Decision Making Under the Risk Using Assets Liability Model (ALM): Case Study on Four Assets with no Transaction Costs

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Abstract
This paper focuses on the Asset Liability Model (ALM) with multistage stochastic model. The model is based on four assets with no transaction costs. The initial wealth is $W_0$ should be invested wisely to meet the liability $L$ at the end of the planned horizon $H$. The best possible decision is to keep the final wealth larger than liability $L$. Using excel solver we try to optimize solution as best possible decision that will at least meeting the liability $L$ at the end of the terminal wealth. The optimization case was adopted from the book (Brandimarte, 2011, pp.754-758) which has been modified with four assets and with no transaction costs. In adapting the case, we added additional returns for extra 2 stocks, while returns for the initial stock and bond remain.

1. INTRODUCTION
The main purpose of the stochastic programming is to find a wise and optimal solution when giving the managerial decision with uncertain data which are random not deterministic. And, programming in this terminology is related to the truth that some problems of certain cases could be mathematically modeled as liner or non-linear programming (Birge and Louveaux, 2011, pp.11.). The stochastic ALM model can be used in many different business decision makings. For instance it is proved as a very effective tool in in international capital market where managerial advices are necessarily needed (N. Topaloglou, et.al. 2008). This ALM model covers a way to manage assets to attain a certain and appropriate return and at the same time “maintaining a comfortable surplus of assets over existing and future liabilities” (Gülpinar, Pachamanova, 2013).

This paper is based on the case from the book (Brandimarte, 2011, pp.754-758) using the multistage stochastic models is a simple asset-liability management (ALM) model and it the following text.
of time instants \(t = 1, \ldots, H\), with no transaction cost; the initial portfolio is chosen at time \(t = 0\), and the liability must be paid at time \(H\). Time period \(t\) is the period between time instants \(t - 1\) and \(t\). In order to represent uncertainty, we may build a tree like that in Fig. 1. Each node \(n_k\) in the tree corresponds to an event, where we should make some decision. We have an initial node no corresponding to time \(t = 0\). Then, for each event node, we have two branches; each branch is labeled by a conditional probability of occurrence, \(P(n_k|n_{n})\), where \(n_z = a(n_k)\) is the immediate predecessor of node \(n_k\). Here, we have two nodes at time \(t = 1\) and

At each node in the tree, we must make a set of decisions. In practice, we are interested in the decisions that must be implemented here and now, i.e., those corresponding to the first node of the tree; the other (recourse) decision variables are instrumental to the aim of devising a robust plan, but they are not implemented in practice, as the multistage model is solved on a rolling-horizon basis. This suggests that, in order to model the uncertainty as accurately as possible with a limited computational effort, a possible idea is to branch many paths from the initial node, and less from the subsequent nodes. Each decision at each stage may depend on the information gathered so far, but not on the future; this requirement is called a non-anticipativity condition. Essentially, this means that decisions made at time \(t\) must be the same for scenarios that cannot be distinguished at time \(t\).

To build a model ensuring that the decision process makes sense, there are two choices:

- We can introduce a set of decision variables \(x'\), representing wealth allocated to asset \(i\) at time \(t\) on scenario \(s\); we should force decision variables to take the same value when appropriate, by writing explicit nonanticipativity constraints for scenarios that cannot be distinguished at time \(t\).
- We can associate decision variables with nodes in the scenario trees and write the model in a way that relates each node to its predecessors. We will illustrate the second alternative in detail, using the following numerical data:
  - The initial wealth is 55.
  - The target liability is 80.
  - There are two assets, say, stocks and bonds; hence, \(I = 2\).
  - In the scenario tree of Fig. 13.11 we have up- and downbranches; in the (lucky) upbranches, total return is 1.25 for stocks and 1.14 for bonds; in the (bad) downbranches, total return is 1.06 for stocks and 1.12 for bonds. We see that bonds play the role of safer assets here. We also see that returns are a sequence of i.i.d. random variables, but more realistic scenarios can be defined.
  - The reward rate \(q\) for excess wealth above the target liability is 1.
  - The penalty rate \(r\) for the shortfall below the target liability is 4. Let us introduce the following notation:
    - \(N\) is the set of event nodes; in our case \(N = \{n_0, n_1, n_2, \ldots, n_8\}\).
    - \(\pi^s\) is the probability of each scenario on its path. If each branch at each node is equiprobable, i.e., the conditional probabilities are always 2, each scenario in the figure has probability \(\pi^s = \frac{1}{8}\), for \(s = 1, \ldots, 8\).
    - \(a(n)\): for instance, \(a(n_3) = n_2\).

