ for } k = 1,2,\dots,\nu \quad (19)$$

And

$$\lambda_{ij} = \begin{cases} n-\nu+j, \text{if } i \leq j \\ n-\nu+j, \text{if } i > j \end{cases} \quad (20)$$

for $i,j = 1,2,\dots,\nu$.

Note that the lambda matrix $L = \left(\lambda_{ij}\right)$ in K_l does not depend on l. λ_{ij} are the covariance components of $Y_{n_1,l},\cdots,Y_{n_v,l}$ that depend on time n. The means μ_{ik} are nonnegative for $n \geq \nu = 1, k = 1,2,\dots,\nu$ and $l = 1,2,\dots,m$. Similarly, $\lambda_{ij} \geq 0$for all $i,j = 1,2,\dots,\nu$ if $n \geq \nu - 1$.

When $\nu = 1$ and $m = 3$, becomes:

$$b_{n+1}, k = \frac{x_{n,1}E(Y_{nk}Y_{n1}) + x_{n,2}E(Y_{nk}Y_{n2}) + x_{n,3}E(Y_{nk}Y_{n3})}{\sum_{j=1}^{3}\left[x_{n,1}E\left(Y_{nj}Y_{n1}\right) + x_{n,2}E\left(Y_{nj}Y_{n2}\right) + x_{n,3}E\left(Y_{nj}Y_{n3}\right)\right]} \quad (21)$$

For $k = 1,2.3$

Since the Brownian process are independent, when $\nu = 1$, we have.

$$E(Y_{nk}^2) = n(\sigma_k^2 + n\mu_k^2) \quad (22)$$

$$E(Y_{nk}Y_{ni}) = E(Y_{nk})E(Y_{ni}) = n^2\mu_k\mu_i \text{ for } k \neq i \quad (23)$$

$$E\left(Y_{nk}Y_{nj}\right) = E(Y_{nk})E\left(Y_{nj}\right) = n^2\mu_k\mu_j \text{ for } k \neq j \quad (24)$$

3.4 Software Configuration

This research will employ Python as the major tools to study data, simulate the portfolio, analyse and compare the results. Since the study aim to cover all combination of available listed company in each of the sampled economy major index during the pandemic period, the heavily computation work preparation must be addressed. To ensure one can achieve as efficient as this research, here are the major hardware and software configurations.

3.4.1 Hardware / Software setting

Core Hardware:

CPU: Intel core I7 -9700 8 core 8 thread

Ram: 16GB

Core software:

Operation System: Window 11

Anaconda Version: 2022 May released distribution

Programming Language: Python 3.9

Main Python Package:

Window: Numpy (version 1.21.5), Numba (version 0.55.2), Pandas (version 1.4.2), Pickle (version 4.0)

Linux (Window Subsystem WSL2): Numpy (version 1.23.4), Numba (version 0.51.2), Pandas (version 1.5.0), Pickle (version 4.0)

3.5 Data collection and Data Cleansing

The three economy (Malaysia, Singapore, Thailand) daily return are collected from open-source library (Yahoo Finance with python library). To ensure the parallel compatibility and stocks investable within pandemic period, this research only consider sample stocks that available from the beginning of 2020 to the end of June 2022. This research will include stock that available from any day 1st to 10th January 2020 to any day 20th to 30th June 2022. This method is aimed to include as many stock that available in the sample period as possible.

There are only 29 stocks out of 30 stocks from Malaysia KLCI component stocks, 28 stocks out of 30 stocks from Singapore Strait Time Index and 25 stocks out of top 30 stocks from Thailand SET 50 Index. The data clearing assumed survivorship bias, however, the stocks excluded is small in sample of Malaysia and Singapore and may bring some bias to Thailand's result.

This research assumes the stock price remain unchanged should the stock has no transaction during any sample period.

3.5.1 FTSE Bursa Malaysia KLCI

FTSE Bursa Malaysia KLCI is a capitalisation weighted index that consist of top 30 largest firms in Malaysia stock market, by market capitalisation. It is known as the representation of over Malaysia economy.

3.5.2 FTSE Straits Times Index

The Straits Times Index is a market capitalisation weighted index with top 30 companies listed in Singapore Stock Exchange. The performance of the index is representing the economy of Singapore and it has been referred to the "Beta" of Singapore Stock Market.

3.5.3 SET 50

SET 50 serve as a benchmark of investment in Thailand stock market. It is constituent by top 50 firms by market capitalization. It provides a benchmark for investment in Thailand stock market.

3.5.4 Sample period

This research aims to cover pandemic period and yet there is no formal definition of end of COVID-19 pandemic period, so this research covers the study to the end of June 2022 as more than half of global population received at least one dose vaccination according to global database (Mathieu et al., 2021). Most of the country have decided to relax the boarder restriction of even open their board to vaccinated personal.

The three economies studied in this research have also open their boarder to the globe at the end of sample period.

3.6 Portfolio construction

For each portfolio, it is constructed with combination of three stocks from respective country and assigning a range of stochastic Brownian motion with μ and σ. The objective of the portfolio is to maximizing portfolio return at the end investment period.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

The result is simulated based on the data collected and assumed zero slippage and zero transaction fee. Although the assumption is theoretical, this should not produce significant impact to the result since the stocks selected are index component listed company from respective economy, the liquidity of the stocks should be sufficient. The transaction fees would be small for institute trading as most institute trading arm since trading on the most liquid stock within the economy.

4.2 Simple Optimal Allocation

This research includes 29 stocks from Malaysia, 28 stocks from Singapore and 25 from Thailand. For each economy, this research includes all possible combinations and reasonable μ and σ parameter variation. With using different set of Brownian motion parameters of μ and σ for each portfolio, the performance of the portfolio can be found at the table below.

BMUP: Brownian Motion generated Universal Portfolio;
EWP: Equally Weight Portfolio.

Table 4.2.1: Return statistic of BMUP, EWP and Malaysia's benchmark.

