Stochastic Asset Liability Modelling: An Indian Perspective

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Abstract

In this paper we discuss various stochastic asset models currently available for actuarial applications. We also discuss one possible stochastic mortality model. The technique of portfolio insurance is discussed. Dynamic asset allocation for a life office, an application of stochastic asset liability modelling, is considered using the Wilkie model in an Indian context.

Keywords

Stochastic asset liability modelling; Portfolio insurance; Dynamic asset allocation; Wilkie model.

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1 Introduction

1.1 The insurance industry has had to face a sustained period of historically low interest rates and falling equity markets (although there are signs of a recent recovery in some countries). This has led to increased interest in asset liability modelling by many participants in the market place, particularly insurance companies.

1.2 In this paper we cover the following aspects of stochastic asset liability modelling:

- Recent advances in stochastic modelling of assets and liabilities with particular focus on assets;
- The technique of portfolio insurance;
- Simulation of various economic variables and asset classes using the Wilkie model; and,
- Dynamic asset allocation in an Indian context.

1.3 In Section 2 we introduce various stochastic asset models that are used in life insurance. We briefly describe some of the features of the asset models. In

Section 3 we describe stochastic modelling of mortality as an example of the stochastic modelling of liabilities. Two methods of implementing portfolio insurance are discussed in Section 4. Simulation of economic variables and some asset classes is set out in Section 5. This section also contains output from a stochastic asset liability model calibrated to Indian conditions. The model has been set up on VIP, Watson Wyatt's proprietary actuarial software. The authors acknowledge their gratitude to Watson Wyatt for its support in this regard.

2 Stochastic asset models in life insurance

2.1 Since the Maturity Guarantees Working Party derived a model of prices of ordinary shares in 1980 actuaries have developed many stochastic asset models. These include interest rate models, option and other derivative models, multi-asset models and multi-currency models besides equity models.

2.2 The table below sets out the various models highlighting some of their applications:

Asset class	Application	Models
Equity	Pricing equity options	Black Scholes lognormal model; Lognormal model with stochastic drift; Hull & White stochastic volatility models; Jump diffusion models*; GARCH^ models
Interest rate	Pricing interest rate options	Black's models
	Modelling short rate	Vasicek; Cox Ingersoll Ross
	Modelling term structure	Heath Jarrow Morton; Hull & White
Multi-asset class	Strategic asset allocation	Wilkie model; Wilkie ARCH; TY model; Smith (jump diffusion model); Cairns
	Tactical asset allocation	Harris (regime switching model); Whitten & Thomas (regime switching model)

*Notes: * - Examples of these include multi-asset class models*
^ - Generalised Autoregressive Conditional Heteroscedastic

2.3 The list of models included in the table above is by no means exhaustive.

2.4 Applications of stochastic asset models include:

- Assessment of liabilities where the payouts depend on interest rates or asset returns, e.g. participating products, guaranteed annuity options, unit-linked contracts with guarantees
- Reserving for guarantees
- Fair value of liabilities
- Financial condition reports

- Business planning
- Dynamic financial analysis
- Risk based capital assesment
- Dynamic asset allocation

2.5 We restrict our discussion of stochastic asset models to life insurance applications. Other applications of stochastic asset models include pricing of derivatives which are outside the purview of this paper. Much of the recent interest in stochastic asset models stems from regulatory developments in the areas of fair value and risk based capital which we will briefly cover later in the section. In Section 5 we cover an application of the Wilkie model for dynamic asset allocation in an Indian context.

Features of stochastic asset models

Structure

2.6 Most of the models are defined in terms of variables (which may take annual values) with recursive relationships connecting them. The basic variables have a random innovation at each step that drives the stochastic nature of the model. To illustrate, the autoregressive conditional heteroscedastic ("ARCH") variation of the Wilkie model essentially defines each variable as a function of its own previous values and other lower order variables in a cascade structure with variance that varies with time within each simulation. In the Wilkie model, price inflation is the lowest order variable which depends only on its own previous value. Price inflation affects other higher order variables like wage inflation, the short and long term fixed interest rate and share price.

2.7 The Cairns model is defined in terms of stochastic differential equations with driving Brownian motions. The Smith model, which is an example of a jump diffusion model, is defined in terms of continuous time equations with Compound Poisson diffusion processes. A jump diffusion model, as its name suggests, can incorporate discrete "jumps" in the values of the variables. As an aside, jump diffusion models are commonly used in other actuarial applications; for example, in ruin theory to model the aggregate loss on an insurance portfolio.

Frequency

2.8 The majority of the models are defined in terms of annual steps, except the Cairns and Smith models which are continuous time models. Models with annual steps are not suitable for the pricing of derivatives as the term of such contracts is often less than a year. For short-term applications like pricing of derivatives, market consistency is of paramount importance. The concept of market consistency is further discussed later in the Section.

