Expert Systems with Applications 39 (2012) 2684–2689

Contents lists available at SciVerse ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

Generating effective defined-contribution pension plan using simulation optimization approach

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ARTICLE INFO

Keywords:
Defined-contribution pension
Evolution strategies
Multi-period asset allocation
Simulation optimization

ABSTRACT

This paper presents an optimization approach to analyze the problems of portfolio selection for long-term investments, taking into consideration the specific target replacement ratio for defined-contribution (DC) pension scheme; the purpose is to generate an effective multi-period asset allocation that reaches an amount matching the target liability at retirement date and reduce the downside risk of the investment. A multi-period asset liability simulation model was used to generate 4000 asset return predictions, and an evolutionary algorithm, *evolution strategies*, was incorporated into the model to generate multi-period asset allocations under four conditions, considering different weights for measuring the importance of matching the target liability and different periods of downside risk measurement. Computational results showed that the evolutionary algorithm, *evolution strategies*, is a very robust and effective approach to generate promising asset allocations under all the four cases. In addition, computational results showed that the promising asset allocations revealed valuable information, which is able to help fund managers or investors achieve a higher average investment return or a lower level of volatility under different conditions.

1. Introduction

The core purpose of pension funds is to serve as an attractive form of savings for employees with the ultimately goal of providing them with benefit payments when they have ended their active income earning careers. There are two types of pension plans: defined contribution (DC) and defined benefit (DB). There has recently been a rapid trend of employees around the world shifting from the DB scheme to the DC scheme with an increasing number of the new workforce joining defined contribution schemes. A DC pension plan is relatively simple; each participant accumulates his contributions and investment returns in a distinct personal pension account. Typically, a longer tenure is associated with a greater probability of being better rewarded in a DB plan. Under the DC scheme, employers transfer the pension fund investment risk to the employees. Such a scheme usually performs very badly in periods of high inflation because wages and salaries rise as fast as or faster than prices, whereas the value of funds often does not. No one knows if the DC plan will be able to provide a good pension benefit when the day of retirement arrives. Therefore, it is essential for the employees to choose optimal investment strategies during the accumulation phase so that they will have sufficient funds accumulated on retirement.

The traditional single-period mean–variance (MV) approach (Markowitz, 1959) has dominated the portfolio selection process in the investment management profession for over a decade (Sharpe & Tint, 1990; Wilkie, 1985; Wise, 1984a, 1984b, 1987a, 1987b; Sherris, 1992). The MV approach is applied to single period investments and solves the problem of single-period asset allocation under a restrictive set of assumptions; however, this method is not suitable for a long-term investments, where multi-period asset allocation is more appropriate, since holding the same proportions of assets for thirty years may have a lower average investment return or a higher volatility than a so called "life cycle" or "top–down" investment strategy. In addition, the MV approach has the disadvantage of being a single-point forecast. A different mean and variance of the forecast may result in very different asset allocations (Chopra & Ziemba, 1993; Koskosidis & Duarte, 1997).

Merton introduced a multi-period context of portfolio strategy (Merton, 1971, 1990) and his dynamic programming (DP) technique is widely applied to the financial optimization in a continuous-time model (Basak & Shapiro, 2001; Battocchio & Menoncin, 2004; Cuoco & Cvitanic, 1998; Devolder, Princep, & Fabian, 2003; Gerrard, Haberman, & Vigna, 2004; Haberman & Sung, 2005; Haberman & Vigna, 2002; Hipp & Taksar, 2000; Josa-Fombellida & Rincon-Zapatero, 2004; Lioui & Poncet, 2001; Yiu, 2004). However, it is sometimes difficult to apply this technique to realistic problems because it generally needs very strong assumptions to obtain closed-form solutions in a continuous-time model. For example, if,

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doi:10.1016/j.eswa.2011.08.124

according to some regulations, the weight of a specific asset must be lower than a specified proportion of the portfolio, say 50%, then the DP technique will not be able to attain a closed-form solution. It is even more difficult to consider more complicated constraints such as the monitoring of downside risk. In addition, a multi-period context of portfolio strategy in a discrete-time model normally leads to sets of recursive equations (Huang & Cairns, 2004). The difficulty of applying constraints further increases in discrete-time models and prevents the DP technique from being applicable in realistic problems.

