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Original Research Article

Insurer Optimal Asset Allocation in a Small and Closed Economy: The Case of Iran's Social Security Organization

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We seek to determine the optimal amount of the insurer's investment in all types of assets for a small and closed economy. The goal is to detect the implications and contributions the risk seeker and risk aversion insurer commonly make and the effectiveness in the investment decision. Also, finding the optimum portfolio for each is the main goal of the present study. To this end, we adopted the optimal asset-liability management (ALM) method to control the firm's risk of financial stability and growth by balancing the assets and liabilities of the firm. In the process, stochastic interest rates and inflation risks were taken into account according to the expected utility maximization framework. All assets were established and calculated by the Kalman Filter with the stochastic interest rate following the Hull-White model; an additional stochastic process models the inflation risk. To consider the stochastic process, we employed the geometric Brownian motion in the liability process to ensure a definite liability value. We chose Iran's Social Security Organization as our sample insurer company since it has a portfolio of five types of assets and four types of liabilities, and operates in a small and closed economy. By Applying the ALM method with the stochastic control theory approach, we acquire the optimal investment strategies for insurers to minimize their risk. Our findings demonstrate the effects of model parameters, such as the degree of risk-taking on the insurer decision.

Keywords: ALM, Portfolio, Optimization, Insurer, Decision-Making, Financial Market.
JEL Classification*:* G00

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1 Introduction

Pension funds play an essential role in global capital markets. For example, the assets under the management of the US Pension Fund are 80% of its GDP (OECD, 2015). Watson (2016) studied 16 cases of major global investment markets. According to him, pension funds in the US, UK, Canada, and Japan invested, on average, equal to almost 85% of their GDP in 2016. In the same year, the total assets of these funds increased by 4% as compared to 2006. The US, followed by the UK, Japan, and Australia, had the largest pension fund assets. The growth rate of these funds was approximately 5.8%, on average, in the past ten years. According to OECD (2014), these funds were invested mainly in the capital markets. In addition to the economic importance of these pension funds and other social organizations, and the relatively stable inflow of cash and probable risk of loss, these funds need proper planning to ensure suitable assets investment to meet their liabilities.

In other words, sustainable cash flow is particularly important for these insurance organizations and pension funds. Since these organizations regularly receive premiums and pay for medical and service costs, they handle a large amount of cash inflow and outflow. Since asset investment is risky, pension funds and insurers make investments based on the nature of their activity. Therefore, providing an optimal investment strategy can help insurers achieve more stable cash flow. Watson (2017) contends that pension funds mainly hold their assets in the form of stocks, bonds, cash, and real estate. He examined the contribution of each of these methods to pension fund holdings of seven selected countries. The lowest and highest investments were in cash and stock, respectively. According to OECD (2015), the following issues make the study of these pension funds very challenging: (1) low-interest rates in global economies, (2) an increase in life expectancy, and (3) a severe birth rate decline in the near future. These issues, along with the importance of sustainable cash flow, affect the majority of retirement systems and national economies, urging scholars to have an in-depth focus on Iran's social service system.

To this end, we intended to determine the optimal investment portfolio by Social Security Organizations in different assets. The proposed solution is to calculate the optimal investment portfolio using the asset-liability management (ALM) method. ALM is the allocation of resources to the flow of debt funds. Pension funds are chosen to obtain the benefit from conflicts between the demands and needs of different groups since various internal and external factors affect these funds. It is valuable because there is a scarcity of

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research on pension funds with ALM modeling in Iranian financial economics.

This paper is organized as follows. The next part deals with the literature review. In Section 3, we will establish our ALM optimization model and its framework by applying the stochastic control theory to assess interest rate and liability. Then, we will offer the solution of optimal investment strategies for the power utility and exponential utility functions through the change-of-variable and partial differential equation (PDE) technique. Section 4 provides Iranian insurance examples in order to show the effects of model parameters on optimal investment strategies. Final Section presents findings and conclusion.

2 Literature Review

Asset–liability management (ALM) involves the management of assets so that an adequate return could be earned while maintaining a comfortable surplus of assets over existing and future liabilities (Li et al. (2018)).