Select period

2.9 In their paper [4] Lee and Wilkie discuss the problem of high standard deviation for certain items over the short term, for example inflation. The standard deviation of the forecast for the rate of inflation over one year ahead is the same as over any year ahead. This is contrary to what most people would expect as they would have greater confidence over their forecast for the next year compared to future years. This is simply because many more economic variables can be considered while forecasting inflation over one year that are ignored in the actuarial models. For example, in the Wilkie model, the rate of inflation simply depends on the history of inflation and no other variable.

2.10 One possible way to deal with this is to use exogenous information to improve the estimate of the mean and standard deviation of the rate of inflation. This adjustment can be made for those variables for which alternate estimates are available with greater accuracy than any actuarial model provides. Much like the concept of select period in mortality investigations, the select period should be restricted to a short term, say two years.

Regime switching models

2.11 Models which assume more than one "regime" or "state" are known as regime switching models. The investment world is assumed to behave in two different states with a different set of parameters applying to each variable in each state. There are two distinct ways in which such models have been developed. They are briefly described below.

2.12 One is the threshold model, which has been used by Whitten & Thomas. In each year of each simulation the rate of inflation determines the state, with one or the other state applying if the force of inflation in the previous year is less than or greater than 10%. Thus the investment market is assumed to behave differently when inflation is greater than about 10%.

2.13 Harris' model follows a different approach for modelling the two state investment world. In each year of each simulation a Markov chain determines which state the investment world is in. If the simulation is in state 1 in year t-1 there is a probability, denoted p1, of moving to state 2; the probability of remaining in state 1 is 1- p1. Correspondingly, if the simulation is in state 2 in year t-1 there is a probability, denoted p2, of moving to state 1; the probability of remaining in state 1 is 1- p2.

2.14 Regime switching models may be used by financial institutions in setting tactical asset allocation levels. For example, when the investment market is behaving differently, a regime switching model is capable of capturing this different state whereas other actuarial models will fail to do so and are arguably inappropriate for such applications.

2.15 In financial economics, there are two main methods for calculating values of cashflows:

- Using risk-neutral probabilities and discounting at the risk-free rate; and,
- Using real world probabilities and deflators.

Risk neutral valuation

2.16 Risk-neutral valuation is a technique employed in financial economics to value derivative securities. It introduces an equivalent martingale measure with respect to which the discounted stochastic process (where the discounting is at the risk-free rate) under consideration becomes a martingale. The importance of this valuation method lies in the fact that for every stochastic process there exists an equivalent martingale measure (not necessarily unique) with respect to which the discounted stochastic process becomes a martingale. The equivalent martingale measure is known as the risk-neutral probability measure.

2.17 Since the discounted stochastic process does not grow at all, it implies that under the risk-neutral measure the stochastic process grows at the risk-free rate of return. The risk-neutral measure is often referred to in literature as the 'Q-measure' to distinguish it from the real world measure, often called the 'P-measure'.

2.18 It is important to understand that under the real world measure risky assets (like equities, corporate bonds) will grow at interest rates different from the risk-free rate of return. The risk-neutral valuation framework does not assume that investors will be satisfied with risk-free rate of returns for risky assets.

2.19 Thus, under the risk-neutral valuation framework, the price of a security is given by the expectation of the discounted payoff, where the expectation is taken with respect to the risk-neutral probability measure. The use of risk-neutral probabilities eliminates the need for a subjective choice of discount rate.

State price deflator approach

2.20 A state price deflator is defined as the ratio of state price, $\phi(s)$ and the probability of state s occurring, $p(s)$. A state price security, also known as Arrow-Debreu security, pays out 1 if state s occurs and 0 otherwise. $\phi(s)$ is the price of the state price security and is always positive. $\phi(s)$ is the price of this security at time T=0 which takes into account possible future states at different points in time in the future.

2.21 State price deflators and state probabilities can then be used to value assets. These methods of valuation use discount rates that depend on the occurrence of a particular future state at a time in the future. Interested readers are referred to [3].

Market consistency

2.22 Regulatory developments regarding fair value and those by the Financial Services Authority ("FSA") in the UK have led to increased interest in the profession regarding market consistent valuation. The FSA's preferred approach to the valuation of guarantee, option and smoothing costs is a stochastic valuation carried out using economic scenarios generated from a market consistent asset model.

2.23 A market consistent asset model is defined as a model that:

- delivers prices for assets and liabilities that can be directly verified from the market; and
- must be calibrated to deliver market consistent prices for those assets that reflect the nature and term of participating liabilities.

2.24 Market consistent asset models can be either risk neutral or deflator. A key issue when dealing with market consistent asset models is the calibration of the model. There are several assumptions required by market consistent asset models that cannot be directly implied from market prices. These include the correlation between asset classes, implied volatilities for equities, property and credit.

2.25 Each firm will thus need to have an asset model calibrated not only to market conditions where possible but also to its own unique circumstances. This will lead to every firm having its own scenario file (simulations from the calibrated asset model) rather than an industry wide standard. For further details regarding regulatory developments in the UK, the interested reader is referred to [6].