Simulation techniques, such as the dynamic financial analysis system, have been a commonly used tool for financial analysis, and it certainly is an appropriate tool to deal with the DC pension plan problem. It allows users to take into consideration all kinds of constraints to simulate real world problems and helps users make appropriate decisions under different conditions. Although simulation techniques are powerful, it usually generates decisions by employing users' professional knowledge and the trial-and-error method and cannot guarantee promising solutions. Therefore, the approach of integrating simulation techniques with optimization methods is valuable for researchers and practitioners to conduct financial analysis. Furthermore, since simulation models for financial analysis can be very complicated, optimization methods should be carefully chosen and properly applied so that promising decisions can be obtained. Lately, evolutionary algorithms have become the most important techniques for optimization problems. The SCI and SSCI database contains more than ten thousand technical papers developed in the past decade that have reported successful applications of evolutionary algorithms in many different research fields. Several of the papers applied genetic algorithms to solve portfolio optimization problems: Abiyev and Menekay (2007), Baglioni, Pereira, Sorbello, and Tettamanzi (2000), Chan, Wong, Cheung, and Tang (2002), Chang, Meade, Beasley, and Sharaiha (2000), Chang, Yang, and Chang (2009), Oh, Lim, and Min (2005), Lin and Ko (2009) and Yang (2006). To our knowledge, the papers of Baglioni et al. (2000), Chan et al. (2002) and Yang (2006) were the only research papers considering simulation models for multi-period asset allocation and applied basic genetic algorithms to determine effective asset allocations. However, all the applications were in some ways preliminary; therefore, in this research an evolutionary algorithm, evolution strategies, is chosen to be integrated with simulation models for the thorough investigation of the DC pension plan problem.

We developed a multi-period discrete-time asset liability simulation model and integrated an evolution strategies algorithm with the model to generate a DC pension plan that can match a target liability and decrease the downside risk. For the purpose of illustration, Wilkie's investment model is adopted (Wilkie, 1995) to simulate a representative set of equal-probability plausible scenarios of future returns. Each scenario represents one possible uncertain return over the planning horizon. A large set of scenarios is generated to adequately represent highly unlikely market swings, and the proposed simulation optimized approach is applied to obtain a promising investment strategies. In this research, 4000 equal-probability scenarios of returns in 40 years were generated for the simulation model, and the proposed approach was applied to generate investment strategies under conditions considering different weights for measuring the importance of matching the target liability and the period to reduce downside risk. Computational results showed that the proposed approach is effective for finding promising investment strategies to match the target liability and decrease the downside risk during the accumulation phase in a DC plan. In addition, the investment strategies generated under different conditions provide valuable information for fund managers or investors to make proper decisions under different conditions.

The rest of this paper is organized as follows. Section 2 describes our asset liability management models for pension funds. Section 3 introduces the evolution strategies algorithm and explains how the algorithm is applied to generate promising multi-period asset allocations to achieve the objectives of the models. The computational results are discussed in Sections 4 and 5 concludes some findings in this paper.

2. Asset liability management for pension funds

Generally speaking, the main goal of asset liability management for pension funds is to find acceptable investment returns and contributions that ensure that the fund is sufficient during the planning horizon. In this paper, we investigate the investment allocation and the downside risk faced by retiring members of DC plans. We assume that each individual has a pre-specified target liability (a specific income replacement ratio). Hence, achieving the asset–liability matching is the major objective of the participants of DC plans. A trade-off between investment returns and insolvency is an important factor that must be considered. Usually, the solvency is evaluated by the amounts of unfunded liabilities, which is the difference between liabilities and assets. Generally speaking, when compared with a single-period investment strategy, a multi-period asset allocation strategy provides a larger allowance for temporary underfunding, which allows investors to hold more equity at the beginning of the term and possibly enhances investment returns during the entire period. Therefore, a multi-period investment strategy is more likely to provide a higher average return, subject to a certain allowance of risk, than a single period investment strategy. It is then important to construct a model of a multi-period investment strategy for a long-term liability.

The purpose of this paper is to establish an effective asset allocation to a long-term liability such as pension benefits. With the asset allocation, fund managers or investors are able to follow their schedules to meet their target obligations as long as the market is consistent all the time. If the market changes after a period, fund managers or investors need to simulate the new market information and apply the model of the multi-period investment strategy to obtain another effective asset allocation for the rest of the period of the target liability. A pension fund has long-term obligations; and therefore, a long-term view of investment strategy is required because of its long planning horizon. Thus, we use the standard asset classes used by pension funds such as short-term bonds, consols, index-linked gilts and equities.

In order to evaluate the asset value of the portfolio, we define.

P_{kj} : proportion held in asset type j at the kth year,

where $j = 1$ is for short-term bonds; $j = 2$ is for consols; $j = 3$ is for ILGs; $j = 4$ is for equities.

$A(0)$: total initial asset holding.
$A(k)$: total asset value at the kth year.
$A(n)$: total asset value at the end of the term.
c%: contribution rate, a percentage of an individual's salary contributed to his (or her) pension account each year in order to reach a target liability.
S_1: initial salary.
S_k: salary at the kth year.
S_n: salary at the last year of the term.
$r_i(k)$ is the investment return of the ith asset at the kth year.

The value of the total asset at the time of the kth year is:

$$A(k) = (A(k-1) + c\% \times S_k) \times \left[\sum_{j=1}^{4} P_{kj} \times (1 + r_j(k)) \right], \; j = 1, \ldots, 4 \qquad (1)$$

where $k = 1, \ldots, n$.

Thus, the value of the total asset at the maturity date is: