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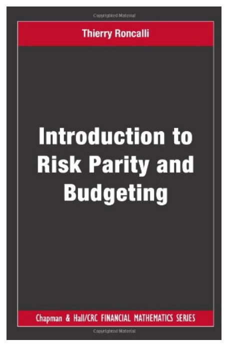
Introduction to Risk Parity and Budgeting

This book describes the Gauss library RPB, which has been developed for the book TR-RPB:

(TR-RPB) Roncalli T. (2013), *Introduction to Risk Parity and Budgeting*, Chapman & Hall/CRC Financial Mathematics Series, 410 pages.



Description and materials of *Introduction to Risk Parity and Budgeting* are available on the author's website:

`http://www.thierry-roncalli.com/riskparitybook.html`

or on the Chapman & Hall website:

`http://www.crcpress.com/product/isbn/9781482207156`

Remark 1 *This manual is a work in progress. Many procedures are not yet described. I continue to write this manual every week. So please check from time to time in order to have the latest version.*

Contents

Chapter 1

Introduction

1.1 Installation

1. The file *gauss-rpb.zip* is a zipped archive file. Copy this file under the root directory of Gauss, for example `c:\gauss`.

2. Unzip the file. Directories will then be created and files will be copied over them:

`target_path\dlib`	DLLs
`target_path\lib`	library file RPB.LCG
`target_path\rpb`	*readme.txt*
`target_path\rpb\prg`	example and tutorial files
`target_path\rpb\src`	source code files
`target_path\src`	source code files

3. If the root of Gauss is `c:\gauss`, the installation is finished, otherwise we have to modify the paths of the library using notepad or the LibTool. Another way to update the library is to run Gauss, log on to the `target_path\rpb\src` directory, delete the path with the command **lib rpb -n** and add the path to the library with the command **lib rpb -a**.

1.2 Getting started

Gauss 6.0+ for Windows is required to use the **RPB** routines.

1.2.1 readme.txt file

The file *readme.txt* contains last minute information on the **RPB** procedures. Please read it before using them.

1.2.2 Setup

In order to use these procedures, the **RPB** library must be active. This is done by including **RPB** in the LIBRARY statement at the top of your program:

library rpb;

To reset global variables in subsequent executions of the program and in order to load DLLs, the following instruction should be used:

rpbSet;

1.3 What is RPB ?

RPB is a Gauss library designed to accompany the book *Introduction to Risk Parity and Budgeting.*

RPB contains the procedures whose list is given below.

1. **Backtesting**

   (a) **Capitalized_Libor**: Computes the value of an investment in Libor.

   (b) **Estimate_Monthly_Statistics**: Computes the monthly performances of a strategy.

   (c) **Estimate_Yearly_Statistics**: Computes the yearly performances of a strategy.

   (d) **Reporting_Basktest**: Computes the main performance and risk statistics of a backtest.

   (e) **Simulate_Monthly_Basktest**: Simulates the performance of a basket of strategies with a rebalancing scheme at the end of the month.

   (f) **Simulate_Basktest**: Simulates the performance of a basket of strategies with given rebalancing dates.

2. **Bond portfolios**

   (a) **Barbell_Calibrate**: Calibrates a barbell portfolio.

   (b) **Bond_Duration**: Computes the duration of a bond.

   (c) **Bond_Generate_Portfolio**: Generates a bond portfolio.

(d) **Bond_Portfolio_VaR**: Computes the value-at-risk of a bond portfolio.

(e) **Bond_Portfolio_VaR_PCA**: Computes the risk contributions of a bond portfolio with respect to PCA factors.

(f) **Bond_Portfolio_VaR_RC**: Computes the risk contributions of a bond portfolio.

(g) **Bond_Price**: Computes the price of a bond.

(h) **Bond_VaR**: Computes the value-at-risk of a bond.

(i) **Bond_VaR_RC**: Computes the risk contributions of a bond.

(j) **Bond_YTM**: Computes the yield to maturity of a bond.

(k) **Compute_RC_Credit**: Computes the risk contributions of a credit portfolio.

(l) **Risky_Bond_Price**: Computes the price of a risky bond.

(m) **Risky_Bond_Price_EDT**: Computes the price of a risky bond (exponential default time).

3. **Copula models**

(a) Cumulative density function

i. **cdfCopulaAMH**: Computes the cdf of the AMH copula.
ii. **cdfCopulaClayton**: Computes the cdf of the Clayton copula.
iii. **cdfCopulaDeheuvels**: Computes the cdf of the Deheuvels copula.
iv. **cdfCopulaFGM**: Computes the cdf of the FGM copula.
v. **cdfCopulaFrank**: Computes the cdf of the Frank copula.
vi. **cdfCopulaGalambos**: Computes the cdf of the Galambos copula.
vii. **cdfCopulaGumbel**: Computes the cdf of the Gumbel copula.
viii. **cdfCopulaGumbel3**: Computes the cdf of the Gumbel copula (three-dimension case).
ix. **cdfCopulaGumbelBarnett**: Computes the cdf of the Gumbel-Barnett copula.
x. **cdfCopulaHuslerReiss**: Computes the cdf of the Husler-Reiss copula.
xi. **cdfCopulaLogisticGumbel**: Computes the cdf of the Logistic Gumbel copula.
xii. **cdfCopulaLower**: Computes the cdf of the lower bound copula.
xiii. **cdfCopulaLower2**: Computes the cdf of the lower bound copula (two-dimension case).

xiv. **cdfCopulaMarshallOlkin**: Computes the cdf of the Marshall-Olkin copula.

xv. **cdfCopulaNormal**: Computes the cdf of the normal copula.

xvi. **cdfCopulaNormal2**: Computes the cdf of the normal copula (two-dimension case).

xvii. **cdfCopulaPlackett**: Computes the cdf of the Plackett copula.

xviii. **cdfCopulaProduct**: Computes the cdf of the product copula.

xix. **cdfCopulaProduct2**: Computes the cdf of the product copula (two-dimension case).

xx. **cdfCopulaStudent**: Computes the cdf of the Student copula.

xxi. **cdfCopulaStudent2**: Computes the cdf of the Student copula (two-dimension case).

xxii. **cdfCopulaUpper**: Computes the cdf of the upper bound copula.

xxiii. **cdfCopulaUpper2**: Computes the cdf of the upper bound copula (two-dimension case).

xxiv. **cdfSurvivalCopula**: Computes the cdf of the survival copula.

(b) Probability density function

i. **pdfCopulaFrank**: Computes the pdf of the Frank copula.

ii. **pdfCopulaGalambos**: Computes the pdf of the Galambos copula.

iii. **pdfCopulaGumbel**: Computes the pdf of the Gumbel copula.

iv. **pdfCopulaGumbel3**: Computes the pdf of the Gumbel copula (three-dimension case).

v. **pdfCopulaGumbelBarnett**: Computes the pdf of the Gumbel-Barnett copula.

vi. **pdfCopulaLogisticGumbel**: Computes the pdf of the Logistic Gumbel copula.

vii. **pdfCopulaNormal**: Computes the pdf of the normal copula.

viii. **pdfCopulaNormal2**: Computes the pdf of the normal copula (two-dimension case).

ix. **pdfCopulaPlackett**: Computes the pdf of the Plackett copula.

x. **pdfCopulaStudent**: Computes the pdf of the Student copula.

xi. **pdfCopulaStudent2**: Computes the pdf of the Student copula (two-dimension case).

