ABSTRACT

The mean-variance (MV) efficient portfolios (Markowitz, 1952) are obtained by searching for portfolios that attain the global minimum variance at a given level of expected return. However, MV efficient portfolios may not yield superior result due to the fact that the distribution of returns to financial assets is not normal but skewed. Past studies proved that investors whose utility can be approximated by the third-order Taylor's series expansion exhibit preference for positive skewness. This preference implies that portfolio selections should consider the mean-variance-skewness (MVS) model. However, studies on implications of skewness preference on portfolio selection are very limited due to computation difficulty.

To overcome this difficulty, this study proposes the use of multi-objective evolutionary algorithms (MOEAs) that are applied in the field of engineering for solving the multi-objective MVS portfolio optimization problem. The superiority of this method is its ability to generate a set of MVS efficient portfolios within a single run of algorithm. The non-dominated sorting genetic algorithm II (NSGA-II), the improved strength Pareto evolutionary algorithm II (SPEA-II), and the compressed objective genetic algorithm II (COGA-II) were applied. The MVS efficient surface was graphically plotted in the three-dimension MVS space.

The analysis started with an application to the stock market. Using the annualized weekly and monthly rates of return of 16 emerging market indices, expected returns of the MVS efficient portfolios are found to be smaller for those with larger skewness, at a given value

of standard deviation. The results suggest that investors have to sacrifice expected return for skewness. At a given value of expected return, the standard deviation decreases for MVS efficient portfolios with smaller skewness. Investors have to expose themselves to a larger return dispersion in order to increase the probability of gaining extreme expected returns.

This study develops a single-period model that allows for heterogeneous degree of risk aversion and skewness preference to investigate the impact of skewness preference on the efficient portfolio choice. Applying the returns of 29 component securities of Dow Jones Industrial Average index (DJIA), it was found that investors with greater skewness preference are willing to accept lower expected returns for a portfolio with higher skewness. In addition, investors with greater skewness preference are willing to accept larger return dispersion in exchange for a flatter right tail of the return distribution. The results explain why investors hold underdiversified portfolios. Investment allocations tend to concentrate on a small number of securities when the degree of skewness preference increases for a fixed level of degree of risk aversion.

The MVS analysis is extended to solve the electricity allocation problem in the electricity market, where the number of trading choices is considerably small. The electricity spot prices of nine pricing zones in the Pennsylvania-New Jersey-Maryland (PJM) market were utilized. To prevent excessive under-diversification, the MVS model is modified (MVS-D) by incorporating an additional objective to increase the number of trading choices included in the portfolio solutions. COGA-II, designed for handling an optimization problem with many objectives, have good optimization performance, particularly for the MVS-D model.

While the MVS efficient portfolios are found in the efficient set of MVS-D model, the MVS strategy provides better results than the MV model to a generation company.

ABSTRAK

Portfolio efisien min-varian (MV) diperolehi dengan mencari portfolio yang mencapai varian minimum global bagi suatu tahap pulangan dijangka. Walau bagaimanapun, portfolio efisien MV mungkin tidak memberi hasil terbaik kerana taburan pulangan kepada aset kewangan adalah tidak normal tetapi pencong. Kajian lepas menunjukkan pelabur yang utilitinya boleh dianggarkan oleh perkembangan Taylor peringkat ketiga mempunyai keutamaan untuk kepencongan positif. Implikasi keutamaan ini adalah pemilihan portfolio harus mempertimbangkan model min-varian-kepencongan (MVS). Walau bagaimanapun, kajian implikasi keutamaan kepencongan terhadap pemilihan portfolio adalah sangat terhad disebabkan kesukaran komputasi.

Untuk mengatasi kesukaran ini, kajian ini mencadangkan penggunaan *multi-objective evolutionary algorithms* (MOEAs) dari bidang kejuruteraan untuk menyelesaikan masalah multi-objektif pengoptimuman portfolio MVS. Kaedah ini mempunyai keupayaan untuk menjana satu set portfolio efisien MVS dalam larian tunggal algoritma. *Non-dominated sorting genetic algorithm II* (NSGA-II), *improved strength Pareto evolutionary algorithm II* (SPEA-II), dan c*ompressed objective genetic algorithm II* (COGA-II) telah digunakan. Permukaan efisien MVS diplot secara grafik dalam ruang MVS tiga-dimensi.

Analisis dimulakan dengan aplikasi untuk pasaran stok. Dengan kadar pulangan tahunan bagi indeks mingguan dan bulanan untuk 16 pasaran membangun, didapati bahawa pulangan dijangka portfolio efisien MVS adalah lebih kecil untuk portfolio dengan kepencongan yang lebih besar pada nilai sisihan piawai tertentu. Ini bermakna pelabur

perlu mengorbankan pulangan dijangka untuk kepencongan. Pada nilai pulangan dijangka tertentu, sisihan piawai menurun bagi portfolio efisien MVS dengan kepencongan yang lebih kecil. Pelabur perlu mendedahkan diri mereka kepada pulangan yang lebih tertabur untuk meningkatkan kebarangkalian mendapat pulangan dijangka ekstrem.