It has been extensively studied across a wide range of financial institutions such as insurance companies and pension fund providers. Although establishing an effective ALM model is essential not only for institutional investors such as banks, pension fund providers, and insurance companies but also for individual investors such as banks and credit institutions who can increase their wealth through loans (Pan and Xiao (2017)).

Besides achieving much progress in solving dynamic M-V formulations, many scholars have adopted the M-V model to study the ALM problems. According to Sharpe and Tint (1990) that applied the portfolio selection techniques to an ALM problem in a static M-V framework, to progress that come across from the work of Chen et al. (2008) into the works of Chiu and Li (2006) and Leippold et al. (2004) to use in the Markovian regime-switching market. Li et al. (2015) considered an optimal reinsurance and investment problem under the M-V framework and derived the time-consistent optimal investment strategy.

Many scholars have recently worked on ALM-related issues. Chiu and Wong (2014) and Zhang et al. (2017) studied an ALM problem with state-dependent risk aversion under the mean-variance criterion. Wei et al. (2013) and Wei and Wang (2017) investigated the time-consistent strategies of mean-variance ALM problems under the Markov regime-switching model and random coefficients setting. Also, Pan and Xiao (2017) used the stochastic interest rates and inflation risks into optimal M-V ALM formulations.

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Li et al. (2018) considered a portfolio optimization by maximizing the expectation of the terminal surplus to satisfy the company's liability while minimizing risks by the variance of the terminal surplus.

This is acclaimed that the purpose of the mean-variance (M-V) is not adjustable enough to deal with the effect of an investor's risk aversion. Furthermore, in recent years, the utility theory, especially the expected utility theory introduced by Neumann and Morgenstern (1944), has determined an impact in finance. It has been recognized for its usefulness in financial modeling. The expected utility maximization or optimal ALM problems are new objectives in ALM problems

For investigating the effect of an investor's risk aversion on an ALM problem, the expected utility maximization framework was introduced and expanded by many types of research. Rudolf and Ziemba (2004) and Hoevenaars et al. (2008) investigated a continuous-time ALM problem and a discrete-time ALM problem, respectively. In their models, the optimal investment strategies for the utility function of the constant relative risk aversion (CRRA) were developed.

By employing the stochastic linear–quadratic control theory, Chiu and Li (2006) modeled a continuous-time ALM with m–v paragon and geometric Brownian motions for the price of risky assets and liabilities. Xie et al. (2008) described the liability by Brownian motion with a drift. Chen (2009) studied a continuous-time ALM problem in the regime-switching setting and derived the corresponding optimal investment strategies.

Battocchio and Menoncin (2004) considered the optimal pension management in a stochastic model using the stochastic dynamic programming approach. Although Gelbart (2015) eliminated the shortcomings of the model, there were equity, interest rate, and inflation risks involved in the financial market, while only two assets (stock and zero-coupon bond) could be independently determined. It implied that the investor could not hedge against the inflation risk according to his risk-aversion. In the financial market, there were also some financial instruments used to hedge against the inflation risk, such as inflation-indexed bonds (i.e., Treasury Inflation-Protected Securities (TIPS) and UK inflation-linked gilt-edged securities (ILGS)). Chiu and Wong (2014) considered the ALM problem with a stochastic interest rate under the CRRA utility framework, where the liability followed a risk model of compound Poisson process, and the interest rate was assessed based on Cox–Ingersoll–Ross (CIR) model. Since the ALM plan may take quite a long time for an investor, it would be reasonable to take into account the risks of interest

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rate and inflation in particular. Regarding the portfolio selection problem with stochastic interest rates and inflation risks.

Fischer (1975) was the first who studied inflation risk and the demand for inflation-indexed bonds. He was solving the inter-temporal optimization problem under the inflation risk and highlighted the role of inflation-indexed bonds. Brennan et al. (2002) and Kwak and Lim (2014) probed the importance of inflation-indexed bonds for long-term and conservative investment.

By introducing inflation-indexed bonds, Han and Hung (2012) focused on the optimal investment problem for the defined contribution (DC) pension plan with the risks of interest rate and inflation. The found that the inflation-indexed bond is indispensable for the pension plan to hedge against the inflation risk and to provide downside protection with the annuitants. Later, Guan and Liang (2014) introduced the two kinds of risks into the optimal insurance and investment problem for an insurer with a power utility preference.

