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Coupling a memetic algorithm to simulation models for promising multi-period asset allocations

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ABSTRACT

The use of simulation models to manage and regulate property–liability insurers has gained in popularity over the last decade. This paper introduces a hybridized search optimization algorithm, also known as a Memetic Algorithm, for use with these insurer simulation models. The proposed algorithm combines the merits of both local and global search optimization techniques, and provides an efficient and robust approach for insurance model application. Our research investigated whether this enhanced optimization algorithm could further improve the results of a simulation model. As part of this investigation, a company-wide simulation model of a property–liability insurer was coupled with the proposed hybrid algorithm to tackle a typical multi-period asset allocation problem. The resulting asset allocations obtained by the proposed memetic algorithm coupled with the simulation model demonstrated better results than currently available investment strategies. The significant and robust improvements put forth in the present research demonstrate the great potential of our multi-phase hybrid algorithm in enhancing simulation model capabilities.

1. Introduction

Recent advancements in computing have made optimization techniques available to many real-life applications. They have been widely applied to engineering, management, and financial problems. In the wake of the financial crisis of the last decade, much research has focused on computational finance, or utilizing quantitative analysis to determine financial risk. Insurance businesses typically use case studies for computational finance issues. The insurance industry can be categorized into two sub-sectors: property–liability (P/L) and life-health. P/L insurance, also referred to as non-life insurance, covers property and liability losses. Incorporating liabilities into investment decisions is vital for P/L insurers, as this insurance is highly leveraged, and a slight mismatch between assets and liabilities can cause substantial losses to shareholder equity. Unfortunately, finding an effective tool to implement asset–liability management is difficult when the liabilities have long maturities and high levels of volatility. For instance, a P/L insurer may keep paying losses for decades when there is significant uncertainty regarding a payment amount. The commonly used Markowitz mean-variance analysis model [1] has been found to be unsuitable, having been characterized by Sharpe [2] as a myopic and highly parsimonious characterization of investors' goals. This is due to the fact that it focuses on only the first two moments of probability distribution for possible returns over a given period. Furthermore, a continuous-time stochastic control method [3,4], while theoretically sound, is difficult to implement, especially when uncertainties are driven by several or many state variables, as they exponentially increase the size of the stochastic optimal control problem. In short, P/L insurers lack appropriate, feasible tools to conduct multi-period asset–liability analyses.

Computational finance employs many different approaches, including statistics, data mining and simulation optimization in decision-making and prediction analysis within different financial businesses. Applications of this approach include Chen [5], who utilized the neural network to forecast the direction of index return in stock market. Sancho et al. adopted genetic programming algorithm to predict insolvency for financial company [6], and Jiao et al. applied genetic algorithms to portfolio planning and selection [7].

Computational finance is a perfect fit for the insurance industry, where risk and uncertainty are the major concerns. Many studies have reflected this trend, including Sodhi [8], who utilized linear programming modeling for asset–liability management in the banking industry. However, linear programming is incapable of solving complicated asset allocation models, since many applications are nonlinear. A wide range of studies have employed stochastic programming methods to address the problem of

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asset allocation and asset–liability management, including Kusy and Ziemba [9], Mulvey and Vladimirou [10], Carino et al. [11], Consigli and Dempster [12], Gondzio and Kouwenberg [13], Gaivoronski and Delange [14], Hibiki [15], and Hilli et al. [16]. However, research [17] has shown that the computational work involved with stochastic programming effectively explodes as the number of decision stages increases. In addition, this method is often forced to make a trade-off between the number of decision stages and the number of event tree nodes used to approximate the underlying return distributions.

On the other hand, heuristic algorithms provide a general-purpose modeling framework capable of considering a multiplicity of constraints. Because of this flexibility, heuristic algorithms have become some of the most commonly used techniques in computational finance. Baglioni et al. [18], Chan et al. [19], and Yang [20] each applied evolutionary algorithms in the context of an asset allocation problem. However, their models did not consider liabilities. In another study, Consiglio et al. [21] examined asset–liability management for minimum guarantee life insurance products without describing their optimization algorithms.