(c) Simulation

i. **rndCopula2**: Simulates a two-dimensional copula.

ii. **rndCopulaClayton**: Simulates the Clayton copula.

iii. **rndCopulaFrank**: Simulates the Frank copula.

iv. **rndCopulaGumbel**: Simulates the Gumbel copula.
v. **rndCopulaLower2**: Simulates the two-dimensional lower bound copula.
vi. **rndCopulaNormal**: Simulates the normal copula.
vii. **rndCopulaNormal2**: Simulates the normal copula (two-dimension case).
viii. **rndCopulaSobol**: Initializes the sobol generator to simulate copula models.
ix. **rndCopulaStudent**: Simulates the Student copula.
x. **rndCopulaStudent2**: Simulates the Student copula (two-dimension case).
xi. **rndCopulaUpper2**: Simulates the two-dimensional upper bound copula.

(d) Other tools

i. **Dependogram**: Computes the dependogram of a data matrix.
ii. **GiniCopula**: Computes the Gini index associated to a copula function.
iii. **KendallCopula**: Computes the Kendall's tau associated to a copula function.
iv. **KendallCopulaAMH**: Computes the Kendall's tau associated to the AMH copula.
v. **KendallCopulaClayton**: Computes the Kendall's tau associated to the Clayton copula.
vi. **KendallCopulaFGM**: Computes the Kendall's tau associated to the FGM copula.
vii. **KendallCopulaFrank**: Computes the Kendall's tau associated to the Frank copula.
viii. **KendallCopulaGumbel**: Computes the Kendall's tau associated to the Gumbel copula.
ix. **KendallCopulaNormal**: Computes the Kendall's tau associated to the Normal copula.
x. **KendallCopulaStudent**: Computes the Kendall's tau associated to the Student copula.
xi. **KendallCopula**: Computes the Kendall's tau associated to the AMH copula.
xii. **KendallCopula**: Computes the Kendall's tau associated to the AMH copula.
xiii. **KendallCopula**: Computes the Kendall's tau associated to the AMH copula.
xiv. **KendallTau**: Estimates the Kendall's tau from a data matrix.
xv. **PhiSqrCopula**: Computes the Φ^2 dependence measure associated to a copula function.

xvi. **qrCopulaNormal**: Computes the quantile regression by assuming a Normal copula.

xvii. **qrCopulaStudent**: Computes the quantile regression by assuming a Student copula.

xviii. **regCopulaNormal**: Estimates the parameters of the Normal copula.

xix. **regCopulaStudent**: Estimates the parameters of the Student copula.

xx. **SigmaCopula**: Computes the σ dependence measure associated to a copula function.

xxi. **SpearmanCopula**: Computes the Spearman's rho associated to a copula function.

xxii. **SpearmanCopulaAMH**: Computes the Spearman's rho associated to the AMH copula.

xxiii. **SpearmanCopulaFGM**: Computes the Spearman's rho associated to the FGM copula.

xxiv. **SpearmanCopulaFrank**: Computes the Spearman's rho associated to the Frank copula.

xxv. **SpearmanCopulaNormal**: Computes the Spearman's rho associated to the Normal copula.

xxvi. **SpearmanCopulaPlackett**: Computes the Spearman's rho associated to the Plackett copula.

xxvii. **SpearmanCopulaStudent**: Computes the Spearman's rho associated to the Student copula.

xxviii. **SpearmanRho**: Estimates the Spearman's rho from a data matrix.

4. **Covariance matrix**

   (a) **Rolling_Covariance**: Estimates the covariance matrix with a rolling window.

   (b) **vcx2**: Estimates the covariance matrix when the data contains missing values.

   (c) **vcx_cc**: Estimates the covariance matrix by assuming a uniform correlation.

   (d) **vcx_factor**: Estimates the covariance matrix using m risk factors.

   (e) **vcx_rmt**: Estimates the covariance matrix using the random matrix theory.

5. **Differentiation and Integration**

   (a) **gradp1**: Computes the first-order derivatives of a specified function $f(x)$.

(b) **gradp2**: Computes the first-order derivatives of a specified function $f(x, y)$.

(c) **quadHermite1**: Integrates a specified function $f(x)$ using Gauss-Hermite quadrature.

(d) **quadHermite2**: Integrates a specified function $f(x, y)$ using Gauss-Hermite quadrature.

(e) **quadLaguerre1**: Integrates a specified function $f(x)$ using Gauss-Laguerre quadrature.

(f) **quadLaguerre2**: Integrates a specified function $f(x, y)$ using Gauss-Laguerre quadrature.

(g) **quadLegendre1**: Integrates a specified function $f(x)$ using Gauss-Legendre quadrature.

(h) **quadLegendre2**: Integrates a specified function $f(x, y)$ using Gauss-Legendre quadrature.

(i) **quadLegendre3**: Integrates a specified function $f(x, y, z)$ using Gauss-Legendre quadrature.

(j) **Simpson1**: Integrates a specified function $f(x)$ using Simpon's method.

6. **Estimation methods**

(a) **regKernelDensity**: Estimates the probability density function using the kernel approach.

(b) **regML**: Estimates the parameters of a statistical model using the maximum likelihood method.

(c) **regPCA**: Computes principal components of a data matrix.

7. **Factor models**

(a) **Compute_RB_Factor**: Computes the risk budgeting portfolio with respect to linear factors.

(b) **Compute_RB_Factor_NG**: Computes the risk budgeting portfolio with respect to linear factors (non-Gaussian risk measures).

(c) **Compute_RC_Factor**: Computes the risk contributions of a portfolio with respect to linear factors.

(d) **Compute_RC_Factor_NG**: Computes the risk contributions of a portfolio with respect to linear factors (non-Gaussian risk measures).

(e) **regCorr1F**: Estimates the one-factor correlation model.

(f) **regCorrMF**: Estimates the multi-factor correlation model.

(g) **regLinearFactorModel**: Estimates the parameters of the linear factor model.

8. **Garch models**

   (a) **regIGarch**: Estimates an integrated Garch(p,q) model.
   (b) **regIGarch1**: Estimates an integrated Garch(1) model.
   (c) **regGarch**: Estimates a Garch(p,q) model.

9. **Portfolio Optimization Methods**

   (a) **Compute_BL_Risk_Premium**: Computes the implied risk premia in the Black-Litterman model.
   (b) **Compute_BL_Portfolio**: Computes the Black-Litterman optimized portfolio.
   (c) **Compute_EMN_Portfolio**: Computes the optimal portfolio of an equity market-neutral strategy.
   (d) **Compute_Lifestyle_Portfolio**: Computes the optimal portfolio in a lifestyle framework.
   (e) **Compute_MDP_Portfolio**: Computes the MDP portfolio.
   (f) **Compute_MSR_Portfolio**: Computes the MSR portfolio.
   (g) **Compute_MV_Portfolio**: Computes the minimum variance portfolio.
   (h) **Compute_MVO_Portfolio**: Computes the mean-variance optimized portfolio.
   (i) **Compute_MVO_Portfolio_TC**: Computes the mean-variance optimized portfolio by taking into account transaction costs.
   (j) **Compute_Sampling_Portfolio**: Computes the sampling optimized portfolio.
   (k) **Compute_Tangency_Portfolio**: Computes the tangency portfolio.
   (l) **Compute_TE_Portfolio**: Computes the tracking error optimized portfolio.
   (m) **Compute_TE_Maximum**: Computes the portfolio with the maximum tracking error.
   (n) **Compute_TE_Minimum**: Computes the portfolio with the minimum tracking error.
   (o) **Generate_Turnover_Matrices**: Generates the matrices of the quadratic program to compute the mean-variance optimized portfolio with a turnover constraint.
   (p) **Implied_Risk_Premium**: Computes the implied risk premia.

(q) **Implied_Risk_Premium2**: Computes the implied risk premia (two-asset case).

10. **Risk Budgeting Methods**

(a) **Compute_Cornish_Fisher_VaR**: Estimates the Cornish-Fisher value-at-risk.

(b) **Compute_Empirical_RC**: Computes the empirical risk contributions of a portfolio.

(c) **Compute_ERC_ES**: Computes the ERC portfolio (expected shortfall measure).

(d) **Compute_ERC_LS**: Computes the ERC long/short portfolio.

(e) **Compute_ERC_Portfolio**: Computes the ERC portfolio (volatility risk measure).

(f) **Compute_ERC_SD**: Computes the ERC portfolio (standard deviation-based risk measure).

(g) **Compute_ERC_VaR**: Computes the ERC portfolio (value-at-risk measure).

(h) **Compute_ERC_Vol**: Computes the ERC portfolio (volatility risk measure).

(i) **Compute_RB_2A**: Computes the risk budgeting portfolio (two-asset case).

(j) **Compute_RB_CC**: Computes the risk budgeting portfolio (constant correlation case).

(k) **Compute_RB_CF**: Computes the risk budgeting portfolio (Cornish-Fisher VaR measure).

(l) **Compute_RB_ES**: Computes the risk budgeting portfolio (expected shortfall measure).

(m) **Compute_RB_NG**: Computes the risk budgeting portfolio (non-Gaussian risk measures).

(n) **Compute_RB_Portfolio**: Computes the risk budgeting portfolio (volatility risk measure).

(o) **Compute_RB_SD**: Computes the risk budgeting portfolio (standard deviation-based risk measure).

(p) **Compute_RB_Turnover**: Computes the risk budgeting portfolio with turnover constraints.

(q) **Compute_RB_VaR**: Computes the risk budgeting portfolio (value-at-risk measure).

(r) **Compute_RB_Vol**: Computes the risk budgeting portfolio (volatility risk measure).

(s) **Compute_RC_CF**: Computes the risk contributions of a portfolio (Cornish-Fisher VaR measure).

(t) **Compute_RC_ES**: Computes the risk contributions of a portfolio (expected shortfall measure).

(u) **Compute_RC_LS**: Computes the risk contributions of a long/short portfolio.

(v) **Compute_RC_NG**: Computes the risk contributions of a portfolio (non-Gaussian risk measures).

(w) **Compute_RC_SD**: Computes the risk contributions of a portfolio (standard deviation-based risk measure).

(x) **Compute_RC_VaR**: Computes the risk contributions of a portfolio (value-at-risk measure).

(y) **Compute_RC_Vol**: Computes the risk contributions of a portfolio (volatility risk measure).

(z) **Compute_Risk_Contribution**: Computes the risk contributions of a portfolio (volatility risk measure).

11. **Shrinkage Methods**

(a) **Compute_Lasso_portfolio**: Computes the penalized lasso MVO portfolio.

(b) **Compute_Ridge_portfolio**: Computes the penalized ridge MVO portfolio.

(c) **Shrinkage_JM_MV**: Returns the Jagannathan-Ma covariance matrix associated to the constrained minimum variance portfolio.

(d) **Shrinkage_JM_MVO**: Returns the Jagannathan-Ma covariance matrix associated to the constrained mean-variance optimized portfolio.

(e) **Shrinkage_LW_CC**: Returns the Ledoit-Wolf covariance matrix by assuming a uniform correlation.

(f) **Shrinkage_LW_Factor**: Returns the Ledoit-Wolf covariance matrix by using m risk factors.

12. **Simulation**

(a) **init_Sobol**: Initializes the Sobol generator.

(b) **rndmn**: Simulates a Gaussian random vector.

(c) **simulate_GBM**: Simulates a one-dimensional geometric Brownian motion.

(d) **simulate_GBM2**: Simulates a two-dimensional geometric Brownian motion.

(e) **rndn_Sobol**: Simulates normal random numbers with the Sobol generator.

(f) **rndu_Sobol**: Simulates uniform random numbers with the Sobol generator.

13. **Skew-Normal and Skew−t distributions**

    (a) **cdfMSN**: Computes the cdf of the MSN distribution.

    (b) **cdfMST**: Computes the cdf of the MST distribution.

    (c) **cdfSN**: Computes the cdf of the SN distribution.

    (d) **cdfSNi**: Computes the inverse of the cdf of the SN distribution.

    (e) **cdfST**: Computes the cdf of the ST distribution.

    (f) **cdfSTi**: Computes the inverse of the cdf of the ST distribution.

    (g) **ml_skew**: Estimates the parameters of SN/ST models by maximum likelihood method.

    (h) **pdfMSN**: Computes the pdf of the MSN distribution.

    (i) **pdfMST**: Computes the pdf of the MST distribution.

    (j) **pdfSN**: Computes the pdf of the SN distribution.

    (k) **pdfST**: Computes the pdf of the ST distribution.

    (l) **rndMSN**: Simulates random numbers from the MSN distribution.

    (m) **rndMST**: Simulates random numbers from the MST distribution.

    (n) **rndSN**: Simulates random numbers from the SN distribution.

    (o) **rndST**: Simulates random numbers from the ST distribution.

14. **Spline functions**

    (a) **csspline**: Estimates the cubic spline function.

    (b) **dspline**: Computes the first-order derivative of the cubic spline function.

    (c) **fspline**: Computes the cubic spline function.

    (d) **intspline**: Integrates the cubic spline function.

    (e) **invspline**: Computes the inverse of the cubic spline function.

15. **Statistics**

    (a) **Diversification_Index**: Computes the diversification index.

    (b) **Diversification_Ratio**: Computes the diversification ratio.

    (c) **Entropy_Index**: Computes the Shannon entropy.

    (d) **Estimate_Kurtosis**: Estimates the kurtosis.

(e) **Estimate_Maximum_Drawdown**: Computes the maximum drawdown of a strategy.
(f) **Estimate_Skewness**: Estimates the skewness.
(g) **EWMA_Volatility**: Estimates the exponential weighted moving average volatility.
(h) **Gini_Index**: Computes the Gini index.
(i) **Herfindahl_Index**: Computes the Herfindahl index.
(j) **Lorenz_Curve**: Estimates the lorenz curve of concentration.
(k) **Rolling_Return**: Estimates the return with a rolling window.
(l) **Rolling_Volatility**: Estimates the volatility with a rolling window.

16. **Tools**

(a) **Bisection**: Finds the zero of a function with the bi-section algorithm.
(b) **closest_index**: Checks one numeric vector against another and returns the closest indices of the elements of the first vector in the second vector.
(c) **delif_closest_points**: Deletes closest points (x, y).
(d) **etdays2**: Computes the number of days between two dates.
(e) **ftosa**: Converts a vector into a string array containing the decimal character representation of these numbers.

17. **Yield curve**

(a) **NelsonSiegel_Forward_Rate**: Computes the forward interest rate in the Nelson-Siegel model.
(b) **NelsonSiegel_Spot_Rate**: Computes the spot interest rate in the Nelson-Siegel model.
(c) **NelsonSiegel_ZC_Rate**: Computes the zero-coupon interest rate in the Nelson-Siegel model.

Chapter 2

Command References

Barbell_Calibrate

■ **Purpose**

Calibrates a barbell portfolio.

