Stochastic Programming Models for Managing International Investment Portfolios

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Points of Discussion:

➢ Problem Issues
  ▪ Problem framework & risk factors
  ▪ Diversification & Hedging policies
  ▪ Risk management metrics

➢ Modeling Approaches
  ▪ Scenario Generation
  ▪ Optimization Models (Stochastic Programs)
    (jointly determine portfolio composition and hedging levels in each market – selective hedging)
  ▪ Introduction of Derivative Securities in Portfolio

➢ Empirical Assessment of Models & Investment Strategies
  ▪ Risk/Return Profiles of Portfolios (static tests)
  ▪ Out-of-sample Performance (Consistency)
  ▪ Backtesting (Ex-post performance)
International Portfolio Management:

**The Problem:**
Allocation of funds to international assets
Dynamic management of portfolio

**The Objectives:**
Effective Management of Risk/Return Tradeoffs (parametric programs)
Diversification & Hedging

**The Needs:**
Representation of uncertainty capturing market & exchange rate risks
Portfolio Optimization Models utilizing suitable risk measures

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International Diversification

- It pays to diversify internationally
- Positive empirical evidence holds for portfolios of equities and bonds
- Intl. diversification entails additional risks (currency exchange fluctuations)
Effects of international diversification?

They depend on the volatility and correlation structures of the international markets and currency exchange rates.


Observations:

- General *increase* in local return correlations
- Volatility is *contagious* across markets
- Intl. diversification benefits derived in part from exposure to *currency risk*
- Currency risk (partly) hedged with forward currency exchanges
- Derivative securities - alternative risk management means
  (to hedge either market risk, or exchange risk, or both)

Holistic risk management tools needed.

To Hedge or Not to Hedge Currency Risk?

  Yes! *Free lunch* in currency hedging!
- Kaplanis and Schaefer, *J. of Economics and Business*, 1991:
  Some times Yes and some times No, else we don’t know!
- P. Jorion, *J. of Portfolio Management*, 1989:
  Some times Yes, some times No, else we need to determine a hedge ratio!
- F. Black, *J. of Finance*, 1990:
  Universal hedge ratio for all investors and all foreign holdings.
  Some times Yes, some times No, else we have a hedge ratio!
- Abken and Shrikhande, *Federal Reserve Bank of Atlanta Economic Review*, 1997:
  Course of action influenced by various factors.
- Beltratti, Laurent and Zenios, “*Scenario Modeling of Selective Hedging Strategies*”,
  *JEDC* (forthcoming):
  *Selective Hedging is the Preferred Strategy!*
  *We also formulate implementable hedging policies.*

  Single period MAD model Historical observations used as scenarios
Factors found empirically to affect the performance of alternative hedging policies

The literature presents different views as to the optimal course of (currency hedging) action for international portfolio management depending on factors such as:

• Investment opportunity set
• Investor’s reference currency denomination
• Representation of uncertainty
• Timeframe of study (calibration data)
• Investor’s time horizon and risk taking criteria
• Investment strategy (static vs dynamic)

Selective Hedging: Integrative framework
Endogenize hedging decisions in portfolio selection procedure

- Scenarios of index domestic returns and exchange rates capturing correlations between them (define scenarios of holding period returns)
- Currency hedging via forward exchanges and/or derivatives (alternatives for controlling hedging decisions)
- Portfolio optimization models determine portfolio compositions and currency hedging levels

Extensions/Contributions:
- CVaR risk measure (more appropriate for skewed distributions, coherent)
- Scenario generation procedures (& Stability investigation)
- Operationalization of hedging decisions (specification of forward contracts)
- Introduction of derivatives in portfolio optimization models
**The Problem:**
- International asset-allocation problem
  (single- and two-stage SP models; monthly time steps)

**Assets:**
- Stock Indices in various countries (USD, GBP, DEM, JPY)
- Government Bond Indices in various countries
  - Short-term bonds (1-3 years)
  - Intermediate-term bonds (3-7 years)
  - Long-term bonds (7-10 years)
- Derivative Securities:
  - Stock Index Options & Quantos

**Data Sources:**
- Morgan-Stanley MSCI Data (Stock Indices)
- Datastream
  - Salomon Brothers Government Bond Indices
  - Spot & Forward Exchange Rates

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### Descriptive Statistics of Historical Data

<table>
<thead>
<tr>
<th>Country</th>
<th>Mean</th>
<th>St.Dev.</th>
<th>Skewness</th>
<th>Kurtosis</th>
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<tr>
<td>USS</td>
<td>1.519%</td>
<td>3.900%</td>
<td>-0.465</td>
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<td>GRS</td>
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<td>5.773%</td>
<td>-0.511</td>
<td>4.503</td>
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<tr>
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<td>6.336%</td>
<td>0.022</td>
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<tr>
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<td>US7</td>
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<td>1.646%</td>
<td>-0.047</td>
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<tr>
<td>UK1</td>
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<td>UStoGR</td>
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<td>UStoJP</td>
<td>0.303%</td>
<td>0.133%</td>
<td>1.123</td>
<td>6.904</td>
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</table>