Leippold et al. (2004) studied a multi-period ALM problem under the mean-variance criterion and derived explicit expressions for the optimal strategy and efficient frontier. Applying the Backward Stochastic Different Equation (BSDE) method, Chiu and Wong (2012, 2013a, 2013b) studied mean-variance ALM problems with risky integrated assets. Yao et al. (2016) studied a dynamic M-V asset allocation problem with stochastic interest rates and inflation rates, where an inflation-indexed bond was not introduced. Besides, Liang and Zhao (2016) investigated the optimal M-V efficiency of a family with life insurance under the risks of interest rate and inflation. The financial market was composed of a risk-free asset (cash), a zero-coupon bond, an inflation-indexed bond, and a risky asset (stock).

Chiu (2017) derived a new ALM solution for maximizing the expected utility subject to cointegrated assets and compound Poisson type of Liabilities. Similarly, Pan and Xiao (2017) investigated an optimal ALM problem under the expected utility maximization framework with inflation risks and liquidity constraints, respectively.

Kopa et al. (2018) introduced “multi-stage stochastic programming” ALM and stressed the portfolio with a discrete scenario tree contamination technique. For the modeling procedure, they employed the “second-order stochastic dominance” with the benchmark portfolio as constraints. They also inquired the “hedge financial contracts” in the form of put options for preserving the pension fund against fluctuations.

Izadbakhsh et al. (2017) identified key factors influencing the management of assets and liabilities in pension funds and analyzed them through the

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dynamics of system identification. They used the system of fuzzy fusion system, effective risks examined by the strategies, different effects. They found that the key to successful asset management is observing integrated assets and the interests of stakeholders in designing and addressing demographic risks, particularly risk-taking. Nevertheless, there is a scarcity of research on pension funds with ALM modeling in the Iranian economic system.

Yao et al. (2016(a and b)), Liang and Zhao (2016), and Pan and Xiao (2017) principally focused on finding the optimal asset liability model by using inflation risks and stochastic interest rates based on the M-V framework. They considered the financial market as being made up a risk-free asset, a zero-coupon and an inflation-indexed bond with risky assets. Also, the liability process was described by a geometric Brownian motion instead of a Brownian motion to assure a liability.

The novelty of our study lies in the following two endeavors. Firstly, the ALM formula was adapted for an insurance company in Iran, which is a developing country with a closed economy and a different financial market construction opposite to a developed country such as the US market. Secondly, having collected all the materials required for solving the ALM model in a single study, we provided the optimum portfolio to the insurance company in Iran to satisfy all its liabilities.

3 Formulating an Optimized ALM Model

In this section, we introduce a model for optimal investment based on the ALM tenets and utility maximization criteria. Next, the problem of determining the optimal investment is formulated, and the parameters are estimated in detail. The model is then defined concerning all types of portfolios available to the “Social Security Organization of IRAN”. In Section 4, the results of the model will be represented.

3.1 Formulate the ALM

The returns on financial market assets from Brownian motion (Winnie's) models are estimated for random rates. The Brownian motions depend on some random variables. Generally, we consider them-Brownian motions. At the time of estimation, these dimensions will be limited to the number of assets and liabilities of the "Iran Social Security Organization".

In the financial market, the investor has four assets for investment, i.e., a risk-free asset, zero-bound treasury inflation-protected securities, and a risky asset (Lee et al. (2018)). The available portfolio in the financial market of

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developing and closed-economic countries includes 5 types of assets. Likewise, the assets portfolio of the "Social Security Organization" of Iran consists of bank deposits and equity securities, equity markets consisting of subsidiary investments, investments in affiliates, and investments in other companies (stock market), real estate, and cash. The concessional financing facilities are the additional income source for insurer organizations in a developing country, which is funded by the government. In the present study, we calculated in cash form of assets. In our case study together with all insurer (pension funds) organizations, there are 4 types of liabilities, including the salaries and other benefits of members' pensions, treatment costs and insurance premiums transferred to other plans, and project administration costs.