■ **Format**

{n1,n2,n3,n4} = Barbell_Calibrate(DV01,Price,T,beta);

■ **Input**

DV01	matrix 3×1, sensitivity of the three bonds
Price	matrix 3×1, price of the three bonds
T	matrix 3×1, maturity of the three bonds
beta	scalar, value of the parameter β

■ **Output**

n1	matrix 3×1, 50/50 barbell portfolio
n2	matrix 3×1, cash-neutral barbell portfolio
n3	matrix 3×1, maturity-weighted barbell portfolio
n4	matrix 3×1, regression-weighted barbell portfolio

■ **Globals**

■ **Remarks**

The calibration of barbell portfolios is explained on pages 217-220.

■ **Source**

rpb-bond.src

Bond_Duration

■ Purpose
Computes the sensitivity of a bond.

■ Format
S = Bond_Duration(t,Ct,YTM);

■ Input

t	matrix $m \times 1$, vector of fixing dates
Ct	matrix $m \times 1$, vector of coupons
YTM	scalar, yield to maturity $r^\star$

■ Output

S	scalar, sensitivity S of the bond

■ Globals

_Bond_Continuous_Time	scalar 0 for the actuarial method 1 for the continuous method

■ Remarks
We use the formula on page 198 to compute the sensitivity of the bond.

■ Source
rpb-bond.src

Bond_Generate_Portfolio

■ **Purpose**

Generates a bond portfolio.

■ **Format**

{t,Ct} = Bond_Generate_Portfolio(t1,Ct1,t2,Ct2);

■ **Input**

t1	matrix $m_1 \times 1$, vector of fixing dates
Ct1	matrix $m_1 \times n_1$, matrix of coupons
t2	matrix $m_2 \times 1$, vector of fixing dates
Ct2	matrix $m_2 \times n_2$, matrix of coupons

■ **Output**

t	matrix $(m_1 + m_2) \times 1$, vector of fixing dates
Ct	matrix $(m_1 + m_2) \times (n_1 + n_2)$, matrix of coupons

■ **Globals**

■ **Remarks**

Each column of the matrix `Ct` corresponds to a specific bond. We use this procedure in an iterative way if we would like to aggregate a set of bonds.

■ **Source**

rpb-bond.src

Bond_Portfolio_VaR

Purpose

Computes the value-at-risk of a bond portfolio.

Format

{gVaR1,gVaR2,hVaR1,hVaR2,hVaR3,ES} = Bond_Portfolio_VaR(nB,t,Ct,Rt,
dR,alpha,h,mtd);

Input

nB	matrix $n \times 1$, vector of the numbers ϖ_i of bonds in the portfolio
t	matrix $m \times 1$, vector of fixing dates
Ct	matrix $m \times n$, matrix of coupons
Rt	matrix $m \times 1$, vector of zero-coupon interest rates
dR	matrix $T \times m$, data matrix of interest rate variations
alpha	scalar, value of the confidence level α
h	scalar, time horizon h
mtd	scalar, method to compute the risk measures 1 for computing the risk measures with respect to the fixing dates 2 for computing the risk measures with respect to the bonds

Output

gVaR1	scalar, Gaussian value-at-risk G1
gVaR2	scalar, Gaussian value-at-risk G2
hVaR1	scalar, historical value-at-risk H1 (order statistic)
hVaR2	scalar, historical value-at-risk H2 (uniform window smoothing)
hVaR3	scalar, historical value-at-risk H3 (covariance principle)
ES	scalar, empirical expected shortfall

Globals

_Bond_Continuous_Time	scalar 0 for the actuarial method 1 for the continuous method
_bond_window	scalar, length of the uniform window (default = 20)

Remarks

We use the formulas on pages 87-88, 92-93 and 204-205 to compute the different risk measures.

Source

rpb-bond.src

Bond_Portfolio_VaR_PCA

Purpose

Computes the risk contributions of a bond portfolio with respect to PCA factors.

Format

{RC_gVaR1,_gVaR2,_hVaR1,_hVaR2,_hVaR3,_ES} = Bond_Portfolio_VaR_PCA(nB, t,Ct,Rt,dR,alpha,h,mtd);

Input

nB	matrix $n \times 1$, vector of the numbers ϖ_i of bonds in the portfolio
t	matrix $m \times 1$, vector of fixing dates
Ct	matrix $m \times n$, matrix of coupons
Rt	matrix $m \times 1$, vector of zero-coupon interest rates
dR	matrix $T \times m$, data matrix of interest rate variations
alpha	scalar, value of the confidence level α
h	scalar, time horizon h
mtd	scalar, method to compute the Gaussian value-at-risk 1 for the formula (4.2) on page 204 2 for the formula (4.3) on page 205

Output

RC_gVaR1	matrix $m \times 1$, risk contributions with respect to the Gaussian value-at-risk G1
RC_gVaR2	matrix $m \times 1$, risk contributions with respect to the Gaussian value-at-risk G2
RC_hVaR1	matrix $m \times 1$, risk contributions with respect to the historical value-at-risk H1 (order statistic)
RC_hVaR2	matrix $m \times 1$, risk contributions with respect to the historical value-at-risk H2 (uniform window smoothing)
RC_hVaR3	matrix $m \times 1$, risk contributions with respect to the historical value-at-risk H3 (covariance principle)
RC_ES	matrix $m \times 1$, risk contributions with respect to the empirical expected shortfall

Globals

_Bond_Continuous_Time	scalar 0 for the actuarial method 1 for the continuous method
_bond_window	scalar, length of the uniform window (default = 20)

Remarks

The i^{th} row of output variables corresponds to the risk contribution with respect to the i^{th} PCA factors.

■ **Source**

rpb-bond.src

Bond_Portfolio_VaR_RC

Purpose

Computes the risk contributions of a bond portfolio.

Format

{RC_gVaR1,_gVaR2,_hVaR1,_hVaR2,_hVaR3,_ES} = Bond_Portfolio_VaR_RC(nB, t,Ct,Rt,dR,alpha,h,mtd);

Input

nB	matrix $n \times 1$, vector of the numbers ϖ_i of bonds in the portfolio
t	matrix $m \times 1$, vector of fixing dates
Ct	matrix $m \times n$, matrix of coupons
Rt	matrix $m \times 1$, vector of zero-coupon interest rates
dR	matrix $T \times m$, data matrix of interest rate variations
alpha	scalar, value of the confidence level α
h	scalar, time horizon h
mtd	scalar, method to compute the risk contributions 1 for computing the risk contributions with respect to the fixing dates 2 for computing the risk contributions with respect to the bonds

Output

RC_gVaR1	matrix $m \times 1$ or $n \times 1$, risk contributions with respect to the Gaussian value-at-risk G1
RC_gVaR2	matrix $m \times 1$ or $n \times 1$, risk contributions with respect to the Gaussian value-at-risk G2
RC_hVaR1	matrix $m \times 1$ or $n \times 1$, risk contributions with respect to the historical value-at-risk H1 (order statistic)
RC_hVaR2	matrix $m \times 1$ or $n \times 1$, risk contributions with respect to the historical value-at-risk H2 (uniform window smoothing)
RC_hVaR3	matrix $m \times 1$ or $n \times 1$, risk contributions with respect to the historical value-at-risk H3 (covariance principle)
RC_ES	matrix $m \times 1$ or $n \times 1$, risk contributions with respect to the empirical expected shortfall

Globals

_Bond_Continuous_Time	scalar 0 for the actuarial method 1 for the continuous method
_bond_window	scalar, length of the uniform window (default = 20)

Remarks

We use the formulas on pages 87-88, 92-93 and 204-205 to compute the different risk measures. If the variable `mtd` is equal to 1, the risk contributions are computed with respect to the fixing dates t_m. In this case, the dimension of the output variables is $m \times 1$. If the variable `mtd` is equal to 2, the risk contributions are computed with respect to the bond exposures ϖ_i. In this case, the dimension of the output variables is $n \times 1$.

■ **Source**

rpb-bond.src

Bond_Price

■ **Purpose**

Computes the price of a bond.

■ **Format**

P = Bond_Price(t,Ct,Rt);

■ **Input**

t	matrix $m \times 1$, vector of fixing dates
Ct	matrix $m \times 1$, vector of coupons
Rt	matrix $m \times 1$, vector of zero-coupon interest rates

■ **Output**

P	scalar, price of the bond

■ **Globals**

_Bond_Continuous_Time	scalar 0 for the actuarial method 1 for the continuous method

■ **Remarks**

We use the formula on page 197 to compute the price of the bond.

■ **Source**

rpb-bond.src

Bond_VaR

■ Purpose

Computes the value-at-risk of a bond.

■ Format

{gVaR1,gVaR2,hVaR1,hVaR2,hVaR3,ES,Results} = Bond_VaR(t,Ct,Rt,
dR,alpha,h);

■ Input

t	matrix $m \times 1$, vector of fixing dates
Ct	matrix $m \times 1$, vector of coupons
Rt	matrix $m \times 1$, vector of zero-coupon interest rates
dR	matrix $T \times m$, data matrix of interest rate variations
alpha	scalar, value of the confidence level α
h	scalar, time horizon h

■ Output

gVaR1	scalar, Gaussian value-at-risk G1
gVaR2	scalar, Gaussian value-at-risk G2
hVaR1	scalar, historical value-at-risk H1 (order statistic)
hVaR2	scalar, historical value-at-risk H2 (uniform window smoothing)
hVaR3	scalar, historical value-at-risk H3 (covariance principle)
ES	scalar, empirical expected shortfall
Results	matrix $m \times 6$, matrix containing t_m, $C(t_m)$, $R_t(t_m)$, $B_t(t_m)$, $D_t(t_m)$ and $\delta_t(t_m)$

■ Globals

_Bond_Continuous_Time	scalar 0 for the actuarial method 1 for the continuous method
_bond_window	scalar, length of the uniform window (default = 20)

■ Remarks

We use the formulas on pages 204-205 to compute the different risk measures.

■ Source

rpb-bond.src

Bond_VaR_RC

Purpose

Computes the risk contributions of a bond.

Format

{RC_gVaR1,RC_gVaR2,RC_hVaR1,RC_hVaR2,RC_hVaR3,RC_ES} = Bond_VaR_RC(t, Ct,Rt,dR,alpha,h);

Input

t	matrix $m \times 1$, vector of fixing dates
Ct	matrix $m \times 1$, vector of coupons
Rt	matrix $m \times 1$, vector of zero-coupon interest rates
dR	matrix $T \times m$, data matrix of interest rate variations
alpha	scalar, value of the confidence level α
h	scalar, time horizon h

Output

RC_gVaR1	matrix $m \times 1$ or $n \times 1$, risk contributions with respect to the Gaussian value-at-risk G1
RC_gVaR2	matrix $m \times 1$ or $n \times 1$, risk contributions with respect to the Gaussian value-at-risk G2
RC_hVaR1	matrix $m \times 1$ or $n \times 1$, risk contributions with respect to the historical value-at-risk H1 (order statistic)
RC_hVaR2	matrix $m \times 1$ or $n \times 1$, risk contributions with respect to the historical value-at-risk H2 (uniform window smoothing)
RC_hVaR3	matrix $m \times 1$ or $n \times 1$, risk contributions with respect to the historical value-at-risk H3 (covariance principle)
RC_ES	matrix $m \times 1$ or $n \times 1$, risk contributions with respect to the empirical expected shortfall

Globals

_Bond_Continuous_Time	scalar 0 for the actuarial method 1 for the continuous method
_bond_window	scalar, length of the uniform window (default = 20)

Remarks

The risk contributions of a bond are computed with respect to the fixing dates (see Footnote 15 on page 207).

Source

rpb-bond.src

Bond_YTM

■ **Purpose**

Computes the yield to maturity of a bond.

■ **Format**

YTM = Bond_YTM(t,Ct,P);

■ **Input**

t	matrix $m \times 1$, vector of fixing dates
Ct	matrix $m \times 1$, vector of coupons
P	scalar, price of the bond

■ **Output**

YTM	scalar, yield to maturity $r^\star$ of the bond

■ **Globals**

_Bond_Continuous_Time	scalar 0 for the actuarial method 1 for the continuous method

■ **Remarks**

We use the formula on page 198 to compute the yield to maturity of the bond.

■ **Source**

rpb-bond.src

Compute_BL_Risk_Premium

Purpose

Computes the implied risk premia in the Black-Litterman model.

Format

{phi,mu_tilde,mu_bar} = Compute_BL_Risk_Premium(x0,Sigma,SR,r,
Gamma_Matrix,P,Q,Omega);

Input

x0	matrix $n \times 1$, vector of portfolio weights
Sigma	matrix $n \times n$, covariance matrix of asset returns
SR	scalar, value of the Sharpe ratio
r	scalar, value of the risk-free rate
Gamma_Matrix	matrix $n \times n$, Γ matrix
P	matrix $g \times n$, P matrix of the manager views
Q	matrix $g \times 1$, Q vector of the manager views
Omega	matrix $g \times g$, Ω matrix of the manager views

Output

phi	scalar, implied value of ϕ
mu_tilde	matrix $n \times 1$, implied expected returns
mu_bar	matrix $n \times 1$, expected returns conditional to the manager views

Globals

Remarks

The Black-Litterman model is explained on pages 22-26.

Source

rpb-black-litterman.src

Compute_BL_Portfolio

■ Purpose

Computes the Black-Litterman optimized portfolio.

■ Format

{x,mu_x,sigma_x,sigma_te,retcode} = Compute_BL_Portfolio(x0,Sigma,
SR,r,Gamma_Matrix,P,Q,Omega,Bounds);

■ Input

x0	matrix $n \times 1$, vector of portfolio weights
Sigma	matrix $n \times n$, covariance matrix of asset returns
SR	scalar, value of the Sharpe ratio
r	scalar, value of the risk-free rate
Gamma_Matrix	matrix $n \times n$, Γ matrix
P	matrix $g \times n$, P matrix of the manager views
Q	matrix $g \times 1$, Q vector of the manager views
Omega	matrix $g \times g$, Ω matrix of the manager views
Bounds	matrix $n \times 2$, lower and upper bounds

■ Output

x	matrix $n \times 1$, optimal portfolio
mu_x	scalar, expected return of the optimal portfolio
sigma_x	scalar, volatility of the optimal portfolio
sigma_te	scalar, tracking error volatility
retcode	scalar, return code of the quadratic programming algorithm

■ Globals

■ Remarks

The Black-Litterman model is explained on pages 22-26.

■ Source

rpb-black-litterman.src

Compute_Cornish_Fisher_VaR

■ **Purpose**

Estimates the Cornish-Fisher value-at-risk.

■ **Format**

{var,rc,databuf} = Compute_Cornish_Fisher_VaR(x,R,alpha);

■ **Input**

x	matrix $n \times 1$, vector of portfolio weights
R	matrix $T \times n$, data matrix of asset returns
alpha	scalar, value of the confidence level α

■ **Output**

var	scalar, value-at-risk of the portfolio
rc	matrix $n \times 1$, risk contributions
databuf	matrix, data buffer containing: the four moments $\mu(L)$, $\sigma(L)$, $\gamma_1(L)$ and $\gamma_2(L)$ (buffer name = `"moments"`) the first moment matrix M_1 (buffer name = `"M1"`) the second moment matrix M_2 (buffer name = `"M2"`) the third moment matrix M_3 (buffer name = `"M3"`) the fourth moment matrix M_4 (buffer name = `"M4"`) the four centered moments μ_1, μ_2, μ_3 and μ_4 (buffer name = `"mu"`) the skewness γ_1 and kurtosis γ_2 statistics (buffer name = `"gamma"`) the derivatives $\partial_x \gamma_1$ and $\partial_x \gamma_2$ (buffer name = `"d_gamma"`) the value of the Cornish-Fisher quantile z (buffer name = `"z"`) the derivatives $\partial_x z$ (buffer name = `"d_z"`)

■ **Globals**

■ **Remarks**

The Cornish-Fisher value-at-risk is defined on pages 94-95.

■ **Source**

rpb-cornish-fisher.src

Compute_EMN_Portfolio

■ **Purpose**

Computes the optimal portfolio of an equity market-neutral strategy.

■ **Format**

{x,vol,mr,rc,prc} = Compute_EMN_Portfolio(x0,Sigma,vol_target,Method);

■ **Input**

x0	matrix $n \times 1$, vector of initial values
Sigma	matrix $2n \times 2n$, covariance matrix of asset returns
vol_target	scalar, value of the targeted volatility $\sigma^\star$
Method	scalar
	0 for the $1/\sigma$ solution
	1 for the ERC solution

■ **Output**

x	matrix $n \times 1$, optimal portfolio
vol	scalar, portfolio volatility
mr	matrix $n \times 1$, marginal risks
rc	matrix $n \times 1$, risk contributions
prc	matrix $n \times 1$, risk contributions expressed in %

■ **Globals**

■ **Remarks**

The optimization problem associated to the EMN strategy is explained on pages 254-257.

■ **Source**

rpb-ls.src

Compute_Empirical_RC

■ **Purpose**

Computes the empirical risk contributions of a portfolio.

■ **Format**

{var,rc_var,es,rc_es} = Compute_Empirical_RC(L,mtd);

■ **Input**

L	matrix $n \times 1$, values of the portfolio loss
mtd	scalar or matrix $n \times 1$
	scalar lower than 1, value of confidence level α
	matrix $n \times 1$, weights of the kernel

■ **Output**

var	scalar, value-at-risk of the portfolio
rc_var	matrix $n \times 1$, risk contributions (VaR)
es	scalar, expected shortfall of the portfolio
rc_es	matrix $n \times 1$, risk contributions (ES)

■ **Globals**

■ **Remarks**

The empirical risk contributions are defined on pages 87-88.

■ **Source**

rpb-rb.src

Compute_ERC_ES

Purpose
Computes the ERC portfolio (Gaussian expected shortfall).

Format
{x,es,mr,rc,prc} = Compute_ERC_ES(sv,mu,Sigma,alpha);

Input

sv	matrix $n \times 1$, initial values of the optimization problem
mu	matrix $n \times 1$, vector of expected returns
Sigma	matrix $n \times n$, covariance matrix of asset returns
alpha	scalar, value of the confidence level α

Output

x	matrix $n \times 1$, weights of the ERC portfolio
es	scalar, expected shortfall of the portfolio
mr	matrix $n \times 1$, marginal risks
rc	matrix $n \times 1$, risk contributions
prc	matrix $n \times 1$, risk contributions expressed in %

Globals

_rpb_algorithm	scalar, choice of the numerical algorithm 1 for the CCD algorithm (default) 2 for the SQP algorithm 3 for the Newton algorithm

Remarks
The ERC portfolio is defined on page 119.

Source
rpb-rb.src

Compute_ERC_LS

■ Purpose

Computes the ERC long/short portfolio.

■ Format

{x,vol,mr,rc,prc} = Compute_ERC_Portfolio(sv,Sigma,vol_target);

■ Input

sv	matrix $n \times 1$, vector of initial values
Sigma	matrix $2n \times 2n$, covariance matrix of asset returns
vol_target	scalar, value of the targeted volatility $\sigma^\star$

■ Output

x	matrix $n \times 1$, optimal portfolio
vol	scalar, portfolio volatility
mr	matrix $n \times 1$, marginal risks
rc	matrix $n \times 1$, risk contributions
prc	matrix $n \times 1$, risk contributions expressed in %

■ Globals

■ Remarks

The optimization problem associated to the ERC long/short portfolio is explained on pages 255-256.

■ Source

rpb-ls.src

Compute_ERC_Portfolio

■ Purpose

Computes the ERC portfolio (volatility risk measure).

■ Format

{x,vol,mr,rc,prc} = Compute_ERC_Portfolio(sv,Sigma);

■ Input

sv	matrix $n \times 1$, initial values of the optimization problem
Sigma	matrix $n \times n$, covariance matrix of asset returns

■ Output

x	matrix $n \times 1$, weights of the ERC portfolio
vol	scalar, portfolio volatility
mr	matrix $n \times 1$, marginal risks
rc	matrix $n \times 1$, risk contributions
prc	matrix $n \times 1$, risk contributions expressed in %

■ Globals

_rpb_algorithm	scalar, choice of the numerical algorithm 1 for the CCD algorithm (default) 2 for the SQP algorithm 3 for the Newton algorithm

■ Remarks

The ERC portfolio is defined on page 119.

■ Source

rpb-rb.src

Compute_ERC_SD

- **Purpose**

  Computes the ERC portfolio (standard deviation-based risk measure).

- **Format**

  {x,risk,mr,rc,prc} = Compute_ERC_SD(sv,mu,Sigma,c);

- **Input**

sv	matrix $n \times 1$, initial values of the optimization problem
mu	matrix $n \times 1$, vector of expected returns
Sigma	matrix $n \times n$, covariance matrix of asset returns
c	scalar, value of parameter c

- **Output**

x	matrix $n \times 1$, weights of the ERC portfolio
risk	scalar, portfolio risk
mr	matrix $n \times 1$, marginal risks
rc	matrix $n \times 1$, risk contributions
prc	matrix $n \times 1$, risk contributions expressed in %

- **Globals**

_rpb_algorithm	scalar, choice of the numerical algorithm 1 for the CCD algorithm (default) 2 for the SQP algorithm 3 for the Newton algorithm

- **Remarks**

  The ERC portfolio is defined on page 119.

- **Source**

  rpb-rb.src

Compute_ERC_VaR

■ Purpose

Computes the ERC portfolio (Gaussian value-at-risk).

■ Format

{x,var,mr,rc,prc} = Compute_ERC_VaR(sv,mu,Sigma,alpha);

■ Input

sv	matrix $n \times 1$, initial values of the optimization problem
mu	matrix $n \times 1$, vector of expected returns
Sigma	matrix $n \times n$, covariance matrix of asset returns
alpha	scalar, value of the confidence level α

■ Output

x	matrix $n \times 1$, weights of the ERC portfolio
var	scalar, value-at-risk of the portfolio
mr	matrix $n \times 1$, marginal risks
rc	matrix $n \times 1$, risk contributions
prc	matrix $n \times 1$, risk contributions expressed in %

■ Globals

_rpb_algorithm	scalar, choice of the numerical algorithm 1 for the CCD algorithm (default) 2 for the SQP algorithm 3 for the Newton algorithm

■ Remarks

The ERC portfolio is defined on page 119.