	BMUP	EWP		Benchmark: KLCI
Count	3,654.0000	3,654.0000	Count	1.0000
Mean return	0.3313	0.1392	Return	- 0.0942
Min return	- 0.2543	- 0.2577		
Max return	1.3171	1.3014		
Return Std. Dev.	0.3443	0.2000		

Table 4.2.2: Return statistic of BMUP, EWP and Singapore's benchmark.

	BMUP	EWP		Benchmark: STI
Count	3,654.0000	3,654.0000	Count	1.0000
Mean return	0.3313	0.1392	Return	- 0.0942
Min return	- 0.2543	- 0.2577		
Max return	1.3171	1.3014		
Return Std. Dev.	0.3443	0.2000		

Table 4.2.3: Return statistic of BMUP, EWP and Thailand's benchmark.

	BMUP	EWP		Benchmark: SET50
Count	3,654.0000	3,654.0000	Count	1.0000
Mean return	0.3313	0.1392	Return	- 0.0942
Min return	- 0.2543	- 0.2577		
Max return	1.3171	1.3014		
Return Std. Dev.	0.3443	0.2000		

From the simple statistic above, we can notice that the Brownian motion generated portfolio mean return is higher than benchmark (respective index within each economy, i.e., KLCI for Malaysia, SIT for Singapore and SET for Thailand) and traditional equally weighted portfolio.

Further investigate of each portfolio abovementioned within each economy, this research finds that some portfolios perform extremely good or terribly bad as the portfolio lack of diversification since the combination may taking 3 stocks that perform consistently bad and lead to worst result. To minimize overconcentration risk, the further research may include more stocks into single portfolio.

Besides, this research further investigate the risk profile of the portfolios above, including Sharpe ratio, Sortino ratio and Maximum D

Table 4.2.4: Top 5 Losing and Top 5 Wining BMUP of Malaysia's stock.

Stock 1	Stock 2	Stocl 3	μ_1, μ_2, μ_3	$\sigma_1, \sigma_2, \sigma_3$	Final Wealth Grow
Tenaga Nasional Bhd	Maxis Bhd	Hartalega Holdings Bhd	9, 7, 5	0.5625, 1.0000, 0.0100	-0.2543
Tenaga Nasional Bhd	Maxis Bhd	Dialog Group Bhd	1, 3, 7	0.2500, 1.0000, 0.0100	-0.2329
Maxis Bhd	Dialog Group Bhd	Hartalega Holdings Bhd	5, 9, 3	1.0000, 0.0900, 0.0100	-0.2329
Tenaga Nasional Bhd	Dialog Group Bhd	Hartalega Holdings Bhd	5, 9, 3	1.0000, 0.9025, 0.0100	-0.2289
Maxis Bhd	Top Glove Corp Bhd	Hartalega Holdings Bhd	7, 9, 1	1.0000, 0.0625, 0.0100	-0.2096
Sime Darby Plantation Bhd	Telekom Malaysia Bhd	Inari Amertron Bhd	1, 7, 9	1.0000, 0.0100, 0.9025	1.2707
RHB Bank Bhd	Telekom Malaysia Bhd	Inari Amertron Bhd	1, 7, 9	0.0100, 0.0225, 1.0000	1.2743
Genting Malaysia Bhd	Telekom Malaysia Bhd	Inari Amertron Bhd	1, 7, 9	1.0000, 0.0100, 0.9025	1.2764
MISC Bhd	Telekom Malaysia Bhd	Inari Amertron Bhd	1, 7, 9	0.0100, 0.0225, 1.0000	1.2817
Telekom Malaysia Bhd	Press Metal Aluminium Holdings Bhd	Inari Amertron Bhd	5, 3, 7	0.0100, 0.0225, 1.0000	1.3171

Table 4.2.5: Top 5 Losing and Top 5 Wining BMUP of Singapore's stock.

Stock 1	Stock 2	Stock 3	μ_1, μ_2, μ_3	$\sigma_1, \sigma_2, \sigma_3$	Final Wealth Grow
ComfortDelGro Corporation Limited	DFI Retail Group Holdings Limited	Genting Singapore Limited	5, 1, 9	0.0100, 0.0225, 1.0000	-0.2137
ComfortDelGro Corporation Limited	SATS Ltd.	DFI Retail Group Holdings Limited	3 ,9, 1	0.0625, 0.9025, 0.0100	-0.1842
ComfortDelGro Corporation Limited	DFI Retail Group Holdings Limited	Jardine Matheson Holdings Limited	3, 1, 9	1.0000, 0.0900, 0.0100	-0.1778
SATS Ltd.	DFI Retail Group Holdings Limited	Genting Singapore Limited	9, 1, 7	0.0100, 0.0225, 1.0000	-0.1567
DFI Retail Group Holdings Limited	Jardine Matheson Holdings Limited	Genting Singapore Limited	1, 9, 7	0.0100, 0.0225, 1.0000	-0.1515
Thai Beverage Public Company Limited	Keppel DC REIT	Wilmar International Limited	9, 3, 1	0.9025, 0.0400, 0.0100	5.5287
Mapletree Industrial Trust	Thai Beverage Public Company Limited	Keppel DC REIT	1, 9, 3	0.0100, 1.0000, 0.0225	5.5407
Thai Beverage Public Company Limited	Keppel DC REIT	Mapletree Logistics Trust	9, 3, 1	1.0000, 0.0400, 0.0100	5.5490
Thai Beverage Public Company Limited	Keppel DC REIT	Frasers Logistics & Commercial Trust	9, 3, 1	0.9025, 0.0400, 0.0100	5.5632
Thai Beverage Public Company Limited	Sembcorp Industries Ltd	Keppel DC REIT	9, 1, 3	1.0000, 0.0225, 0.0100	5.5737

Table 4.2.6: Top 5 Losing and Top 5 Wining BMUP of Thailand's stock.