Initially, we classified all types of assets into risky and risk-free categories and then modeled all two asset categories.

The risk-free asset is the first that follows a fixed rate of return (banking deposit). The stochastic differential interest rate equation with the Hull-White single-factor form is formulated as follows:

$$\frac{dS_0(t)}{S_0(t)} = dR(t) = a[\theta(t) - R(t)]dt + \sum_{j=1}^{m} \sigma_{Rj} dW_j(t)$$
$$, R(0) = R_0 > 0 \qquad (1)$$

$\theta(t)$ is a definite value and denotes the average long-term interest rate, a is a positive constant indicating the degree of return to the mean, $\sigma_R = (\sigma_{R1}, \sigma_{R2}, \dots, \sigma_{Rm})$ is a constant vector and denotes the variance of interest rate volatility into the winner process. In "Social Security Organization," sources of investment, "holding cash" is one of the non-returnable assets with the inflation risk only. Thus, it can be classified as one of the first assets with free risk.

To calculate the inflation risk in its equations, by changing the variable of Equation (1) and the nominal interest rate variable, r (t) is assumed to be obtained by the following stochastic differential equation:

$$dr(t) = a_1[\theta_1(t) - r(t)]dt + \sum_{j=1}^{m} \sigma_{rj} dW_j(t), r(0) = r_0 > 0, i = 1,2 \quad (2)$$

So far, two assets have been introduced. By dividing assets into two categories of risky and risk-free assets, the 3 remaining assets in risky assets will be equity, stocks, and real estate's market, which have a risk beyond inflation. Those assets will have a risk premium $\mu_i(t)$.

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$$\frac{dS_i(t)}{S_i(t)} = [R(t) + \mu_i(t)]dt + \sum_{j=1}^{m} \sigma_{ij} dW_j(t)\,, i = 3,4,5 \qquad (3)$$

$\frac{dS_i(t)}{S_i(t)}$ is the differentiated rate of asset return for risky ones like stocks and real estate's market. The first part of this Equation is the risk-free asset return that would be obtained in the financial market. The second part is the risk premium from investing in that specific asset, and the last part is the volatility of the asset returns to multiply differential of the winner process.

To calculate the components of asset and liability management, it should be noted that the ALM model consists of the ratio of total assets to total liabilities. In a developing country, an insurer's portfolio assets are a combination of assets for which the calculation of the rate of return has been explained. The total assets return (X) of an insurance organization will be the sum of the probability ratio of investment in each type of asset.

Since it is regarded as two types of assets, risky and risk-free assets type, we will use $\sum_{i=1}^{n} \pi_i\,(t)$ to represent the probability of investing in the former case, and $1 - \sum_{i=1}^{n} \pi_i\,(t)$ for the latter. The volatility of asset return can be calculated through $\frac{dX(t)}{X(t)}$, expanded as Equation (4) which is the combination product of Equations 1 and 3

$$\frac{dX(t)}{X(t)} = \sum_{i=1}^{n} \pi_i\,(t) \frac{dS_i(t)}{S_i(t)} + (1 - \sum_{i=1}^{n} \pi_i\,(t)) \frac{dS_0(t)}{S_0(t)} = [R(t) + \sum_{i=1}^{n} \pi_i\,(t)\,\mu_n(t)]dt + \sum_{i=1}^{n} \pi_i\,(t) \sum_{j=1}^{m} \sigma_{nj} dW_j(t) = [R(t) + \acute{\pi}(t)\,\mu_n(t)]dt + \acute{\pi}(t)\sigma(t)dW(t), \qquad (4)$$

The insurer holds an initial value of X_0 to invest in various sources the liability of which can be paid off at an initial value of L_0. Since the assumption (in this paper) is that the insurer's liability is positive, the geometric winner process method is used to model the liabilities ($W(t)$)

$$\frac{dL(t)}{L(t)} = [R(t) - r(t) + \alpha(t)]dt + \beta(t)dW(t), L(0) = L_0 \qquad (5)$$

Now, we can build the ALM model using the equations of assets (equation 4) and liabilities (equation 5) of the insurer. The ALM equation is expressed as Y (t) = X (t) - L (t).