3 Stochastic liability modelling in life insurance

3.1 In this section we cover stochastic modelling of liabilities. For a deferred annuity product with guaranteed annuity options, mortality improvement represents a significant risk to the insurer. A realistic valuation of the liabilities would require stochastic modelling of mortality which can result in a significant increase in reserves.

Stochastic mortality

3.2 One possible approach to stochastically model mortality is described in the paper Reserving, Pricing and Hedging for Guaranteed Annuity Options [8]. The method starts with a base mortality table applicable for a particular year, for e.g. the LIC a(96-98), say q(x,0). It then uses mortality improvement factors RF(x,t), so that the mortality for age x in year t is q(x,t) = RF(x,t)*q(x,0). This is a deterministic calculation. The method then introduces two random variables applicable to year t, X(t) and Y(t).

3.3 X(t) is a random walk with zero mean and σ_x^2 variance. It takes the following form:

$$X(t) = X(t\text{-}1) - \frac{1}{2}\sigma^2{}_X + \sigma_X . z_X(t)$$

where the $z_x(\ )s$ are independent with zero mean and unit variance.

3.4 Y(t) is dependent on X(t) in the following manner:

$$Y(t) = X(t) - \frac{1}{2}\sigma_y^2 + \sigma_{y.} z_y(t)$$

where the $z_y(\ )s$ are independent of each other and of the $z_x(\ )s$ and are unit distributed. σ_y^2 denotes the variance of Y(t). We start with X(0) = 0 and then the experienced mortality rates in year *t* are assumed to be

$$q(x,t) \times \exp(Y(t)) .$$

3.5 In the above X(t) represents the overall drift of mortality rates that continues from year to year, while Y(t) includes both X(t) and an annual factor that is peculiar to that year, representing for example the effects of an epidemic.

3.6 A limitation of this model is that in any one year it applies the same multiplicative factor at each age *x*. It might be preferable to have a model in which the adjustment factors varied smoothly with *x*. To illustrate, if one were to look at the mortality improvement in India it is not constant with respect to age.

4 Portfolio insurance

4.1 In this section we discuss the technique of portfolio insurance ("PI") and its application to dynamic asset allocation for life offices. PI is based on the principle of replication in option pricing theory. The value of a call option can be replicated by a dynamic portfolio consisting of a combination of a varying proportion of the underlying stock (on which the call option is written) and the risk-free asset. This proportion is known in option pricing literature as the *hedge ratio* and is defined as the inverse of the delta of the call option.

4.2 PI is essentially a technique that determines what proportion of the portfolio should be invested in equities, known as the equity backing ratio ("EBR"). The proportion depends on:

- Solvency ratio (excess of assets over liabilities expressed as a percentage of assets)
- Risk tolerance

4.3 The proportion invested in equities increase with the solvency ratio and the risk capacity. When the solvency ratio declines to zero, all the assets are invested in risk-free assets.

4.4 The basic idea behind PI can best be explained by the use of a simple example. Consider an investment strategy that guarantees a minimum return of 4.5%. With a starting fund of 100 units, assuming a risk-free interest rate of 10% implies that the fund must be able to accumulate to 104.5 in a year's time. The present value of this amount at the risk-free rate of interest is 95 units. Thus 5 units are available to be invested in equities. Using the hedge ratio, PI would convert these 5 units into a percentage (about 20-30% depending upon various parameters) allocation in equities.

4.5 Theoretically, this percentage would be varied on a continuous time basis depending upon the performance of the risky asset and the value of various parameters. Traders in today's time have PI systems at their disposal that are programmed to implement such decision rules.

4.6 Before discussing practical ways of implementing PI it is worth mentioning that the infamous Black Monday (stock market crash in October 1987) is attributed to a large number of players using portfolio insurance. As the market started declining, traders that used PI started selling which led to a vicious downward spiral leading to a fall of more than 20% in the Australian stock market in a single day. Stock markets have since introduced circuit breakers that stop trading after a certain pre-defined fall in the market.

4.7 There are two methods of implementing portfolio insurance:

- Constant proportion portfolio insurance
- Option-based portfolio insurance

Constant proportion portfolio insurance ("CPPI")

4.8 CPPI is the simpler of the two strategies of implementing PI and takes the following form:

Amount in equities = m (Assets –Floor)

4.9 where m is a fixed multiplier, Assets is the current value of assets and Floor is the minimum amount of assets required by the investor. In the case of the investor being a life office, the floor is determined as the minimum solvency margin. The choice of m would depend on the risk aversion of the investor. For example, for the par fund a life office may chose a higher value of m and a lower value for the non-par fund.

4.10 A CPPI strategy sells equities as they fall (as the solvency ratio falls) and buys equities as they rise. The strategy ensures that the value of assets is mostly above the floor, hence the word insurance. This statement is however a probabilistic one, as there is a small probability of a precipitous decline in equities leading to the asset value falling below the floor before the investor has had a chance to completely move into risk-free assets. In bull markets CPPI strategies perform better compared to a reversal (change in market sentiment) which hurts the CPPI investor.