■ Source

rpb-rb.src

Compute_ERC_Vol

Purpose

Computes the ERC portfolio (volatility risk measure).

Format

{x,vol,mr,rc,prc} = Compute_ERC_Vol(sv,Sigma);

Input

sv	matrix $n \times 1$, initial values of the optimization problem
Sigma	matrix $n \times n$, covariance matrix of asset returns

Output

x	matrix $n \times 1$, weights of the ERC portfolio
vol	scalar, portfolio volatility
mr	matrix $n \times 1$, marginal risks
rc	matrix $n \times 1$, risk contributions
prc	matrix $n \times 1$, risk contributions expressed in %

Globals

_rpb_algorithm	scalar, choice of the numerical algorithm 1 for the CCD algorithm (default) 2 for the SQP algorithm 3 for the Newton algorithm

Remarks

The ERC portfolio is defined on page 119.

Source

rpb-rb.src

Compute_Lifestyle_Portfolio

■ Purpose

Computes the optimal portfolio in a lifestyle framework.

■ Format

{x_C,x_B,x_S,params} = Compute_Lifestyle_Portfolio(a,b,sigma,pi_B,D,
pi_S,sigma_S,rho,tau,gamma_);

■ Input

a	matrix $n \times 1$, parameter a of the Vasicek model
b	matrix $n \times 1$, parameter b of the Vasicek model
sigma	matrix $n \times 1$, parameter σ of the Vasicek model
pi_B	matrix $n \times 1$, bond risk premium
D	matrix $n \times 1$, constant duration of the bond
pi_S	matrix $n \times 1$, equity risk premium
sigma_S	matrix $n \times 1$, equity volatility
rho	matrix $n \times 1$, stock/bond correlation
tau	matrix $n \times 1$, time horizon
gamma_	matrix $n \times 1$, parameter of the CRRA utility function

■ Output

x_C	matrix $n \times 1$, optimal proportion of cash
x_B	matrix $n \times 1$, optimal proportion of bond
x_S	matrix $n \times 1$, optimal proportion of equity
params	matrix, data buffer containing: the parameter σ_B (buffer name = `"sigma_B"`) the parameter $\sigma(t,T)$ (buffer name = `"sigma_T"`) the parameter σ_1 (buffer name = `"sigma1"`) the parameter λ (buffer name = `"lambda"`) the parameter λ' (buffer name = `"lambda_p"`)

■ Globals

■ Remarks

The lifestyle model is explained on pages 326-328.

■ Source

rpb-lifestyle.src

Compute_MDP_Portfolio

Purpose

Computes the MDP portfolio.

Format

{x,vol,mr,rc,prc} = Compute_MDP_Portfolio(sv,Sigma,bounds);

Input

sv	matrix $n \times 1$, initial values of x
Sigma	matrix $n \times n$, covariance matrix of asset returns
Bounds	matrix $n \times 2$, upper and lower bounds

Output

x	matrix $n \times 1$, optimal portfolio
vol	scalar, portfolio volatility
mr	matrix $n \times 1$, marginal risks
rc	matrix $n \times 1$, risk contributions
prc	matrix $n \times 1$, risk contributions expressed in %

Globals

Remarks

The MDP portfolio is defined on pages 168-171.

Source

rpb-mdp.src

Compute_MSR_Portfolio

■ **Purpose**

Computes the MSR portfolio.

■ **Format**

{x,mu_x,sigma_x,SR_x,retcode} = Compute_MSR_Portfolio(sv,Sigma,bounds);

■ **Input**

sv	matrix $n \times 1$, initial values of x
Sigma	matrix $n \times n$, covariance matrix of asset returns
Bounds	matrix $n \times 2$, upper and lower bounds

■ **Output**

x	matrix $n \times 1$, optimal portfolio
mu_x	scalar, expected return of the optimal portfolio
sigma_x	scalar, volatility of the optimal portfolio
SR_x	scalar, Sharpe ratio of the optimal portfolio
retcode	scalar, return code of the SQP algorithm

■ **Globals**

■ **Remarks**

The MSR portfolio is defined on page 70.

■ **Source**

rpb-markowitz.src

Compute_MV_Portfolio

■ **Purpose**

Computes the minimum variance portfolio.

■ **Format**

{x,sigma_x,retcode} = Compute_MV_Portfolio(Sigma,A,B,C,D,Bounds);

■ **Input**

Sigma	matrix $n \times n$, covariance matrix of asset returns
A	matrix $m \times n$, A matrix
B	matrix $m \times 1$, B vector
C	matrix $p \times n$, C matrix
D	matrix $p \times 1$, D vector
Bounds	matrix $n \times 2$, lower and upper bounds

■ **Output**

x	matrix $n \times 1$, optimal portfolio
sigma_x	scalar, portfolio volatility
retcode	scalar, return code of the quadratic programming algorithm

■ **Globals**

_rpb_Lagrange	matrix, data buffer containing Lagrange coefficients

■ **Remarks**

The minimum variance optimization problem is defined on pages 164-168. The constraints are defined as follows:

$$\left\{ \begin{array}{l} Ax = B \\ Cx \geq D \end{array} \right.$$

■ **Source**

rpb-markowitz.src

Compute_MVO_Portfolio

■ Purpose

Computes the mean-variance optimized portfolio.

■ Format

{x,mu_x,sigma_x,gamma_x,retcode} = Compute_MVO_Portfolio(mu,Sigma,
A,B,C,D,Bounds,Targets,Method);

■ Input

mu	matrix $n \times 1$, vector of expected returns
Sigma	matrix $n \times n$, covariance matrix of asset returns
A	matrix $m \times n$, A matrix
B	matrix $m \times 1$, B vector
C	matrix $p \times n$, C matrix
D	matrix $p \times 1$, D vector
Bounds	matrix $n \times 2$, lower and upper bounds
Targets	matrix $k \times 1$, vector of targets (γ, $\mu^{\star}$ or $\sigma^{\star}$)
Method	scalar 0 for the γ-problem 1 for the μ-problem 2 for the σ-problem

■ Output

x	matrix $n \times k$, optimal portfolios
mu_x	matrix $k \times 1$, expected return of optimal portfolios
sigma_x	matrix $k \times 1$, volatility of optimal portfolios
gamma_x	matrix $k \times 1$, implied value of γ
retcode	matrix $k \times 1$, return code of the quadratic programming algorithm

■ Globals

■ Remarks

The mean-variance optimization problem is defined on pages 5-7. The constraints are defined as follows:

$$\left\{ \begin{array}{l} Ax = B \\ Cx \geq D \end{array} \right.$$

■ Source

rpb-markowitz.src

Compute_MVO_Portfolio_TC

Purpose

Computes the mean-variance optimized portfolio by taking into account transaction costs.