Stock 1	Stock 2	Stock 3	μ_1, μ_2, μ_3	$\sigma_1, \sigma_2, \sigma_3$	Final Wealth Grow
PTT Global Chemical Public Company Limited	IRPC Public Company Limited	Bangkok Bank Public Company Limited	9, 1, 7	0.9025, 0.0225, 0.0100	-0.1929
Electricity Generating Public Company Limited	IRPC Public Company Limited	Bangkok Bank Public Company Limited	9, 1, 5	1.0000, 0.0225, 0.0100	-0.1871
Electricity Generating Public Company Limited	PTT Global Chemical Public Company Limited	IRPC Public Company Limited	9, 7, 1	0.0225, 1.0000, 0.0100	-0.1732
Electricity Generating Public Company Limited	PTT Global Chemical Public Company Limited	Bangkok Bank Public Company Limited	7, 9, 3	0.7225, 1.0000, 0.0100	-0.1711
Electricity Generating Public Company Limited	IRPC Public Company Limited	Ratch Group Public Company Limited	3, 1, 9	0.0625, 0.0100, 1.0000	-0.1458
Bangkok Commercial Asset Management Public Company Limited	Delta Electronics (Thailand) Public Company Limited	Com7 Public Company Limited	1, 9, 3	0.9025, 1.0000, 0.0100	5.1032
KCE Electronics Public Company Limited	Delta Electronics (Thailand) Public Company Limited	Com7 Public Company Limited	1, 9, 7	0.9025, 0.0100, 1.0000	5.1244
Gulf Energy Development Public Company Limited	Delta Electronics (Thailand) Public Company Limited	Com7 Public Company Limited	1, 9, 7	0.9025, 0.0100, 1.0000	5.1292
Delta Electronics (Thailand) Public Company Limited	Carabao Group Public Company Limited	Com7 Public Company Limited	9, 1, 7	0.0400, 1.0000, 0.9025	5.2120
Bangkok Commercial Asset Management Public Company Limited	KCE Electronics Public Company Limited	Delta Electronics (Thailand) Public Company Limited	1, 3, 9	0.9025, 0.0100, 1.0000	5.3151

Based on the top winning and losing portfolios from each economy, it is intuitive to show that the portfolio tend to perform as good as the heaviest invested stock. By the methodtology of the Brownian motion generated portfolio, the higher μ and σ on stock that has positive return within the portoflio, it tend to drive positive return to the portfolio.

The higher the σ, in fact, assist to provide more weight to the stock within the portfolio. μ plays the most important role in driving the portfolio. It is the majot contributor in deciding the weight of stock should be invested within the portfolio. Stocks that have high μ tend to have high σ as well for winning portfolio. It is same for losing portfolio since investing more in losing stock within portfolio.

According to the discussion above, the top five winning portfolio and top five losing portfolio are just follow the same logic, which invest heavily in stocks that win or lose the most with high μ and σ. However, the positive ssde of the result shows that the winning portfolio are perform more superior than the losing portfolio.

Table 4.2.7: Risk profile of BMUP, EWP and Malaysia's benchmark.

	BMUP	EWP		Benchmark
Sharpe	**0.0197	**0.0107	Sharpe	- 0.0170
Std Dev	0.0166	0.0159	Sortino	- 0.0234
Sortino	**0.0279	**0.0149	Maximum Drawdown	- 0.2431
Std Dev	0.0251	0.0226		
Maximum Drawdown	- 0.3176	- 0.3186		
Std Dev	0.0892	0.0940		

Table 4.2.8: Risk profile of BMUP, EWP and Singapore's benchmark.

	BMUP	EWP		Benchmark
Sharpe	**0.0330	*0.0236	Sharpe	- 0.0052
Std Dev	0.0153	0.0202	Sortino	- 0.0061
Sortino	0.0529	0.0339	Maximum Drawdown	- 0.3193
Std Dev	0.0497	0.0367		
Maximum Drawdown	- 0.3635	- 0.3650		
Std Dev	0.0788	0.0640		

Table 4.2.9: Risk profile of BMUP, EWP and Thailand benchmark.

	BMUP	EWP		Benchmark
Sharpe	**0.0395	**0.0302	Sharpe	- 0.0008
Std Dev	0.0218	0.0216	Sortino	- 0.0008
Sortino	**0.0526	*0.0381	Maximum Drawdown	- 0.3599
Std Dev	0.0306	0.0283		
Maximum Drawdown	- 0.4413	- 0.4285		
Std Dev	0.0772	0.0724		

** One tail greater than benchmark significant at 10% and 5%

* One tail greater than benchmark significant at 10%

Based on the risk profile above, BMUP's shape ratio outperform their benchmark to respective economy. Malaysia and Thailand BMUP show significant positive Sortino ratio compared to their benchmark. Maximum drawdown of BMUP from three economy show indifference compared to respective benchmark. The risk profile between BMUP and EWP are similar.

Overall, good parameter choice can lead to a good investment result and satisfactory risk profile. The result shows BMUP is the better choice among the strategy above-mentioned. The return, although not statistical proved significant, but the mean return is higher than benchmark and EWP. Besides, BMUP shows significant outperforming risk profile compares to benchmark, almost indifference with EWP. BMUP provides better mean return, mean shape ratio and mean sortino ratio, hence, a better choice for investment strategy.

4.3 Follow the Winner and Follow the Loser Strategy

To further improve the work, this research attempt to introduce dynamic BMUP parameters μ and σ variation throughout the investment period. Taking order 1 data as input knowledge and allocate most weight to the highest one day return or the opposite. The rationale of such setting is to utilise one day information to allocate μ and σ for one day investment and boost the fund allocation by including more standard deviation to well-performed stock relative to less-performed stock in the portfolio.

Such parameter tuning is attempting to closer the gap between theorical study and practical portfolio investment. The strategy aims to allocate more weight to either winner or loser stock based on the strategy within each portfolio in hope to capture the capital gain with the given information. For Follow the Winner, the algorithm identifies one day relative return and assign more weight to the winner and lesser to others, least to the loser. Follow the Loser do the opposite.

In the simulated strategy below, the weight allocation (μ) for next investment period is as below.

Table 4.3.1: Weight allocation for Follow the Winner and Follow the loser strategy.

		Weight Allocate		
Strategy	Sub strategy	Top Winner	Mid	Top Loser
Follow the Winner	Extreme Winner	10	1	1
	Medium Winner	10	5	1
Follow the Loser	Extreme Loser	1	1	10
	Medium Loser	1	5	10

Standard deviation is rather static, this research takes the one-day relative return to worst performing stock within respective portfolio to the power of its weight above. However, the number is rather small and negligible. The weight allocated are the main driver for the investment return.

For Follow the Winner Strategy:

$$\sigma_{i,n+1} = \left(\frac{x_{i,n}}{\min(x_{1,n}, x_{2,n}, x_{3,n})}\right)^{weight\ allocate} \tag{25}$$

For Follow the Loser Strategy:

$$\sigma_{i,n+1} = \left(\frac{\max(x_{1,n}, x_{2,n}, x_{3,n})}{\mathrm{x_{i,n}}}\right)^{weight\ allocate} \tag{26}$$

If given $x_{i,n}$ (where $i = 1,2,3$) is the top winner of the day within portfolio, the power of the equation above is 10 for top winner under Extreme Winner, 1 for middle winner, 1 for the loser of the day, where $x_{i,n}$ is the one-day relative return of stock i in day n. Such setting is to provide more weight for top winner (under Extreme Winner), to enhance the idea of the strategy.

Table 4.3.2: Return statistic of Follow the Winner and Follow the Loser of Malaysia's stocks.

	Extreme Win	Medium Win	Extreme Lose	Medium Lose		Benchmark
Count	3654.0000				Count	1.0000
Mean return	- 0.2276	- 0.1656	0.5852	0.4401	Return	- 0.0942
Min return	- 0.8011	- 0.6932	- 0.5691	- 0.5307		
Max return	1.8905	1.2982	3.2233	2.3469		
Return Std. Dev.	0.3583	0.2844	0.5895	0.4131		

Table 4.3.3: Return statistic of Follow the Winner and Follow the Loser of Singapore's stocks.

	Extreme Win	Medium Win	Extreme Lose	Medium Lose		Benchmark
Count	3276.0000				Count	1.0000
Mean return	- 0.0740	- 0.0441	0.3015	0.2367	Return	- 0.0360
Min return	- 0.7209	- 0.5745	- 0.5736	- 0.4642		
Max return	1.2595	0.8503	3.5324	2.0797		
Return Std. Dev.	0.2460	0.1825	0.5212	0.3739		

Table 4.3.4: Return statistic of Follow the Winner and Follow the Loser of Thailand's stocks.

	Extreme Win	Medium Win	Extreme Lose	Medium Lose		Benchmark
Count	2300.0000				Count	1.0000
Mean return	0.3755	0.3274	0.6971	0.5806	Return	- 0.0060
Min return	- 0.6646	- 0.5436	- 0.4805	- 0.3485		
Max return	6.7228	4.3114	5.6559	3.7981		
Return Std. Dev.	1.0331	0.6981	0.7766	0.5577		

Table 4.3.5: Top 5Winning and Losing portfolio Follow the Winner (Extreme Winner) of Malaysia's stocks.

Stock 1	Stock 2	Stock 3	Return
Tenaga Nasional Bhd	Maxis Bhd	Petronas Dagangan Bhd	-0.8011
Maxis Bhd	Petronas Dagangan Bhd	Sime Darby Bhd	-0.7949
Maxis Bhd	Dialog Group Bhd	Petronas Dagangan Bhd	-0.7855
Dialog Group Bhd	Petronas Dagangan Bhd	Sime Darby Bhd	-0.7789
PPB Group Bhd	Petronas Dagangan Bhd	Sime Darby Bhd	-0.7771
Petronas Dagangan Bhd	Press Metal Aluminium Holdings Bhd	Hartalega Holdings Bhd	1.3858
RHB Bank Bhd	Press Metal Aluminium Holdings Bhd	Hartalega Holdings Bhd	1.4510
Press Metal Aluminium Holdings Bhd	Nestle Malaysia Bhd	Hartalega Holdings Bhd	1.6399
Telekom Malaysia Bhd	Press Metal Aluminium Holdings Bhd	Hartalega Holdings Bhd	1.6708
Hong Leong Bank Bhd	Press Metal Bhd	Hartalega Holdings Berhad	1.8905

Table 4.3.6: Top 5Winning and Losing portfolio Follow the Winner (Extreme Winner) of Singapore's stocks.

Stock 1	Stock 2	Stock 3	Return
ComfortDelGro Corporation Limited	Sembcorp Industries Ltd	Singapore Telecommunications Limited	-0.7209
ComfortDelGro Corporation Limited	UOL Group Limited	Sembcorp Industries Ltd	-0.7151
ComfortDelGro Corporation Limited	Sembcorp Industries Ltd	Jardine Matheson Holdings Limited	-0.6871
ComfortDelGro Corporation Limited	Sembcorp Industries Ltd	City Developments Limited	-0.6643
ComfortDelGro Corporation Limited	Sembcorp Industries Ltd	Genting Singapore Limited	-0.6584
Thai Beverage Public Company Limited	Sembcorp Industries Ltd	Mapletree Logistics Trust	0.8162
Sembcorp Industries Ltd	Venture Corporation Limited	Mapletree Logistics Trust	0.8617
Mapletree Industrial Trust	Sembcorp Industries Ltd	Jardine Cycle & Carriage Limited	0.8867
Sembcorp Industries Ltd	Keppel DC REIT	Yangzijiang Shipbuilding (Holdings) Ltd.	1.0003
Sembcorp Industries Ltd	Mapletree Logistics Trust	Yangzijiang Shipbuilding (Holdings) Ltd.	1.2595

Table 4.3.7: Top 5Winning and Losing portfolio Follow the Winner (Extreme Winner) of Thailand's stocks.

