

## Single Stage Model

The problem is the optimal allocation of wealth in international markets and is viewed from the perspective of a US investor who may hold assets denominated in multiple currencies. The scenario generation procedure yields scenarios for the asset returns and exchange rates for the next period that depicts a tree structure. These scenarios are used as inputs to the optimization model. Our problem formulation maximizes the Conditional Value at Risk (CVaR) of the international portfolio returns at the end of the single stage, while parameterizes the expected return at that time. We include instrument and cash flow balance constraints in the root node. The total availability of cash stems from initially available reserves, revenues from the sale of initial asset holdings, and amount received through incoming currency exchanges in the spot market. Correspondingly, the uses of cash include the total expenditures for the purchase of assets and outgoing currency exchange in the spot market. No short sales are allowed in the model. Finally constraints determine the maximum allowable currency hedging via forward contracts. The model takes into account the initial composition of the portfolio, determines optimal rebalancing decisions at the root node that optimizes the CVaR at the end of the holding period (single-stage) while the expected return is constrained by a target return. The model finds the minimum risk and the maximum expected returns points in the efficient frontiers, and a number of intermediate points, in order to construct the Risk/Return efficient frontiers. Two cases of currency hedging are considered: Selective hedging and no hedging.

### Include Files

**Assets1.inc:** Includes the monthly scenario prices of all the asset classes and exchange rates. The assets are the stock indices in four countries: USA, UK, Germany, and Japan (USA.stk, UK.stk, GR.stk, JP.stk), and government bond indices in these countries with 3 different maturities: 1 year (USA.Bnd1, UK.Bnd1, GR.Bnd1, JP.Bnd1), 3 years (USA.Bnd3, UK.Bnd3, GR.Bnd3, JP.Bnd3), and 7 years (USA.Bnd7, UK.Bnd7, GR.Bnd7, JP.Bnd7).

The exchange rates used in the model, include the USD to UKP, USD to DM, and USD to JY exchange rates.

n1 is the root node, with the observed market price of the asset classes and exchange rates while leaves n2-n15001 include the 15000 scenarios.

Finally the file includes the 1-month forward rates: USD to UKP, USD to DM, and USD to JY.

**Probabilities1.inc:** Includes the probabilities for each scenario. In this case the scenarios have the same probabilities.

**Tree1.dat:** Includes the structure of the scenario tree. The root node is the predecessor, connected with the 15000 leaves, which are the successors.

**Initial.dat:** Includes the initial holdings in each asset classes (in domestic currency), as well as the initial cash in each country.

## Multi-Stage Model

The scenario generation procedure yields scenarios for the next two periods that depicts a tree structure. Starting from the root node, we generate a number of scenarios for the first stage, each of which has a number of successor leaves at the second stage. These scenarios are used as inputs to the optimization model. Our problem formulation maximizes the Conditional Value at Risk (CVaR) of the international portfolio returns at the end of the second stage, while parameterizes the expected return at that time. We include instrument and cash flow balance constraints in the root as well as in the first stage scenario nodes. The total availability of cash in each node, stems from initially available reserves, revenues from the sale of initial asset holdings, and amount received through incoming currency exchanges in the spot market. Correspondingly, the uses of cash include the total expenditures for the purchase of assets and outgoing currency exchange in the spot market. No short sales are allowed in the model. Finally constraints determine the maximum allowable currency hedging via forward contracts.

The model takes into account the initial composition of the portfolio, determines optimal rebalancing decisions at the root and first stage scenario nodes that optimizes the CVaR at the end of the holding period (two-stage) while the expected return is constrained by a target return.

The model again finds the minimum risk and the maximum expected returns points in the efficient frontiers, and a number of intermediate points, in order to construct the Risk/Return efficient frontiers. Two cases of currency hedging are considered: Selective hedging and no hedging.

### Include Files

**Assets2.inc:** Includes the monthly scenario prices of all the asset classes and exchange rates, for two-stage model. The assets again are the stock and bond indices in four countries: USA, UK, Germany, and Japan.

n1 is the root node, with the observed market price of the asset classes and exchange rates while nodes n2-n151, connected with the root node, are the nodes in first stage, each of which has 100 successor leaves at the second stage. Thus, the total number of scenarios at the second stage is again 15000.

Finally the file includes the 1-month forward rates for the first stage, and the 150 scenarios for 1-month forward rates starting at the end of the first stage.

**Probabilities2.inc:** Includes the probabilities for each scenario leaf at the second stage. Again, the scenarios have the same probabilities.

**Tree2.dat:** Includes the structure of the scenario tree. The root node is the predecessor, connected with the 150 intermediate nodes, each of which is connected with 100 leaves. The total number of leaves nodes is  $150 * 100$ .