The fluctuation of this rate will be calculated by the multiplication of each factor (X (t) and L (t)) by the rate of its fluctuations (equations (4) and (5)) and omitting common factors with X (t) being replaced by Y (t) - L (t) to omit X (t).

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$$dY(t) = dX(t) - dL(t) = \{X(t)[R(t) + \acute{\pi}(t)\mu(t)] - L(t)[R(t) - r(t) + \alpha(t)]\}dt + [X(t)\acute{\pi}(t)\sigma(t) - L(t)\beta(t)]dW(t) = \{[Y(t) + L(t)][R(t) + \acute{\pi}(t)\mu(t)] - L(t)[R(t) - r(t) + \alpha(t)]\}dt + \left[[Y(t) + L(t)][\acute{\pi}(t)\sigma(t)] - L(t)\beta(t)\right]dW(t) \quad (6)$$

ALM method is based on the logic that the decision-maker calculates the expected "ratio of assets to liabilities," taking into account relevant constraints, so in this calculation, the optimal ratio of investment will be attained in each asset of the organization's investment portfolio. For this reason, we maximize the expected ratio of "assets to liabilities" according to the constraints introduced in Equation (6).

Thus, the optimization problem can be written as Equation (7).

$$Max\, E[\bar{Y}(t)]$$

St:

$$d\bar{Y}(t) = \left\{[\bar{Y}(t) + \bar{L}(t)]\left[r(t) + \acute{\pi}(t)b(t) + \delta(t)\right] - L(t)\bar{\alpha}(t)\right\}dt + \left[[\bar{Y}(t) + \bar{L}(t)][\acute{\pi}(t)\sigma(t) - \eta(t)] - \bar{L}(t)\bar{\beta}(t)\right]dW(t)$$
$$\bar{Y}(0) = \frac{X_0 - L_0}{I_0} \quad (7)$$

In short, as we have in Equation (7), we are looking to maximize our expected $\bar{Y} = \frac{X}{L}$ (asset to liability ratio) with the constraint that shows the relation between the "asset to liability ratio" and the liabilities (Equation 6).

3.2 Solving the Model

For solving the model with respect to Yao et al. (2016) , Liang and Zhao (2016) and Jian Pan, Qingxian Xiao(2017), we employed the control theory with both types of utility functions (power utility and exponential utility (constant absolute risk aversion ((, introduced in equations (8) and (9).

$$U(y) = \begin{cases} \frac{(1-e^{-ay})}{a} & a \neq 0 \\ y & a = 0 \end{cases} \quad (8)$$

$$U(y) = -\frac{e^{ay}}{a} \quad (9)$$

After solving these, we would reach the result of optimal $\pi_i(t)$, the optimal ratio of an insurer's investment in each asset type.

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4 Results

Based on Chiarella et al. (2006), the Kalman Filter method was adopted in this study for estimating the parameters required to implement the optimal intertemporal portfolio introduced in the previous section.

Expectedly, based on the Iranian economic situation economy, there are five types of investment strategies, including cash, bond, bank deposit, real estate, and the stock market. For each of them, Equation (10) would be used as an observation and Equation (11) as a state equation.

$$X_n(t, r_t, \pi_t) = \alpha + \beta r_t + \varsigma \pi_t + \varepsilon_t \quad (10)$$

$$d\pi_t = k_\pi \pi_{t-1} dt + g_\pi dW_t^\pi \quad (11)$$

π_t Denotes the expected inflation, r_t is the real interest rate calculated by the Central Bank of Iran and W_t^π is a vector that denotes the Brownian emotion of the expected inflation. The results are demonstrated in Table (1).

Table 1
Estimating the result of bond, banking deposit, and real estate dynamic.

Asset	Parameter	Estimate	Z test. Prob
Bond	k_π	-0.44	0.0
	g_π	-0. 70	-0.52
	$\rho_{r\pi}$	6.76	0.0
Real Estate	k_π	0.10	0.0
	g_π	0.01	0.0
	$\rho_{r\pi}$	1.02	0.0
Banking deposit	k_π	-0.49	0.0
	g_π	0.03	0.0
	$\rho_{r\pi}$	0.12	0.0

However, to estimate the realized inflation dynamics, Equation (12) was used as an observation and Equation (11) as a state equation.

$$dlnI_t = \left(\boldsymbol{\pi_t} - \frac{\sigma_I^2}{2}\right) dt + \sigma_I W_t^I \quad (12)$$

I_t, denotes the Iran price index published monthly by its Central Bank and W_t^I is a vector that denotes the Brownian emotion of realized inflation. In Table (2), results are summarized.