Option-based portfolio insurance ("OBPI")

4.11 OBPI also involves choosing a floor and an investment horizon. OBPI then determines a portfolio that comprises of the risk-free asset and a call option. The maturity value of the risk-free asset is set equal to the floor and the balance of the value of assets and the price of the risk-free asset is invested in the call option.

4.12 The main difference between CPPI and OBPI is the time dependence of the proportion in risky assets in the case of OBPI. The exposure to equities increases as time passes in the case of OBPI, reaching 100% at the horizon. This can pose problems to the institutional investor for whom it may not make much sense to be 100% invested in equities or risk-free asset (vastly different from the typical asset allocation) simply because one calendar period has ended. Interested readers are referred to [7].

5 Model output

5.1 In this section we set out sample results from a stochastic asset liability model calibrated to Indian conditions. The results are based on Wilkie's stochastic asset model and liabilities that are broadly representative of traditional participating ("par") and non-participating ("non-par") products currently sold in India.

5.2 The section is divided in two parts; the first part is devoted to output from the stochastic asset model, while we set out results from the stochastic asset liability model in the latter half.

Stochastic asset model

5.3 In the following paragraphs, we set out sample output that can be generated from a stochastic asset model after calibration to market conditions.

5.4 We set out a table for summary statistics and a graph each for the following economic variables and asset classes:

- Price inflation
- Wage inflation
- Short term fixed interest rate ("Short FI")
- Long term fixed interest rate ("Long FI")
- Equity (total returns including dividends)

5.5 The following table sets out summary statistics for the five variables mentioned above:

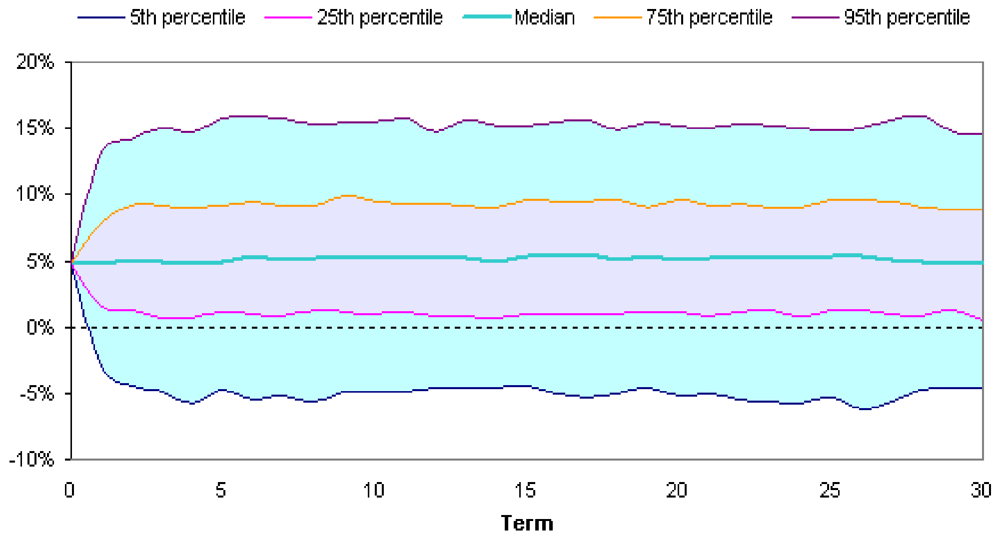
Term (in years)*	5	10	15	20	25	30
Price inflation						
Mean	4.9%	5.0%	5.0%	5.1%	5.1%	5.1%
Standard deviation	5.2%	5.8%	5.9%	6.0%	6.0%	6.1%
Median	4.8%	4.8%	4.8%	4.8%	4.8%	4.9%
Kurtosis	1.04	0.39	0.22	0.15	0.19	0.16
Wage inflation						
Mean	6.5%	6.8%	7.2%	7.4%	7.5%	7.5%
Standard deviation	6.4%	7.6%	8.0%	8.3%	8.5%	8.5%
Median	6.0%	6.0%	6.5%	6.9%	7.1%	7.2%
Kurtosis	0.76	0.36	0.21	0.17	0.13	0.13
Short fixed interest						
Mean	5.9%	6.4%	6.7%	6.9%	7.1%	7.2%
Standard deviation	1.0%	1.3%	1.5%	1.7%	1.7%	1.8%
Median	5.7%	6.2%	6.5%	6.7%	6.9%	7.0%
Kurtosis	0.01	0.01	0.02	0.01	0.01	1.35
Long fixed interest						
Mean	6.5%	6.9%	7.2%	7.4%	7.6%	7.7%
Standard deviation	0.9%	1.3%	1.5%	1.7%	1.8%	1.9%
Median	6.2%	6.6%	6.9%	7.1%	7.2%	7.4%
Kurtosis	2.12	1.76	1.89	1.56	1.41	1.48
Equity (total return)						
Mean	9.0%	9.7%	9.9%	10.1%	10.3%	10.3%
Standard deviation	17.3%	19.0%	19.5%	19.8%	20.0%	20.2%
Median	3.2%	5.8%	6.8%	7.3%	7.7%	7.8%
Kurtosis	1.42	1.06	0.84	0.78	0.71	0.65

*Notes: * - Term X refers to the average over the past X years.*

5.6 The table illustrates that price and wage inflation are marginally positively skewed and are platykurtic (flatter than the normal curve). Interest rates, both long and short, have a low standard deviation.