**Period:** Jan. 1990 - Aug. 2000 (128 monthly observations)

**Generally, asset returns are not normal; exhibit asymmetries and fat tails.**

**Motivation for:**
- alternative scenario generation procedures
- risk metrics suitable for asymmetric distributions (i.e., CVaR)
- alternative option pricing procedure
Scenario Generation:

1. **Principal Component Analysis (PCA)**
   - Calibrated using historical market data
   - Directed selective sampling from empirical distributions of PCs
   - Bayes-Stein estimation corrections
   - Difficult extension to multistage scenario trees
   - Do not match all statistical characteristics

2. **Moment-Matching Scenario Generation Methods**
   (Hoyland, Wallace) – *Management Science*, 2002
   (Hoyland, Wallace, Kaut) – *Comp. Optim. & Appl.*, 2003
   - First four marginal moments & correlations match target values
   - Targets estimated using historical data
   - Scenario tree constructions

   Model calibration: 10 past years (rolling horizon)

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**Scenario Trees**

![Scenario Tree Diagram](image)
Asset inventory constraints:

\[ w_{ik}^0 = h_{ik} + x_{ik}^0 - y_{ik}^0 \quad \forall k \in C, \forall i \in I_k \]
\[ w_{ik}^n = w_{ik}^{p(n)} + x_{ik}^n - y_{ik}^n \quad \forall k \in C, \forall i \in I_k, \forall n \in N \setminus \{0, L\} \]

Cash balance (base currency):

\[ c_k^0 + \sum_{i \in I_k} y_{ik}^0 P_{ik}^0 (1 - \zeta_i) + \sum_{c \in C_f} v_{c}^{00} (1 - \varphi_c) = \]
\[ \sum_{i \in I_k} x_{ik}^0 P_{ik}^0 (1 + \zeta_i) + \sum_{c \in C_f} v_{c}^{00} (1 + \varphi_c) \quad k = C \setminus C_f \]

\[ c_k^n + \sum_{i \in I_k} y_{ik}^n P_{ik}^n (1 - \zeta_i) + \sum_{c \in C_f} v_{c}^{0n} (1 - \varphi_c) + v_{c}^{p(n)} = \]
\[ \sum_{i \in I_k} x_{ik}^n P_{ik}^n (1 + \zeta_i) + \sum_{c \in C_f} v_{c}^{0n} (1 + \varphi_c) \quad k = C \setminus C_f, n \in N \setminus \{0, L\} \]

Cash balance (foreign currencies):

\[ c_k^0 + \sum_{i \in I_k} y_{ik}^0 P_{ik}^0 (1 - \zeta_i) + \frac{1}{e_k^0} v_k^{00} (1 - \varphi_k) = \]
\[ \sum_{i \in I_k} x_{ik}^0 P_{ik}^0 (1 + \zeta_i) + \frac{1}{e_k^0} v_k^{00} (1 + \varphi_k) \quad k \in C_f \]

\[ c_k^n + \sum_{i \in I_k} y_{ik}^n P_{ik}^n (1 - \zeta_i) + \frac{1}{e_k^n} v_k^{0n} (1 - \varphi_k) = \]
\[ \sum_{i \in I_k} x_{ik}^n P_{ik}^n (1 + \zeta_i) + \frac{1}{e_k^n} v_k^{0n} (1 + \varphi_k) + \frac{1}{f_k^{p(n)}} v_k^{p(n)} \quad k \in C_f, n \in N \setminus \{0, L\} \]

Asset Sale Limits

\[ 0 \leq y_{ik}^0 \leq h_{ik} \quad \forall k \in C, \forall i \in I_k \]
\[ 0 \leq y_{ik}^n \leq w_{ik}^{p(n)} \quad \forall k \in C, \forall i \in I_k, \forall n \in N \setminus \{0, L\} \]
### Generic Multistage SP Formulation for International Portfolio Management Problem

**Initial Portfolio Value**

\[
V_0 = \sum_{k \in C} \left( c_k^0 + \sum_{i \in I_k} h_{ik} P_{ik}^0 \right) e_k^0
\]

**Final Portfolio Value**

\[
V_n = c_n^n + \sum_{i \in I_k} w_{ik}^{p(n)} P_{ik}^n + \sum_{c \in C_f} \left( y_c^{p(n)} + e_c^n e_n^n + \sum_{i \in I_c} w_{ic}^{p(n)} P_{ic}^n - \frac{V_c^{p(n)}}{f_c^{p(n)}} \right) \quad n \in L, k \in C \setminus C_f
\]