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Table 2
Estimating the Result of Realized Inflation Dynamics.

Parameter	Estimate	Z test. Prob.
k_π	-0.40	0.0
g_π	-0.47	0.0
σ_I	0.00	0.0

To estimate the stock return dynamics, the average index of daily stock return was utilized for Equation (13).

$$dlnx_s(t) = \left(R_t + \lambda_s\sigma_s - \frac{\sigma_s^2}{2}\right)dt + \sigma_s dW_t^s \qquad (13)$$

As seen in Table (3), $\lambda_s = \frac{\varepsilon_0}{\sigma_s}$ is the price index risk.

Table 3
Estimating the Result of Stock Return Dynamics

Parameter	Estimate	T test. Prob.
λ_s	0.61	0.01
σ_s	0.26	0.01

Before adopting the liability's constraints, the volatility of absolute risk aversion coefficients (ARAC) parameter and the relative risk aversion coefficient (RRAC) were provided as certainty equivalents (CE value) for each investment type in Figures (1) and (2), respectively (Stock market (x1), real state (x2), government securities (x3), banking deposit (x4)).

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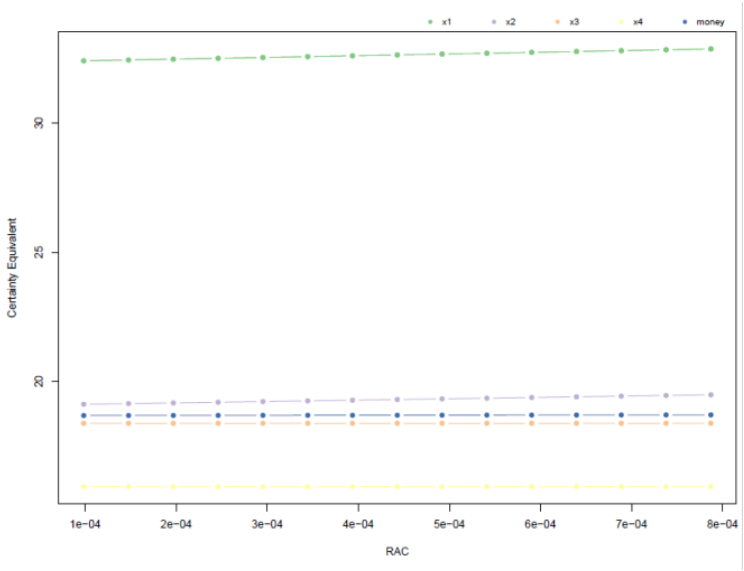

Figure 1. Volatility of the Relative Risk Aversion Coefficient (RRAC).

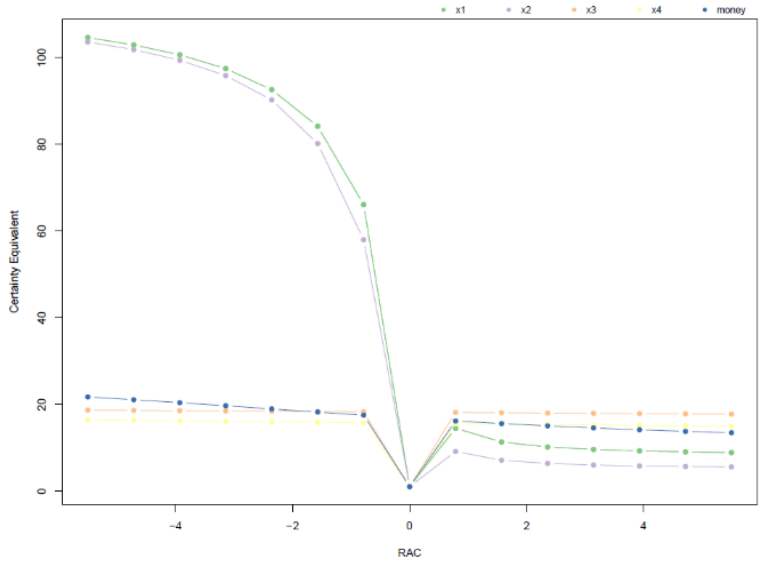

Figure 2. Volatility of Absolute Risk Aversion Coefficients (ARAC).