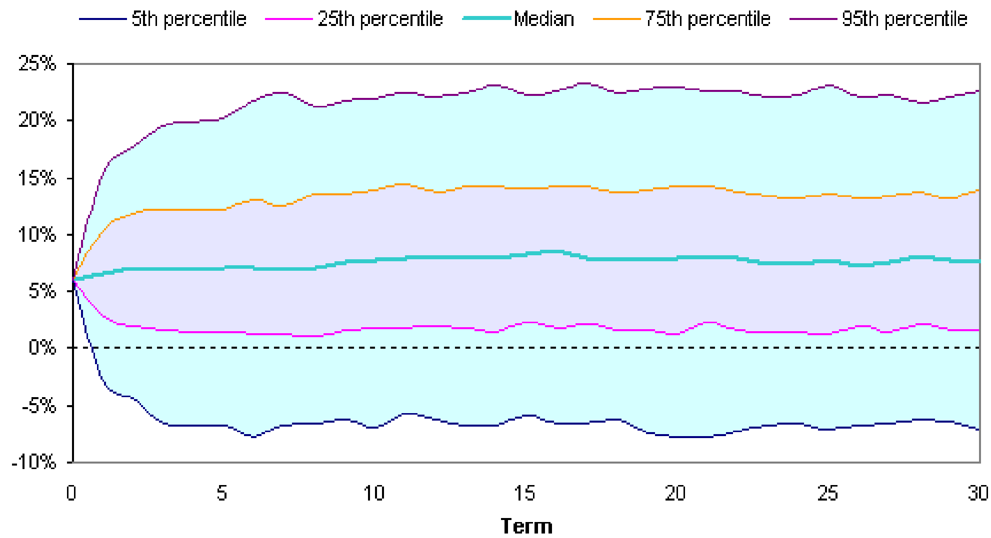
5.7 The graphs below show the various percentiles across varying term for 500 scenarios generated from the Wilkie model.

Force of price inflation



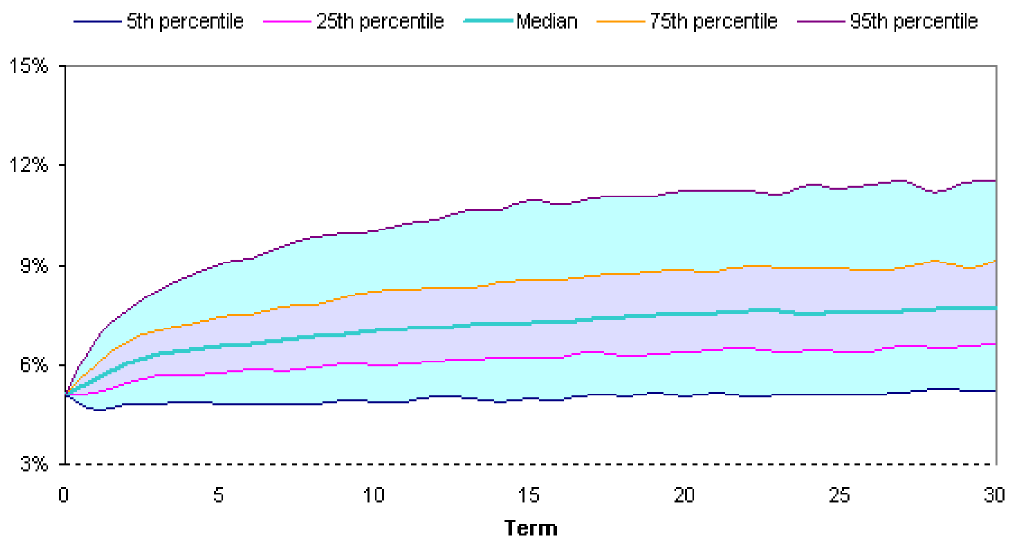
5.8 As can be seen from the graph, the median force of price inflation remains fairly constant over increasing term. The range of values does not diverge in the long term due to a strong mean reversion assumed in the model for price inflation.