Kajian ini membina satu model tempoh tunggal dengan darjah pengelakan risiko dan keutamaan kepencongan yang heterogenous untuk menyiasat kesan keutamaan kepencongan kepada pemilihan portfolio yang efisien. Daripada kadar pulangan untuk 29 sekuriti komponen indeks *Dow Jones Industrial Average* (DJIA), keputusan menunjukkan bahawa pelabur dengan keutamaan kepencongan lebih tinggi bersedia untuk menerima pulangan dijangka yang lebih rendah untuk portfolio yang besar kepencongannya. Selain itu, pelabur dengan keutamaan kepencongan lebih tinggi bersedia untuk menerima pulangan yang lebih tertabur supaya dapat ekor kanan taburan pulangan yang lebih mendatar. Keputusan memberi penjelasan mengapa pelabur memegang portfolio kurang dipelbagaikan. Peruntukan pelaburan cenderung untuk menumpu pada sebilangan sekuriti yang kecil apabila tahap keutamaan kepencongan meningkat pada tahap penghindaran risiko yang tertentu.

Analisis MVS dilanjutkan untuk menyelesai masalah peruntukan elektrik di pasaran elektrik, di mana bilangan pilihan dagangan adalah lebih kecil. Harga elektrik spot untuk sembilan zon harga dalam pasaran *Pennsylvania-New Jersey-Maryland* (PJM) digunakan. Untuk mengelakkan kurang kepelbagaian yang berlebihan, model MVS diubahsuai (MVS-D) dengan memasukkan objektif tambahan untuk meningkatkan bilangan pilihan dagangan dalam penyelesaian. COGA-II, yang direka untuk menangani masalah pengoptimuman dengan banyak objektif, memberikan keputusan yang baik, terutama untuk model MVS-D. Sementara portfolio efisien MVS adalah dirangkumi dalam set efisien MVS-D, strategi MVS memberikan keputusan yang lebih baik daripada model MV kepada syarikat penjanaan.

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LIST OF ABBREVIATIONS

2D	Two-dimension
3D	Three-dimension
CAISO	California Independent System Operator
CAPM	Capital Asset Pricing Model
CE	Certainty Equivalent
COGA-II	Compressed Objective Genetic Algorithm II
CRA	Contribution Ratio to Artificial True Pareto
DJIA	Dow Jones Industrial Average index
DM	Decision Maker
DRA	Downside Risk Aversion
EP	Evolutionary Programming
ES	Expected Shortfall
GA	Genetic Algorithms
GARCH	Generalized Autoregressive Conditional Heteroscedastic
Genco	Generation Company
GMM	Generalized Method of Moments
HML	High (Book-to-Market Ratio) Minus Low
HV	Hypervolume
ISO	Independent System Operator
LHS	Left Hand Side
LMP	Locational Marginal Pricing
LP	Linear Programming
M_1	Average Distance to the True Pareto-optimal Front
MADS	Mean-absolute deviation-skewness
MCP	Market Clearing Price
MOEA	Multi-objective Evolutionary Algorithms
MOGA	multi-objective Genetic Algorithm
MOOP	Multi-objective Optimization Problem
MSCI	Morgan Stanley Capital International

MV	Mean-variance
MV-POP	Mean-variance Portfolio Optimization Problem
MVS	Mean-variance-skewness
MVS-POP	Mean-variance-skewness Portfolio Optimization Problem
NPGA	Niched Pareto Genetic Algorithm
NSGA	Non-dominated Sorting Genetic Algorithm
NSGA-II	Non-dominated Sorting Genetic Algorithm II
NYSE	New York Stock Exchange
OTC	Over-the-counter
PAES	Pareto-archive Evolution Strategy
PESA	Pareto Envelope-based Selection Algorithm
PGP	Polynomial Goal Programming
PJM	Pennsylvania-New Jersey-Maryland market
Prob. 1	Problem 1
Prob. 2	Problem 2
QP	Quadratic Programming
RHS	Right Hand Side
S&P 500	Standard & Poor's
S&P/ASX 300	Australian Securities Exchange from Standard & Poor's
SBX	Simulated Binary Crossover
SD	Standard Deviation
SMB	Small (Market Capitalization) Minus Big
SPEA	Strength Pareto Evolutionary Algorithm
SPEA-II	Improved Strength Pareto Evolutionary Algorithm
VaR	Value at Risk