Stock 1	Stock 2	Stock 3	Return
Charoen Pokphand Foods Public Company Limited	Carabao Group Public Company Limited	Ratch Group Public Company Limited	-0.6646
Electricity Generating Public Company Limited	Charoen Pokphand Foods Public Company Limited	Ratch Group Public Company Limited	-0.6540
Electricity Generating Public Company Limited	Bangkok Commercial Asset Management Public Company Limited	Ratch Group Public Company Limited	-0.6282
Electricity Generating Public Company Limited	Osotspa Public Company Limited	Ratch Group Public Company Limited	-0.6158
Electricity Generating Public Company Limited	Total Access Communication Public Company Limited	Carabao Group Public Company Limited	-0.6065
Total Access Communication Public Company Limited	KCE Electronics Public Company Limited	Delta Electronics (Thailand) Public Company Limited	5.9900
Gulf Energy Development Public Company Limited	KCE Electronics Public Company Limited	Delta Electronics (Thailand) Public Company Limited	6.0458
PTT Global Chemical Public Company Limited	Central Pattana Public Company Limited	Delta Electronics (Thailand) Public Company Limited	6.4015
Central Pattana Public Company Limited	KCE Electronics Public Company Limited	Delta Electronics (Thailand) Public Company Limited	6.5552
Central Pattana Public Company Limited	Delta Electronics (Thailand) Public Company Limited	Com7 Public Company Limited	6.7228

Table 4.3.8: Top 5 Losing and Top 5 Wining portfolio Follow the Wining (Medium Winner) of Malaysia's stocks.

Stock 1	Stock 2	Stock 3	Return
Maxis Berhad	Petronas Dagangan Bhd	Sime Darby Berhad	-0.6932
Tenaga Nasional Berhad	Maxis Berhad	Petronas Dagangan Bhd	-0.6891
Maxis Berhad	Dialog Group Berhad	Petronas Dagangan Bhd	-0.6817
SIMEPLT	Maxis Berhad	Sime Darby Berhad	-0.6792
Maxis Berhad	Petronas Dagangan Bhd	DiGi.Com Berhad	-0.6782
Public Bank Berhad	Press Metal Bhd	Hartalega Holdings Berhad	1.0685
PCHEM	Press Metal Bhd	Hartalega Holdings Berhad	1.1138
Telekom Malaysia Berhad	Press Metal Bhd	Top Glove Corporation Berhad	1.1139
Telekom Malaysia Berhad	Press Metal Bhd	Hartalega Holdings Berhad	1.2514
Hong Leong Bank Berhad	Press Metal Bhd	Hartalega Holdings Berhad	1.2982

Table 4.3.9: Top 5 Losing and Top 5 Wining portfolio Follow the Wining (Medium Winner) of Singapore's stocks.

Stock 1	Stock 2	Stock 3	Return
ComfortDelGro Corporation Limited	Sembcorp Industries Ltd	Singapore Telecommunications Limited	-0.5745
ComfortDelGro Corporation Limited	Sembcorp Industries Ltd	Genting Singapore Limited	-0.5510
ComfortDelGro Corporation Limited	Sembcorp Industries Ltd	Jardine Matheson Holdings Limited	-0.5386
ComfortDelGro Corporation Limited	Sembcorp Industries Ltd	City Developments Limited	-0.5371
ComfortDelGro Corporation Limited	Genting Singapore Limited	Singapore Telecommunications Limited	-0.5118
Singapore Exchange Limited	DBS Group Holdings Ltd	Frasers Logistics & Commercial Trust	0.5365
Mapletree Industrial Trust	Sembcorp Industries Ltd	Yangzijiang Shipbuilding (Holdings) Ltd.	0.5718
Sembcorp Industries Ltd	Singapore Exchange Limited	Yangzijiang Shipbuilding (Holdings) Ltd.	0.6060
Sembcorp Industries Ltd	Keppel DC REIT	Yangzijiang Shipbuilding (Holdings) Ltd.	0.6759
Sembcorp Industries Ltd	Mapletree Logistics Trust	Yangzijiang Shipbuilding (Holdings) Ltd.	0.8503

Table 4.3.10: Top 5 Losing and Top 5 Wining portfolio Follow the Wining (Medium Winner) of Thailand's stocks.

Stock 1	Stock 2	Stock 3	Return
Electricity Generating Public Company Limited	Charoen Pokphand Foods Public Company Limited	Ratch Group Public Company Limited	-0.5436
Electricity Generating Public Company Limited	Total Access Communication Public Company Limited	Ratch Group Public Company Limited	-0.5346
Electricity Generating Public Company Limited	Bangkok Commercial Asset Management Public Company Limited	Ratch Group Public Company Limited	-0.5270
Electricity Generating Public Company Limited	Osotspa Public Company Limited	Ratch Group Public Company Limited	-0.5096
Charoen Pokphand Foods Public Company Limited	Carabao Group Public Company Limited	Ratch Group Public Company Limited	-0.4827
Bumrungrad Hospital Public Company Limited	Delta Electronics (Thailand) Public Company Limited	Com7 Public Company Limited	3.4950
Central Pattana Public Company Limited	Delta Electronics (Thailand) Public Company Limited	Com7 Public Company Limited	3.5634
KCE Electronics Public Company Limited	Delta Electronics (Thailand) Public Company Limited	Com7 Public Company Limited	4.0517
Total Access Communication Public Company Limited	KCE Electronics Public Company Limited	Delta Electronics (Thailand) Public Company Limited	4.0841
Central Pattana Public Company Limited	KCE Electronics Public Company Limited	Delta Electronics (Thailand) Public Company Limited	4.3114

Table 4.3.11: Top 5 Losing and Top 5 Wining portfolio Follow the Loser (Extreme Loser) of Malaysia's stocks.