Force of wage inflation



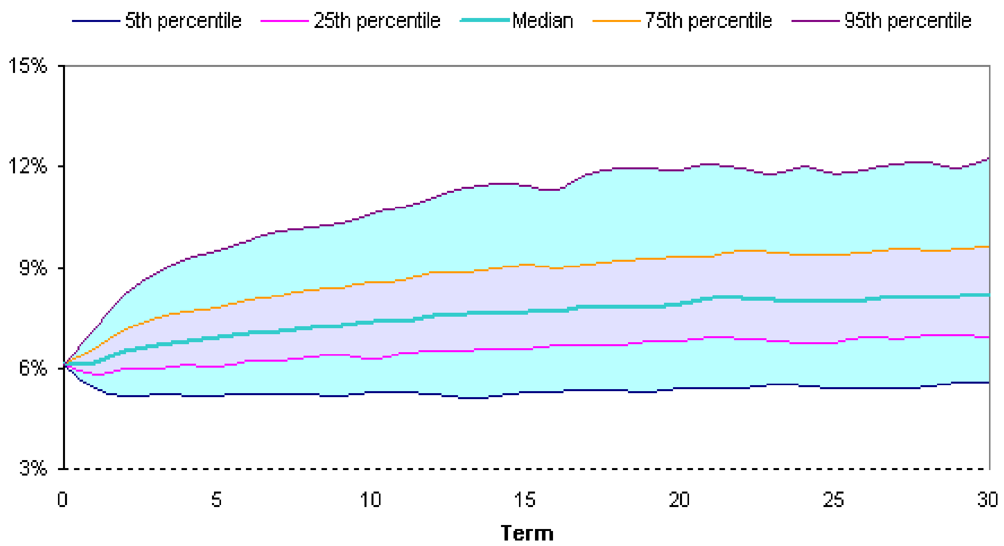
5.9 A more diverse range of values for wage inflation is a consequence of a higher standard deviation assumed in the Wilkie model. In the Wilkie model, wage inflation depends on its own previous values (autoregressive) and also on the previous values of price inflation. For more details on the Wilkie model the interested reader is referred to [9].

Short term fixed interest rate

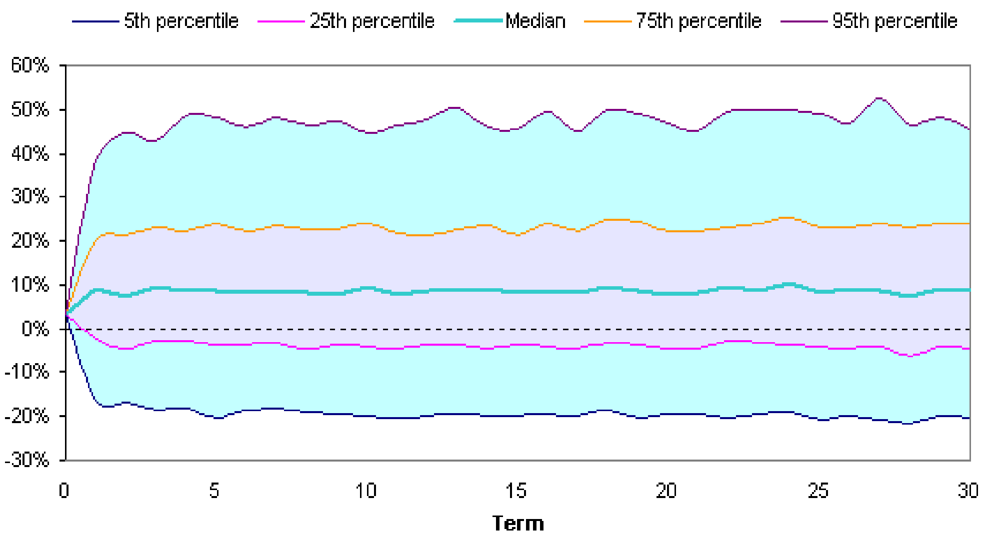


5.10 The short FI (nominal) rate has been prevented to go below 0% by setting a floor in the Wilkie model.

Long term fixed interest rate



Equity



5.11 The high standard deviation assumption for equity yields results in a diverse range of values for equity returns.

Stochastic asset liability model – An example of dynamic asset allocation

5.12 The subsequent paragraphs set out results from the stochastic asset liability model. We have used the CPPI technique to demonstrate dynamic asset allocation for a life office. The results have been shown separately for the par and the non-par fund to illustrate the impact of initial asset allocation.

Description of the model

5.13 In order to demonstrate dynamic asset allocation we have taken the following initial asset allocation for the par and non-par fund:

Initial EBR for the par fund	25%
Initial EBR for the non-par fund	15%

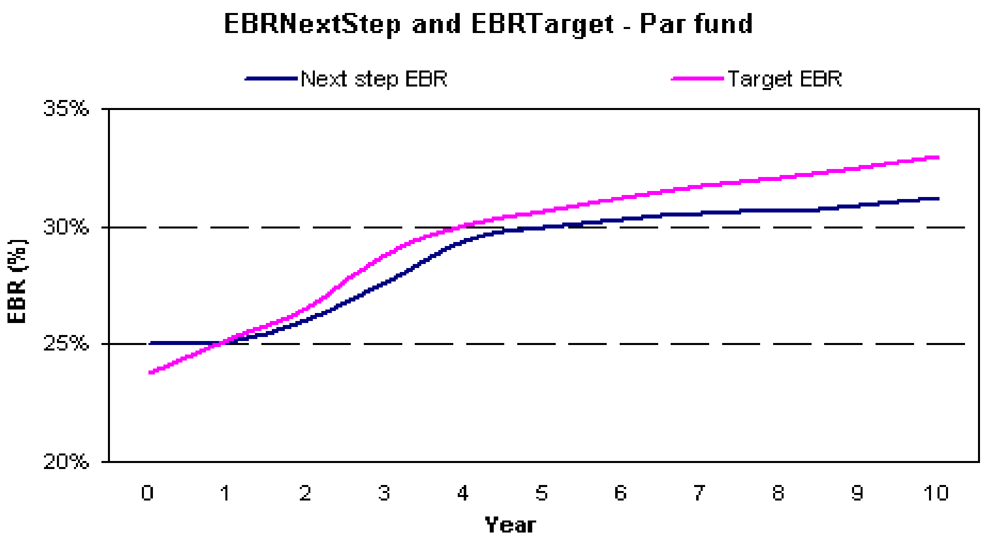
5.14 In accordance with the IRDA Investment Regulations (2002) there currently exists a cap of 35% on the EBR permissible for life offices. The variable 'EBRTarget' is calculated using the CPPI technique where the reserve acts as a floor for the level of assets. We have used the asset share as the value of assets with a pre-defined fall of 20% in the market value of equities as the parameter driving the constant of proportionality m (defined as the inverse of the fall, i.e 5). The variable 'EBRNextStep' denotes the asset allocation proposed by the model for the next year, which varies for each scenario, and is based on the following parameters:

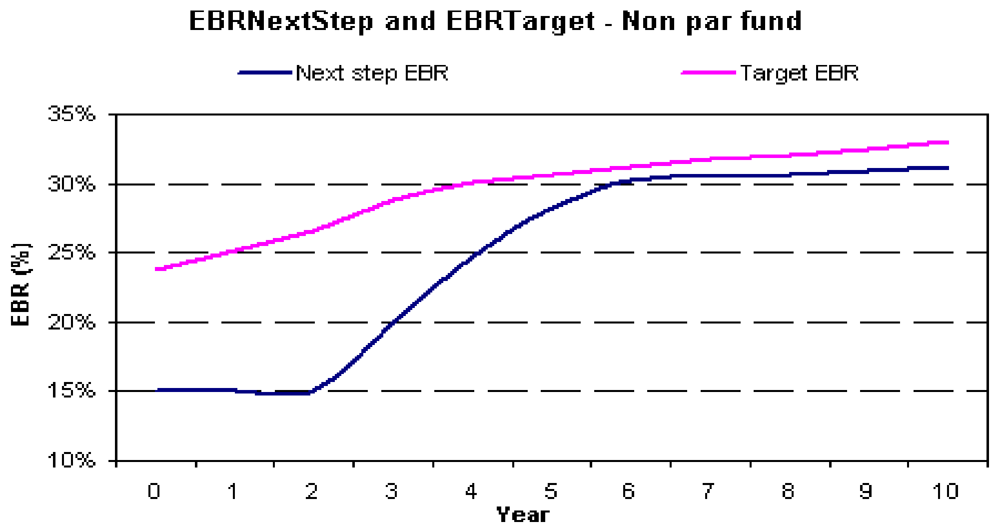
- EBRTarget
- The asset allocation is restricted to be within 5% of the previous year's value
- Capped at 35%

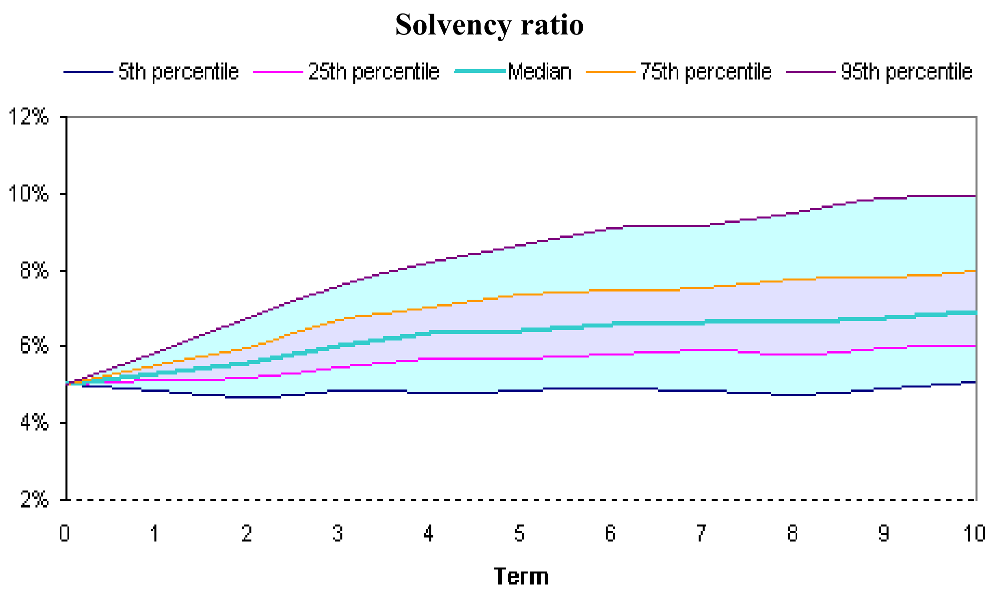
5.15 We set out both these variables and then illustrate the impact of a dynamic strategy on the solvency ratio of the par and non-par funds. For the purpose of this paper, solvency ratio has been defined as the excess of the asset share over the reserve.