Optimization problems are used often in different disciplines such as mathematics, science, economics and others. Optimal or near optimal result related to certain objectives is goal of each researcher that deals with these kinds of problems. In most cases, these problems are multi step constructed, so we execute several processes in a row rather than one. The aim of this paper is to analyze one case study of multistage stochastic problem using solver excel. This problem is about portfolio investment which represents periodical investments and sales of assets. Beside maximization of the wealth, this case has to satisfy some other constrains.

Each node \(n \in V\), apart from the root node no, has a unique direct predecessor node, denoted by \(a(n)\): for instance, \(a(n_3) = n_2\).
• There is a set \( S \subseteq N \) of leaf (terminal) nodes; in our case \( S = \{ n_7, \ldots, n_{14} \} \); for each node \( s \in S \) we have surplus and shortfall variables \( w^+ \) and \( w^- \) related to the difference between terminal wealth and liability.

• There is a set \( T \subseteq N \) of intermediate nodes, where portfolio rebalancing may occur after the initial allocation in node \( n_0 \); in our case \( T = \{ n_1, \ldots, n_6 \} \), for each node \( n \in \{ n_0 \} \cup T \) there is a decision variable \( x_{in} \) expressing the money invested in asset \( i \) at node \( n \). With this notation, the model may be written as follows:

\[
\max \sum_{s \in S} \pi^s (q w^+_s - r w^-_s)
\]
\[
\text{u.t.} \sum_{n=1}^{i} x_{i,n_0} = W_0
\]
\[
\sum_{i=1}^{n} x_{n,n_0} = \sum_{i=1}^{n} x_{in}, \quad \forall n \in T
\]
\[
\sum_{i=1}^{n} R_{n,i} x_{i,n(n)} = \sum_{i=1}^{n} x_{in}, \quad \forall n \in S
\]
\[
x_{in}, w^+_s, w^-_s \geq 0
\]

where \( R_{n,i} \) is the total return for asset \( i \) during the period that leads to node \( n \), and \( \pi^s \) is the probability of reaching the terminal node \( s \in S \); this probability is the product of all the conditional probabilities on the path that leads from root node \( n_0 \) to leaf node \( s \). This is an LP model that may be easily solved by the simplex algorithm, resulting in the solution of Table 13.2. We may notice that in the last period the portfolio is not diversified, since the whole wealth is allocated to one asset, and we should wonder if this makes sense. Actually, it is a consequence of two features of this toy model:

• We are approximating a nonlinear utility function by a piecewise linear function, and this may imply "local" risk neutrality, so that we only care about expected return; we should use either a nonlinear programming model or a more accurate representation of utility with more linear pieces.

2. ADAPTED MODEL WITH FOUR ASSETS

We extend the original model to four assets, three stocks and one bond.

Initial Data

The following is initial data in the table 1 and 2.

| Table 1: Initial data of wealth, liability, reward, penalty and probability and return of assets |
|------------------|-----------------|-----------------|----------------|
| \( W_0 \) | 55.00 | Type | \( R_s \) | \( R_d \) |
| \( L \) | 80.00 | \( R_{s1} \) | 1.26 | 1.07 |
| \( q \) | 1.00 | \( R_{s2} \) | 1.29 | 1.05 |
| \( r \) | 4.00 | \( R_{s3} \) | 1.24 | 1.08 |
| \( pl \) | 0.13 | \( R_b \) | 1.15 | 1.12 |

Where:

\( W_0 \) – initial wealth/investment
\( L \) - liability
\( q \) - reward
\( r \) - penalty
\( pl \) - probability
\( R_{s1} \) - stock1
\( R_{s2} \) - stock2
\( R_{s3} \) - stock3
\( R_b \) - bond

Objective Function and Decision Tree

Adapted case of four assets will be based on the following objective function and the only difference is adding new variables of the additional two stocks, and placing them properly in both the objective function and all the constraints.

Given the above four possible investments (shown in Table 1), and their returns, there is no possibility of achieving the 80$ in all eight possible final outcomes at \( t=3 \). knowing that the objective function gives four times as high priority to reaching the 80$ limit than it does to going further above that limit, it would rather be expected to have the outcome with minimal number of final returns being below the stated limit.
To simplify this objective function we can say that:
Maximize the final outcome giving 4 times higher priority in getting it to be above 80 as oppose to total sum (where more outcomes could be below 80) subject to:

1. In t=0, sum of investments is equal to initial investment (W₀=55).
2. Sum of investments (s₁, s₂, s₃ and B₁) is equal to the return of the previous stage investment
3. Portfolio return at the final stage is equated liability and adjusted wealth (negative if it is below liability value, positive otherwise).