**Portfolio Return**

\[
R_n = \frac{V_n}{V_0} - 1 \quad n \in L
\]

**Parametric bound on Expected Portfolio Return**

\[
\sum_{n \in L} \pi_n R_n \geq \mu
\]

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### Generic Multistage SP Formulation for International Portfolio Management Problem

**CVaR definition**

\[
y_n^+ \geq z - R_n \quad n \in L
\]

\[
y_n^+ \geq 0 \quad n \in L
\]

**Objective Function:**

Maximize \[
\bar{z} - \frac{1}{1 - \beta} \sum_{n \in L} \pi_n y_n^+
\]

\[
z \quad : \text{the VaR of portfolio return (at (1-\(\beta\)) percentile)}
\]

the objective value is the respective CVaR

**Development of CVaR models:**

Q1: Benefits from international diversification

Potential benefits from international diversification

- Improvement in risk-return profiles regardless of risk metric (preferable strategy: selective hedging)
- Benefits more evident for intermediate risk-tolerance levels.
Ex-post benefits from international diversification.

Realized Returns for US and Intl. Selectively Hedged Portfolios of Stocks & Bonds
(CVaR Model with parameters $\mu=0.0\%$, $\beta=95\%$)

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Wealth Level</th>
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<tbody>
<tr>
<td>Jan-98</td>
<td>1.00</td>
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<tr>
<td>Apr-98</td>
<td>1.05</td>
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<tr>
<td>Jul-98</td>
<td>1.10</td>
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<td>Oct-98</td>
<td>1.15</td>
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<td>1.45</td>
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<tr>
<td>Jul-00</td>
<td>1.50</td>
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<tr>
<td>Oct-00</td>
<td>1.55</td>
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<tr>
<td>Jan-01</td>
<td>1.60</td>
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<tr>
<td>Apr-01</td>
<td>1.65</td>
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</table>

Ex-post Realized Returns
(Selective Hedging 95%-CVaR Model with various values of target monthly return ($\mu$))

<table>
<thead>
<tr>
<th>$\mu$ (Target Monthly Return)</th>
<th>Wealth Level</th>
</tr>
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<tbody>
<tr>
<td>0.0%</td>
<td>1.00</td>
</tr>
<tr>
<td>0.8%</td>
<td>1.05</td>
</tr>
<tr>
<td>1.0%</td>
<td>1.10</td>
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<tr>
<td>1.2%</td>
<td>1.15</td>
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Time Period: Jan-98, Apr-98, Jul-98, Oct-98, Jan-99, Apr-99, Jul-99, Oct-99, Jan-00, Apr-00, Jul-00, Oct-00, Jan-01, Apr-01
Comparison of CVaR & MAD models (ex-post performance)

Ex-post Realized Returns with Selective Hedging CVaR and MAD Models
(at target levels of monthly portfolio return $\mu = 0.0\%$ and $0.8\%$)

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<thead>
<tr>
<th>Time Period</th>
<th>Wealth Level</th>
<th>1.00</th>
<th>1.05</th>
<th>1.10</th>
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<th>1.25</th>
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<tr>
<td>Jan-98</td>
<td>MAD ($\mu = 0.0%$)</td>
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<td>Apr-98</td>
<td>CVaR ($\mu = 0.0%$)</td>
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<td>Jul-98</td>
<td>MAD ($\mu = 0.8%$)</td>
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<td>Oct-98</td>
<td>CVaR ($\mu = 0.8%$)</td>
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Comparison of CVaR & MAD models (ex-post performance)

Geometric Mean vs Standard Deviation of ex-post Realized Monthly Returns
Q2: Which is an appropriate hedging strategy?

Comparison of Hedging Policies (CVaR Model)

Efficient Frontiers for CVaR Model (Stocks only)

Efficient Frontiers for CVaR Model (Bonds only)
Comparison of Hedging Strategies (CVaR Model)

Efficient Frontiers for CVaR Model (Stocks and Bonds)

Selective Hedging is the more effective (flexible) strategy.

Alternative Selective Hedging Strategies
(via constraints on Forward Currency Exchange Decisions)

1. \( v^{fh}_{i} \leq e^p_{i} \sum w^{n}_{i} P^{n}_{ik} \quad \forall k \in C_f, \forall n \in N \setminus L \)

2. \( v^{fh}_{i} \leq \sum_{c \in S(n)} \frac{\pi_c}{\pi_n} e^c_{i} \sum w^{n}_{ik} P^{c}_{ik} \quad \forall k \in C_f, \forall n \in N \setminus L \)

3. No constraint on forward currency exchange contracts
   (Transactions in forward markets viewed as separate alternatives in investment opportunity set)
Ex-ante Comparison of Alternative Hedging Strategies

Ex-post Performance of Alternative Hedging Strategies
Single- or Two-Stage SP Model? (Comparison)

In static tests (Ex-ante):
  Two-stage SP model is clearly superior to single-stage
  (Dominant efficient frontiers)

In backtesting experiments (ex-post):
  The models exhibit similar performance/behavior
  No dominating model can be indisputably identified

  1-stage model affords finer representation of
  short-term uncertainty, while
  2-stage model captures effects of subsequent period(s)

Ex-ante Comparison of Single- & Two- Stage Models
Ex-post Comparison of Single- & Two-Stage SP Models
Incorporating Derivatives in Portfolios:

• Introduction of derivatives in portfolio (European options with one-month maturity)
  - Options on stock indices
  - Quantos on foreign stock indices
  - Currency options (in progress)

• Derivatives priced consistently with postulated scenario sets and satisfying arbitrage-free conditions

• Investigation of alternative risk management strategies

Incorporating Derivatives in International Portfolios

Investments in different classes of options:

A. **Quantos**: Fixed exchange rate foreign equity options.
   Relevant for jointly managing foreign market risk and exchange rate risk.
   Payoff of a call Quanto in reference currency:
   \[ C = \text{Max} (S X - K, 0) \]

B. **Simple Options**: Relevant for managing foreign market risk, but unconcerned about exchange rate risk.
   Payoff of a call option in foreign currency:
   \[ C = \text{Max} (S - K, 0) \]

C. **Currency Options**: Rights but not obligations for currency exchanges at prespecified rates at option’s expiration.
Pricing of Options
(Consistently with postulated scenario sets)

- Determine a new (risk neutral) probability measure on postulated scenario set based on Radon-Nikodym principle; satisfy martingale property.
- The price of an option is the expected value (under the risk neutral probability measure) of discounted (with riskless rate) payoffs at maturity.
- Currency options priced using procedure of Corrado & Su.
- No-arbitrage conditions verified.

Risk Neutral Valuation:

- The price of the option on asset S is the expected payoff of the option under all scenarios, in Risk-Neutral Measure, discounted at the risk-free rate. Thus, for a Quanto Call:

\[
c = e^{-rdt} \sum_{n=1}^{N} \bar{p}_n \max(XS_n - K, 0)
\]
Incorporating Derivatives in International Portfolios

Trading Strategies involving Options

**Straddle**
- 1 Long Call and 1 Long Put with the same exercise price \( X \) and the same maturity

**Strangle**
- 1 Long Call (exercise price \( X_2 \))
- 1 Long Put (exercise price \( X_1 \))
- with the same maturity

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Incorporating Derivatives in International Portfolios

**Strip**
- 1 Long Call and 2 Long Puts
- With the same exercise price \( X \) and the same maturity

**Strap**
- 2 Long Call and 1 Long put
- with the same exercise price \( X \)
- and the same maturity
Shaping portfolio risk using options

Risk/Return Efficient Frontiers Of Portfolios with various trading strategies of Quanto Options vs Portfolios Without Options
Ex post Realized Returns of Portfolios with different strategies of Options (μ=1%)
Ex post Realized Returns of Portfolios with Quantos and Simple options
(Strangle Strategy, $\mu=1\%$)

<table>
<thead>
<tr>
<th>Time period</th>
<th>Realized Return</th>
<th>Quantos+Forwards</th>
<th>Simple+Forwards</th>
<th>WithoutOptions</th>
</tr>
</thead>
<tbody>
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<tr>
<td>Aug-98</td>
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<tr>
<td>Nov-98</td>
<td>1.05</td>
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<td>Feb-99</td>
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<td>May-99</td>
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<td>Aug-99</td>
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<td>Nov-99</td>
<td>1.25</td>
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<td>Feb-00</td>
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<td>May-00</td>
<td>1.35</td>
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<td>Aug-00</td>
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<td>Feb-01</td>
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</tbody>
</table>

Ex post Realized Returns of Portfolios with and without Options (Straddle Strategy, $\mu=1\%$)

<table>
<thead>
<tr>
<th>Time period</th>
<th>Realized Return</th>
<th>Quantos+Forwards</th>
<th>Simple+Forwards</th>
<th>WithoutOptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>May-98</td>
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Concluding Remarks:

- Scenario generation methods provide effective means for representing uncertainty
- CVaR models constitute effective risk management tool
- Internalizing currency hedging decisions (via forward contracts) in the models improves ex-ante and ex-post results
- Introduction of derivatives leads to further performance improvements
  Particularly the integrated handling of market and currency risks (use of quantos)

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  (WP 02-02, 03-05, ...)

Support for junior researchers