Stock 1	Stock 2	Stock 3	Return
Tenaga Nasional Berhad	Genting Berhad	Hartalega Holdings Berhad	-0.5691
Tenaga Nasional Berhad	Dialog Group Berhad	Hartalega Holdings Berhad	-0.5683
IHH Healthcare Berhad	Genting Berhad	Top Glove Corporation Berhad	-0.5664
Tenaga Nasional Berhad	Hong Leong Bank Berhad	Hartalega Holdings Berhad	-0.5653
PPB Group Berhad	Tenaga Nasional Berhad	Hartalega Holdings Berhad	-0.5523
Maxis Berhad	Petronas Dagangan Bhd	Sime Darby Berhad	2.7428
SIMEPLT	PCHEM	Sime Darby Berhad	2.7449
Malayan Banking Berhad	Petronas Dagangan Bhd	Sime Darby Berhad	2.9537
Maxis Berhad	Petronas Dagangan Bhd	DiGi.Com Berhad	2.9676
Petronas Dagangan Bhd	PCHEM	Sime Darby Berhad	3.2234

Table 4.3.12: Top 5 Losing and Top 5 Wining portfolio Follow the Loser (Extreme Loser) of Singapore's stocks.

Stock 1	Stock 2	Stock 3	Return
SATS Ltd.	DFI Retail Group Holdings Limited	Keppel DC REIT	-0.5736
DFI Retail Group Holdings Limited	Singapore Telecommunications Limited	CapitaLand Integrated Commercial Trust	-0.5700
Mapletree Industrial Trust	SATS Ltd.	DFI Retail Group Holdings Limited	-0.5642
DFI Retail Group Holdings Limited	United Overseas Bank Limited	Keppel DC REIT	-0.5486
DFI Retail Group Holdings Limited	Keppel Corporation Limited	Keppel DC REIT	-0.5448
Thai Beverage Public Company Limited	Sembcorp Industries Ltd	Frasers Logistics & Commercial Trust	3.1490
Thai Beverage Public Company Limited	Sembcorp Industries Ltd	United Overseas Bank Limited	3.1844
Thai Beverage Public Company Limited	Sembcorp Industries Ltd	Singapore Technologies Engineering Ltd	3.2656
Thai Beverage Public Company Limited	Sembcorp Industries Ltd	Hongkong Land Holdings Limited	3.3593
ComfortDelGro Corporation Limited	Thai Beverage Public Company Limited	Sembcorp Industries Ltd	3.5324

Table 4.3.13: Top 5 Losing and Top 5 Wining portfolio Follow the Loser (Extreme Loser) of Thailand's stocks.

Stock 1	Stock 2	Stock 3	Return
PTT Global Chemical Public Company Limited	Osotspa Public Company Limited	Bangkok Bank Public Company Limited	-0.4805
PTT Global Chemical Public Company Limited	Minor International Public Company Limited	Ratch Group Public Company Limited	-0.4772
PTT Global Chemical Public Company Limited	Bumrungrad Hospital Public Company Limited	Osotspa Public Company Limited	-0.4280
PTT Global Chemical Public Company Limited	Minor International Public Company Limited	Osotspa Public Company Limited	-0.4261
Electricity Generating Public Company Limited	PTT Global Chemical Public Company Limited	Krungthai Card Public Company Limited	-0.4126
Delta Electronics (Thailand) Public Company Limited	Carabao Group Public Company Limited	Thai Union Group Public Company Limited	5.0952
Delta Electronics (Thailand) Public Company Limited	Indorama Ventures Public Company Limited	Thai Union Group Public Company Limited	5.3148
Delta Electronics (Thailand) Public Company Limited	Carabao Group Public Company Limited	Com7 Public Company Limited	5.4408
Energy Absolute Public Company Limited	Delta Electronics (Thailand) Public Company Limited	Thai Union Group Public Company Limited	5.6478
Krungthai Card Public Company Limited	Energy Absolute Public Company Limited	Delta Electronics (Thailand) Public Company Limited	5.6559

Table 4.3.14: Top 5 Losing and Top 5 Wining portfolio Follow the Loser (Medium Loser) of Malaysia's stocks.

Stock 1	Stock 2	Stock 3	Return
Tenaga Nasional Berhad	Genting Berhad	Hartalega Holdings Berhad	-0.5307
Tenaga Nasional Berhad	Dialog Group Berhad	Hartalega Holdings Berhad	-0.4931
Dialog Group Berhad	Genting Berhad	Hartalega Holdings Berhad	-0.4774
Genting Malaysia Berhad	Dialog Group Berhad	Hartalega Holdings Berhad	-0.4664
Tenaga Nasional Berhad	Public Bank Berhad	Hartalega Holdings Berhad	-0.4523
Petronas Gas Bhd	Petronas Dagangan Bhd	PCHEM	1.8021
Malayan Banking Berhad	Petronas Dagangan Bhd	Sime Darby Berhad	1.8182
Petronas Gas Bhd	Petronas Dagangan Bhd	Sime Darby Berhad	1.8895
PPB Group Berhad	Petronas Dagangan Bhd	PCHEM	1.9288
Petronas Dagangan Bhd	PCHEM	Sime Darby Berhad	2.3469

Table 4.3.15: Top 5 Losing and Top 5 Wining portfolio Follow the Wining (Medium Loser) of Singapore's stocks.