The portfolio tree is like the following:

![Portfolio Tree Diagram]

Data Analysis and Interpretation

Once we set up our objective function with the portfolio decision tree and portfolio assumption we apply the objective function in the excel solver where we have:

After the excel solver is applied the results are as follows:

Table 3. Excel results of the objective function and portfolio assumption

| Stock 1 | Stock 2 | Stock 3 | Bond |
|---------|---------|---------|------|
| x₁₀     | x₁₀     | x₁₀     | x₁₀  |
| 55      | x₂₀     | x₁₀     | x₁₀  |
| x₁₁₁    | x₁₁₁    | x₁₁₁    | x₁₁₁ |
| 65.45   | 65.45   | 65.45   | 65.45 |
| x₁₁₂    | x₁₁₂    | x₁₁₂    | x₁₁₂ |
| 6.25    | 6.25    | 6.25    | 6.25 |
| x₁₁₃    | x₁₁₃    | x₁₁₃    | x₁₁₃ |
| 87.43   | 87.43   | 87.43   | 87.43 |
| x₁₁₄    | x₁₁₄    | x₁₁₄    | x₁₁₄ |
| 68.49   | 68.49   | 68.49   | 68.49 |

The above results mean:

1. Based on the outcome, the initial (t=0) investment should consist of Stock 1 only, so initial investment of $55 will be invested in X₁₀. At t=1, in case of positive outcome from t=0 the investment would be split between Stock 1 and Stock 2. $65.45 and $3.84 respectively. On the other hand, in case of negative outcome from first investment, the second investment would be spread between Stock 1 and Stock 3, $6.59 and $52.26 respectively.
2. At t=2:
   - If both t₀ and t₁ had positive outcomes, then the investment would be in Stock 3 only, the amount of $87.43. If t₀ outcome was positive and t₁ negative, then the investment would be in Stock 3 only. If t₀ outcome was negative and t₁ positive, the investment would be split between Stock 3 and Bond, $46.96 and $26.14 respectively. If both outcomes t₀ and t₁ were negative, then the t₂ investment would be in Stock 1 only, the amount of $63.49.
3. The t=3:
   - The final outcome of those would be $112.79, if $87.43 invested in Stock 3 gave positive return.
The second possible final outcome of those would be $91.80, if those same $87.43 invested in Stock 3 gave negative return.

The final outcomes of those would be $91.85, if $74.07 previously invested in Stock 3 returned positively, while having negative return would make the final outcome of $80.

While assuming the portfolio of 46.96 invested in Stock 3 and 26.16 invested in Bond gave positive return, then the final outcomes of those would be $88.30. On the other hand, did that same portfolio respond negatively the final outcome of its would be $80.

Were the return at t=1 and t=2 negative, the the final outcome of the portfolio would be $80, if $63.49 invested in Stock 1 gave positive return. Otherwise, the final outcome of those would be $67.94, if $63.49 invested in Stock 1 gave negative return.

Table 4. Final outcomes for the stage t1,...t3.

| Invested | x(n)ru | x(rd) | L-wu-wd |
|----------|--------|-------|---------|
| 55       | 69.3   | 58.85 | 112.79  |
| 69.3     | 87.4333889 | 74.074075 | 91.81 |
| 58.85    | 73.10587 | 63.492063 | 91.85 |
| 87.43339 | 112.789071 | 91.850585 | 80.00 |
| 74.07407 | 91.8518519 | 80 | 88.30 |
| 73.10587 | 88.298554 | 80 | 80.00 |
| 63.49206 | 80 | 67.946508 | 80.00 |
| Invested | Optimal final outcomes at the final stage t |
| at t-1  | 67.94 |

3. CONCLUSIONS

Application of the assets liability model (ALM) covers a very huge area of financial planning such as risk management, for individuals and institutions, government agencies banks and other financial institutions, pension plans, and insurance companies (Mulveya&Shettyb, 2004).

Problems and cases, or issues resolved in stochastic programming model “overcome the limitation of the static approaches” (Frauendorfer,Schurle, 2003).

Our model based on the case from the book (P. Brandimarte, 2011, pp.754-758) was tested with four assets with assumed rate of returns applying the excel solver techniques. Results show that only one of eight possible outcomes would be below the limit of $80.

It would be interesting to further research how does one of the four (three stocks and one bond) dominate over others at each stage. As in majority of optimal outcomes investment is made in one of the four, while no single suggests spreading investment in three or four of them.

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