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To this end, the effect of liability constraints on optimal strategy is investigated, and the optimal amount of each asset is calculated in the insurer basket. The result of the optimization can be seen in Table (4).

Table 4
Weight of the Optimal Portfolio for Power Utility with Different K.

k	**3**	**2**	**1**	**-1**	**-2**
Banking deposit	0.074	0.99	0	0.090	1
Bonds	0.087	0	0	0.080	0
Real Estate	0.138	0	0	0.118	0
Stock	0.61	0	1	0.62	0
cash	0.086	0	0	0.084	0

For all different q in exponential utility, the result indicated that the stock market was the most efficient asset market for investment. As evident in Table (4) and the results of exponential utility, risk-taker insurers invest a greater proportion of their assets in the bank deposits. Also, they invest more money in the stock market. As shown in Figure 3, the optimal portfolio for the risk-taking insurer would be as follows: stock market (x1) with 61 percent, real state (x2) with 14 percent, government securities (x3) with almost 9 percent, cash (x4) and banking deposit (x5) with 7 percent.

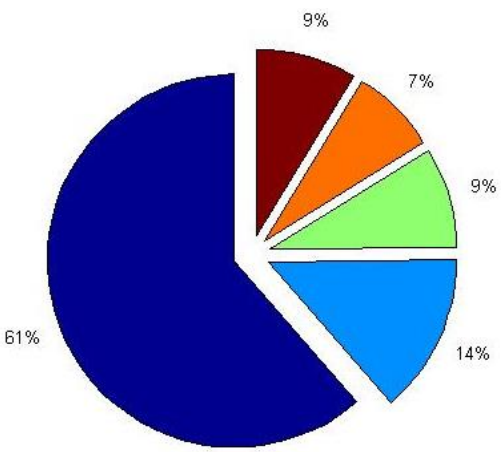

Figure 3. The Subjected Optimum Asset Portfolio of Iran Insurance Company.

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5 Discussion and Conclusion

Given the nature of the asset and liability management method, this method is the best tool for calculating the optimal portfolio for risk aversion companies that seek to optimize the return on their investment assets. Insurance companies are also the biggest client of these methods. With reference to earlier studies, According to the literature review, the net income and expense of insurance companies account for a significant percentage of GDP; therefore, any ungrounded decision in the allocation of assets will cause a potentially large deficit in future payments which will ultimately urge insurers to ask for government grants to avoid bankruptcy.

In developing countries, the government runs the insurance market. Because of its magnitude, any miscalculation in this respect leads to the demand for large loans from the government, which might ultimately cause budget deficits.

Unfortunately, in developing countries, policymakers generally pay little attention to the investment in social insurance because of high inflation, low GDP, and economic problems. This article raises awareness and provides a solution for improving the decision-making process of these organizations, especially in these countries.

In this research, the optimal ALM problem has been investigated with stochastic interest rates and inflation risks under two types of expected utility maximization framework. The addition of liability to asset allocation let to a change in the optimal portfolio. Accordingly, we found that investment in the real state (x2) and stock market (x1) was the most profitable for the risk-seeking investor. Nevertheless, for a risk-averse insurer, considering liability constraints in utility maximization, the ratio of investment in government securities (x3) with a specified interest was higher than the stock market (x1) and real state (x2). Therefore, liability constraints are an important milestone in the decision-making process of organizations.

Moreover, to ensure a definite liability value, it was assumed that the liability process was given by a geometric Brownian motion. The result of this adapted model has shown that for the minimum risk, the insurer should investigate almost 60 percent of its revenue in the stock market. It has also been demonstrated that the risk aversion parameter was one of the most important factors in the investment decisions of the insurer. There are two completely different types of investment portfolios for risk aversion and risk-seeking insurer base on a financial market.

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