Stock 1	Stock 2	Stock 3	Return
DFI Retail Group Holdings Limited	United Overseas Bank Limited	Singapore Telecommunications Limited	-0.4642
SATS Ltd.	DFI Retail Group Holdings Limited	Singapore Telecommunications Limited	-0.4638
DFI Retail Group Holdings Limited	Singapore Telecommunications Limited	CapitaLand Integrated Commercial Trust	-0.4559
Mapletree Pan Asia Commercial Trust	DFI Retail Group Holdings Limited	Singapore Telecommunications Limited	-0.4533
DFI Retail Group Holdings Limited	Keppel DC REIT	Singapore Telecommunications Limited	-0.4436
Thai Beverage Public Company Limited	Sembcorp Industries Ltd	Jardine Cycle & Carriage Limited	1.9377
Thai Beverage Public Company Limited	Sembcorp Industries Ltd	United Overseas Bank Limited	1.9438
Thai Beverage Public Company Limited	Sembcorp Industries Ltd	Oversea-Chinese Banking Corporation Limited	2.0002
ComfortDelGro Corporation Limited	Thai Beverage Public Company Limited	Sembcorp Industries Ltd	2.0516
Thai Beverage Public Company Limited	Sembcorp Industries Ltd	Hongkong Land Holdings Limited	2.0791

Table 4.3.16: Top 5 Losing and Top 5 Wining portfolio Follow the Wining (Medium Loser) of Thailand's stocks.

Stock 1	Stock 2	Stock 3	Return
Electricity Generating Public Company Limited	PTT Global Chemical Public Company Limited	CP ALL Public Company Limited	-0.3485
Electricity Generating Public Company Limited	PTT Global Chemical Public Company Limited	Bangkok Bank Public Company Limited	-0.3363
PTT Global Chemical Public Company Limited	Ratch Group Public Company Limited	CP ALL Public Company Limited	-0.3318
Electricity Generating Public Company Limited	PTT Global Chemical Public Company Limited	Ratch Group Public Company Limited	-0.3265
PTT Global Chemical Public Company Limited	Bangkok Bank Public Company Limited	CP ALL Public Company Limited	-0.3189
Delta Electronics (Thailand) Public Company Limited	Carabao Group Public Company Limited	Com7 Public Company Limited	3.3435
KCE Electronics Public Company Limited	Delta Electronics (Thailand) Public Company Limited	Carabao Group Public Company Limited	3.3463
Energy Absolute Public Company Limited	Delta Electronics (Thailand) Public Company Limited	Carabao Group Public Company Limited	3.3802
Krungthai Card Public Company Limited	Energy Absolute Public Company Limited	Delta Electronics (Thailand) Public Company Limited	3.4013
Energy Absolute Public Company Limited	Delta Electronics (Thailand) Public Company Limited	Thai Union Group Public Company Limited	3.7981

Table 4.3.17: Follow the Wining and Follow the Loser portfolio risk profile of Malaysia's stocks.

	Extreme Win	Medium Win	Extreme Lose	Medium Lose		Benchmark
Sharpe	- 0.0383	- 0.0295	* 0.0404	* 0.0371	Sharpe	- 0.0170
Std Dev	0.0430	0.0366	0.0389	0.0341	Sortino	- 0.0234
Sortino	- 0.0520	- 0.0406	* 0.0589	* 0.0537	Maximum Drawdown	- 0.2431
Std Dev	0.0597	0.0518	0.0576	0.0506		
Maximum Drawdown	- 0.4825	- 0.4068	- 0.3246	- 0.2971		
Std Dev	0.1307	0.1079	0.1439	0.1176		

* One tail greater than benchmark significant at 10%

Table 4.3.18: Follow the Wining and Follow the Loser portfolio risk profile of Singapore's stocks.

	Extreme Win	Medium Win	Extreme Lose	Medium Lose		Benchmark
Sharpe	- 0.0097	- 0.0058	0.0154	0.0153	Sharpe	- 0.0052
Std Dev	0.0263	0.0212	0.0286	0.0247	Sortino	- 0.0061
Sortino	- 0.0121	- 0.0073	0.0256	0.0233	Maximum Drawdown	- 0.3193
Std Dev	0.0362	0.0285	0.0463	0.0384		
Maximum Drawdown	- 0.3689	- 0.3498	- 0.3901	- 0.3706		
Std Dev	0.0962	0.0785	0.0684	0.0554		

Table 4.3.19: Follow the Wining and Follow the Loser portfolio risk profile of Thailand's stocks.

	Extreme Win	Medium Win	Extreme Lose	Medium Lose		Benchmark
Sharpe	0.0057	0.0111	0.0312	*0.0317	Sharpe	- 0.0008
Std Dev	0.0315	0.0277	0.0274	0.0238	Sortino	- 0.0008
Sortino	0.0095	0.0158	0.0398	*0.0395	Maximum Drawdown	- 0.3599
Std Dev	0.0441	0.0380	0.0351	0.0300		
Maximum Drawdown	- 0.4403	- 0.4033	- 0.4246	- 0.4071		
Std Dev	0.0859	0.0725	0.0856	0.0721		

* One tail greater than benchmark significant at 10%

The risk profile suggests that Follow the Winner risk profile is indifference compared to benchmark. Follow the Loser strategy is able achieve significant beating the benchmark's risk profile.

4.4 Summary

The BMUP strategy can produce a higher than benchmark mean return although no significant proved but statistically significant better risk profile. With right parameter choice, one shall be able to produce similar result. However, the choice of parameter can be extremely difficult.

This research attempted to solve such difficulties by looking at previous investment period of winner and loser. This study provide the BMUP to a more practical universal portfolio investment and its mean return able to beat the benchmark. The risk profile with such strategy provides some possible significant result on 10% and 5% p-values on Malaysia and Thailand Follow the Loser (Extreme Loser and Medium Loser weight allocation). The results are encouraging as this a rather practical and this research able to achieve better statistical proven positive Shape and Sortino ratio.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This research shows that Brownian motion generated universal portfolio during COVID-19 period can easily beat the market and traditional investment strategy. The result shows consistent among three countries. Also, this research explores the dynamic μ and σ parameter setting with order 1 information.

This study utilities the properties of Brownian Motion to construct follow the winner and follow the loser strategy. Providing the research objective, a more practical point of view rather than searching a list of optimal Brownian motion parameter that accumulated largest amount of wealth. Follow the winner or loser allocation fund according to order 1 BMUP performance rather than optimize the choice of parameter throughout time series data, it avoids forward looking bias. As a result, follow the loser strategy deliver a similar result as simple optimal allocation, and it also suggest that one should further investigate the BMUP order 1 with more stocks data to refine more information.