However, many simulation models in computational finance are computationally expensive. This is particularly true in insurance models that cover a long-term simulation horizon with many complex constraints. Research has shown that optimization algorithms are typically classified into local and global searches. Both the advantages and drawbacks of these search methods have been widely discussed in related literature [22,23]. Briefly, local search converges faster than global search, yet it is sensitive to initial solutions and often becomes trapped in local optimums. Furthermore, many local search techniques require the derivative of their objective functions. However, obtaining true derivatives for complicated or nonlinear functions is difficult for local search. On the other hand, global search approaches using genetic and evolutionary algorithms that can identify several critical parameters for the algorithm to converge to the right solution. These parameters include population size, number of generations, solution space, and number of decision variables. Nevertheless, a global search algorithm is usually computationally expensive, as it requires a high population and a large number of generations for the algorithm to converge to global optimization. The major weakness of heuristic algorithms is their efficiency, and research into this issue has become widespread. Many approaches in genetic algorithms have attempted to improve convergence and efficiency by providing modified mutation and crossover operators [24,25]. Yet it remains clear that no matter how different operators are utilized, the essential computation still relies on an evaluation of an objective function based on a large population size. One alternative is to use parallel computing to speed up the evaluation phase [26]. Unfortunately, parallel computing hardware is not yet common in the current generation of computers. It is thus necessary to overcome this issue by using an enhanced algorithm. Besides, there are no particular set of parameters capable of generating optimal results for problems of differing complexity. Poorly chosen parameters may prevent the search algorithm from obtaining a global optimal solution. The severity of this problem further increases with the number of decision variables, which dramatically expand the solution space [22,27].

Recently, a newly emerging group of algorithms which combine the features of global and local searches have received widespread attention. They are generally referred to as Memetic Algorithms (MAs). MAs are hybrid methods that use a local search algorithm to refine the solutions during the optimization process [28–30]. These algorithms aim to improve the intensity of the evolution algorithm and to result in more robust and effective optimization results. The idea behind MAs is that the “gene” in the evolution algorithm can be improved by Dawkins's notion of a “meme”, which is defined as a unit of cultural transmission [31]. Several studies have demonstrated the originality and discussed the advances of MAs [27,29,32]. Many other publications also demonstrate that MAs can produce promising results for solving complex nonlinear optimization problems [33] as well as many engineering problems [34,35]. Evolution benchmarks were tested by MAs and the encouraging results have shown greater effectiveness and efficiency compared to the heuristic algorithms [35,36]. Literature shows the performance of current optimization algorithms deteriorates when the size of the determinate variables increase. Unfortunately, many real-world problems are large-scale problems. MAs show improved speed, better convergence performance and high precision for complex continuous large-scale applications [27,37]. Other studies have also confirmed the superiority of MAs applied to more computationally intensive optimizations [36–38].

This study presents the first attempt to enhance *P*/*L* insurer asset–liability management by integrating a simulation model with a multi-phase memetic algorithm combining a genetic algorithm (GA) and a local search algorithm. Specifically, we examine the investment strategy of asset allocation over a multi-period setting, where funds are allocated across various asset classes. Within a multi-period setting, the relationship between assets and liabilities changes from static to dynamic. Our study accounts for these state changes by considering liabilities into our hybrid heuristic algorithm. An enterprise simulation model, called dynamic financial analysis (DFA) in the US, has proven useful in various management and regulation applications. Nevertheless, a simulation model by itself lacks optimization capability. Unfortunately, when applied to a simulation model, optimization search algorithms may be trapped into local optimums when the model generates a non-linear, multi-modal solution surface. Therefore, we have developed a multi-phase memetic algorithm that overcomes the deficiencies of global and local search algorithms and can be used with *P*/*L* simulation models to find promising, or “heuristically optimal”, multi-period asset allocations.

In our simulation, the *P*/*L* insurer underwrites both short-tail (a deferral or loss-development period usually within three years of a property–liability insurance claim) and long-tail (a deferred period of ten years or longer) business and allocates its funds into five asset classes, including one risk-free asset. These assets and liabilities are correlated with each other. Allocation decisions are made four times during the 24-yr simulation period with an industry-standard prohibition on short-selling. The insurer's objective function consists of one return measure and two risk measures over 10,000 simulated paths. The complexity and constraints classify this simulation as a large-scale continuous optimization problem.

The goal for this simulation system was to find promising four-period asset allocations. The performance of the proposed algorithm was first tested by common benchmark functions using 50 decision variables to ensure applicability to the simulation models. We then compared objective function values resulting from the algorithm with those of a single-period strategy and a four-period re-balancing strategy. The initial allocations of the single-period and standard re-balancing strategies were obtained by the grid search method commonly used by institutional investors, such as mutual funds and investment banks, where mean-variance analysis is employed to select the initial allocations among assets and then periodically re-balance the portfolio back to its initial proportions.

The rest of this paper is organized as follows. Section 2 describes the simulation model of the *P*/*L* insurer. Section 3 formulates the optimization problem, explains the Levenberg–Marquardt local search algorithm, the basic GA global search algorithm, and then the multi-phase approach used for optimization. Section 4 delineates two alternative strategies for our multi-phase hybrid genetic algorithm (MPHG) allocations and evaluates their relative performance. Our conclusions are presented in Section 5.