Dynamic asset allocation

5.16 In the following section, we set out sample results from the dynamic asset allocation strategy. The graphs below show the mean values of the variables EBRNextStep and EBRTarget over 500 scenarios for the par and non-par fund.







5.17 As the dynamic asset allocation implies an increase in the EBR the solvency ratio shows an increasing trend as well. The cap on the EBR implies that the solvency ratio is bound within a fairly tight range.

6 Concluding remarks

6.1 This paper has dealt with a topical issue that is confronting the financial services industry and in particular the actuarial profession in many markets. The paper is an attempt to present some of the rudimentary aspects of stochastic asset liability modelling. As an example of the many applications of stochastic asset liability modelling, we demonstrate how it can be used to dynamically manage the asset allocation of a life office.

6.2 The paper demonstrates the sort of output that can be generated from such a model rather than an attempt to simulate a virtual life office operating in India and the results should be viewed in this light.

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About the authors

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Heerak graduated in Mathematics from Cambridge University in 1989 and qualified as a Fellow of the Faculty of Actuaries in 1993. In 1996 he also obtained an MBA from Strathclyde Graduate Business School in the United Kingdom. Prior to joining Watson Wyatt in 1999 Heerak had worked for Scottish Amicable Life Assurance Society in Glasgow and for ANZ Grindlays Bank in Kolkata.

While at Scottish Amicable Heerak was involved in a wide variety of actuarial tasks including product pricing, financial modelling and embedded value work. While at ANZ Heerak was responsible for investing the monies of the retirement benefit funds and for advising on actuarial valuations of retirement benefit funds.

Since joining Watson Wyatt Heerak has been involved in several projects for several players in the Indian insurance market. Heerak has been involved in the areas of strategy development, product pricing, training of insurance company senior management, business planning and market analysis. Heerak has also carried out strategic projects covering the Indian mutual fund and banking sectors.

Heerak is also a Fellow of the Actuarial Society of India and sits on the Executive Committee of the Actuarial Society of India.

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Sanchit Maini

Sanchit graduated in Statistics from Delhi University in 1997 and later completed a postgraduate degree in Actuarial Science from Melbourne University in 1999. He qualified as a Fellow of the Institute of Actuaries of Australia in February 2004.

Sanchit joined Watson Wyatt in January 2001. During an initial period in the UK, he was involved in a review of a life company's embedded value for securitisation purposes. Since being in Delhi he has been involved in the preparation of market reports, the modelling of Indian products on VIP, pricing numerous products for clients and filing them with the IRDA and the preparation of business plans.

He has been involved in a stochastic asset liability modelling project for a major UK life insurer including dynamic asset allocation, cost of guarantees and bonus smoothing. He has also been involved in several valuation projects in Sri Lanka, Singapore, Indonesia and the UK, and in modelling Hong Kong and Japanese products on VIP. He has conducted actuarial and VIP training for a client in India.

Prior to joining Watson Wyatt he was working for GE Capital, both in the US and India. At GE Capital, he was working in product development for the universal life and fixed annuity lines of business.

Sumit Narayanan

Sumit joined Watson Wyatt in July 2001 after graduating with merit in M.Sc. Finance and Economics from the London School of Economics. Currently, he is currently pursuing the 300 series exams of the Institute of Actuaries (UK).

During his initial period with Watson Wyatt in the UK, Sumit underwent training on reserving, product pricing and valuations of life and non-life insurance products.

Since transferring to Delhi in December 2001, he has been involved in the preparation of market reports, the modelling of Indian products on VIP, pricing numerous products for clients and filing them with the local regulatory authority and the preparation of business plans for new life insurers in India. He is regularly involved in drafting the Asian life insurance market update. He has also been involved in market analysis of Indian non-life products and produced a review on the state of healthcare financing in India. He was extensively involved in drafting a study on educational infrastructure in India for a multinational insurance company.

More recently, he has concentrated on VIP projects, including conducting VIP training for clients in Sri Lanka and India and writing VIP program for a stochastic asset liability modelling project for a major UK life insurer that included dynamic asset allocation, cost of guarantees and bonus smoothing. He has recently managed the valuation of a UK Friendly Society and has modelled products for a Japanese life insurer and Hong Kong based clients.