Simple Optimal Allocation has better mean return than follow the winner and follow the loser. Besides, the risk profile of simple allocation is generally significant and follow the loser strategy can attain significant positive ratio in Malaysia and Thailand. This is the first ever attempt for strategy Follow the Loser with BMUP parameters . Although Follow the Loser with parameters μ and σ mean return is less than Simple Optimal Allocation and worse risk profile ratio, it is more practical and portfolio manager can replicate this strategy easily.

The final wealth remains as the major objective function but not the only one as the practical investor also keen in the risk profile of portfolio in making investment decision.

5.2 Recommendations for future work

The future study can form portfolio with more stock to achieve diversification. Also, the relevant study should consider more practical metric to evaluate the performance of a portfolio. The future study can optimize the portfolio with multiple objectives, to beat the market not only in term of final wealth but also based on risk profile.

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APPENDICES

Appendix A: List of Stock Pool from Malaysia

6888.KL	Axiata Group Berhad
1066.KL	RHB Capital Berhad
4065.KL	PPB Group Berhad
5285.KL	SIMEPLT
5347.KL	Tenaga Nasional Berhad
3816.KL	MISC
6012.KL	Maxis Berhad
1155.KL	Malayan Banking Berhad
4715.KL	Genting Malaysia Berhad
6033.KL	Petronas Gas Bhd
5225.KL	IHH Healthcare Berhad
7277.KL	Dialog Group Berhad
5296.KL	*MRDIY*
5819.KL	Hong Leong Bank Berhad
1082.KL	Hong Leong Financial Group Berhad
2445.KL	Kuala Lumpur Kepong Berhad
4863.KL	Telekom Malaysia Berhad
5681.KL	Petronas Dagangan Bhd
3182.KL	Genting Berhad
5183.KL	PCHEM
1295.KL	Public Bank Berhad
8869.KL	Press Metal Bhd
4197.KL	Sime Darby Berhad
1023.KL	CIMB Group Holdings Berhad
4707.KL	NestlÃ© (Malaysia) Berhad
0166.KL	INARI
1961.KL	IOI Corp.Bhd
7113.KL	Top Glove Corporation Berhad
6947.KL	DiGi.Com Berhad
5168.KL	Hartalega Holdings Berhad

Appendix B: List of Stock Pool from Singapore

C52.SI	ComfortDelGro Corporation Limited
ME8U.SI	Mapletree Industrial Trust
Y92.SI	Thai Beverage Public Company Limited
N2IU.SI	Mapletree Commercial Trust
YF8.SI	*Yangzijiang Financial Holding Ltd.*
U14.SI	UOL Group Limited
S58.SI	SATS Ltd.
D01.SI	DFI Retail Group Holdings Limited
U96.SI	Sembcorp Industries Ltd
J36.SI	Jardine Matheson Holdings Limited
U11.SI	United Overseas Bank Limited
BN4.SI	Keppel Corporation Limited
V03.SI	Venture Corporation Limited
AJBU.SI	Keppel DC REIT
M44U.SI	Mapletree Logistics Trust
S68.SI	Singapore Exchange Limited
D05.SI	DBS Group Holdings Ltd
C07.SI	Jardine Cycle & Carriage Limited
G13.SI	Genting Singapore Limited
9CI.SI	*CapitaLand Investment Limited*
O39.SI	Oversea-Chinese Banking Corporation Limited
Z74.SI	Singapore Telecommunications Limited
H78.SI	Hongkong Land Holdings Limited
C38U.SI	CapitaLand Integrated Commercial Trust
S63.SI	Singapore Technologies Engineering Ltd
F34.SI	Wilmar International Limited
A17U.SI	Ascendas Real Estate Investment Trust
C09.SI	City Developments Limited
BUOU.SI	Frasers Logistics & Commercial Trust
BS6.SI	Yangzijiang Shipbuilding (Holdings) Ltd.

Appendix C: List of Stock Pool from Thailand

EGCO.BK	Electricity Generating Public Company Limited
BAM.BK	Bangkok Commercial Asset Management Public Company Limited
PTTGC.BK	PTT Global Chemical Public Company Limited
MINT.BK	Minor International Public Company Limited
CPN.BK	Central Pattana Public Company Limited
IRPC.BK	IRPC Public Company Limited
CPF.BK	Charoen Pokphand Foods Public Company Limited
PTTEP.BK	PTT Exploration and Production Public Company Limited
KTC.BK	Krungthai Card Public Company Limited
SCGP.BK	*SCG Packaging Public Company Limited*
SCB.BK	*SCB X Public Company Limited*
GULF.BK	Gulf Energy Development Public Company Limited
BH.BK	Bumrungrad Hospital Public Company Limited
DTAC.BK	Total Access Communication Public Company Limited
LH.BK	Land and Houses Public Company Limited
EA.BK	Energy Absolute Public Company Limited
OSP.BK	Osotspa Public Company Limited
BBL.BK	Bangkok Bank Public Company Limited
KCE.BK	KCE Electronics Public Company Limited
TIDLOR.BK	*Ngern Tid Lor Public Company Limited*
CRC.BK	*Central Retail Corporation Public Company Limited*
DELTA.BK	Delta Electronics (Thailand) Public Company Limited
ADVANC.BK	Advanced Info Service Public Company Limited
CBG.BK	Carabao Group Public Company Limited
RATCH.BK	Ratch Group Public Company Limited
IVL.BK	Indorama Ventures Public Company Limited
TU.BK	Thai Union Group Public Company Limited
STGT.BK	*Sri Trang Gloves (Thailand) Public Company Limited*
COM7.BK	Com7 Public Company Limited
CPALL.BK	CP ALL Public Company Limited

Italiced stocks are excluded from the pool from each economy as not covered throughout the sample period.