Format

{x,x_m,x_p,mu_x,sigma_x,gamma_x,retcode} = Compute_MVO_Portfolio_TC(x_0, mu,Sigma,A,B,C,D,Bounds,Targets,Method,TC_m,TC_p);

Input

x0	matrix $n \times 1$, current portfolio
mu	matrix $n \times 1$, vector of expected returns
Sigma	matrix $n \times n$, covariance matrix of asset returns
A	matrix $m \times n$, A matrix
B	matrix $m \times 1$, B vector
C	matrix $p \times n$, C matrix
D	matrix $p \times 1$, D vector
Bounds	matrix $n \times 2$, lower and upper bounds
Targets	matrix $k \times 1$, vector of targets (γ, $\mu^\star$ or $\sigma^\star$)
Method	scalar 0 for the γ-problem 1 for the μ-problem 2 for the σ-problem
TC_m	matrix $n \times 1$, transaction costs c^-
TC_p	matrix $n \times 1$, transaction costs c^+

Output

x	matrix $n \times k$, optimal portfolios
x_m	matrix $n \times k$, negative weight changes x^-
x_p	matrix $n \times k$, positive weight changes x^+
mu_x	matrix $k \times 1$, expected return of optimal portfolios
sigma_x	matrix $k \times 1$, volatility of optimal portfolios
gamma_x	matrix $k \times 1$, implied value of γ
retcode	matrix $k \times 1$, return code of the QP algorithm

Remarks

The mean-variance optimization problem with transaction costs is defined on page 60. The constraints are defined as follows:

$$\left\{ \begin{array}{l} Ax = B \\ Cx \geq D \end{array} \right.$$

Source

rpb-markowitz.src

Compute_RB_2A

■ **Purpose**

Computes the risk budgeting portfolio (two-asset case).

■ **Format**

{x1,x2} = Compute_RB_2A(sigma1,sigma2,rho,b);

■ **Input**

sigma1	matrix $n \times n$, volatility of the first asset
sigma2	matrix $n \times n$, volatility of the second asset
rho	matrix $n \times n$, cross-correlation
b	matrix $n \times 1$, risk budget of the first asset

■ **Output**

x1	matrix $n \times 1$, weights of the first asset
x2	matrix $n \times 1$, weights of the second asset

■ **Globals**

■ **Remarks**

The risk budgeting portfolio in the two-asset case is defined on pages 102-103.

■ **Source**

rpb-rb.src

Compute_RB_CC

- **Purpose**
  Computes the risk budgeting portfolio in the case of a constant-correlation matrix.

- **Format**
  x = Compute_RB_CC(n,sigma,rho,b);

- **Input**

n	scslar, number of assets
sigma	matrix $n \times n$, vector of volatilities
rho	scalar, value of the uniform correlation
b	matrix $n \times 1$, vector of risk budgets

- **Output**

x	matrix $n \times 1$, weights of the portfolio

- **Globals**

- **Remarks**
  The risk budgeting portfolio in the case of a constant-correlation matrix is defined on pages 104-106.

- **Source**
  rpb-rb.src

Compute_RB_CF

■ **Purpose**

Computes the risk budgeting portfolio (Cornish-Fisher VaR measure).

■ **Format**

{x,var,mr,rc,prc} = Compute_RB_CF(sv,M1,M2,M3,M4,b,alpha);

■ **Input**

sv	matrix $n \times 1$, initial values of the optimization problem
M1	matrix $n \times 1$, 1^{st} moment matrix
M2	matrix $n \times n$, covariance matrix
M3	matrix $n \times n^2$, co-skewness matrix
M4	matrix $n \times n^3$, co-kurtosis matrix
b	matrix $n \times 1$, vector of risk budgets
alpha	scalar, value of the confidence level α

■ **Output**

x	matrix $n \times 1$, weights of the RB portfolio
var	scalar, Cornish-Fisher value-at-risk of the portfolio
mr	matrix $n \times 1$, marginal risks
rc	matrix $n \times 1$, risk contributions
prc	matrix $n \times 1$, risk contributions expressed in %

■ **Globals**

_rpb_fmin	scalar, value of the objective function to optimize
_rpb_retcode	scalar, return code of the numerical algorithm (CO or SQP)

■ **Remarks**

The Cornish-Fisher VaR measure is defined on pages 94-95. To use the CO library instead of the SQP algorithm, we have to define the compiler directive `#define use_co 1` at the top of the program.

■ **Source**

rpb-rb-ng.src

Compute_RB_ES

■ Purpose

Computes the risk budgeting portfolio (Gaussian expected shortfall).

■ Format

{x,es,mr,rc,prc} = Compute_RB_ES(sv,mu,Sigma,alpha,b);

■ Input

sv	matrix $n \times 1$, initial values of the optimization problem
mu	matrix $n \times 1$, vector of expected returns
Sigma	matrix $n \times n$, covariance matrix of asset returns
alpha	scalar, value of the confidence level α
b	matrix $n \times 1$, vector of risk budgets

■ Output

x	matrix $n \times 1$, weights of the RB portfolio
es	scalar, expected shortfall of the portfolio
mr	matrix $n \times 1$, marginal risks
rc	matrix $n \times 1$, risk contributions
prc	matrix $n \times 1$, risk contributions expressed in %

■ Globals

_rpb_algorithm	scalar, choice of the numerical algorithm 1 for the CCD algorithm (default) 2 for the SQP algorithm 3 for the Newton algorithm

■ Remarks

The risk budgeting optimization problem is defined on pages 98-102.

■ Source

rpb-rb.src

Compute_RB_Factor

■ Purpose

Computes the risk budgeting portfolio with respect to linear factors.

■ Format

{x,y,mr,rc,prc} = Compute_RB_Factor(sv,Sigma,A,Omega,D,
b,indx_Factors,mtd);

■ Input

sv	matrix $n \times 1$, initial values of the optimization problem
Sigma	matrix $n \times n$, covariance matrix of asset returns
A	matrix $n \times m$, factor loading matrix A
Omega	matrix $m \times m$, covariance matrix of risk factors Ω
D	matrix $n \times n$, covariance matrix of specific risks D
b	matrix $p \times 1$, risk budgets with respect to the selected p factors
indx_Factors	matrix $p \times 1$, indices of the selected p factors
mtd	scalar, method to define the objective function 0 for the $\mathcal{L}_2$ absolute norm criterion 1 for the $\mathcal{L}_2$ relative norm criterion 2 for the Herfindahl criterion 3 for the Gini criterion 4 for the Shannon criterion

■ Output

x	matrix $n \times 1$, portfolio weights
y	matrix $n \times 1$, factor weights
mr	matrix $n \times 1$, marginal risks
rc	matrix $n \times 1$, risk contributions
prc	matrix $n \times 1$, risk contributions expressed in %

■ Globals

■ Remarks

The risk budgeting optimization problem with respect to risk factors is defined on pages 144-145. To use the CO library instead of the SQP algorithm, we have to define the compiler directive `#define use_co 1` at the top of the program.

■ Source

rpb-rb-factor.src

Compute_RB_Factor_NG

■ Purpose

Computes the risk budgeting portfolio with respect to linear factors (non-Gaussian risk measures).

■ Format

{x,y,mr,rc,prc} = Compute_RB_Factor_NG(sv,R,Sigma,
A,Omega,D,b,indx_Factors,alpha,model);

■ Input

sv	matrix $n \times 1$, initial values of the optimization problem
R	matrix $T \times n$, data matrix of asset returns
Sigma	matrix $n \times n$, covariance matrix of asset returns
A	matrix $n \times m$, factor loading matrix A
Omega	matrix $m \times m$, covariance matrix of risk factors Ω
D	matrix $n \times n$, covariance matrix of specific risks D
b	matrix $p \times 1$, risk budgets with respect to the selected p factors
indx_Factors	matrix $p \times 1$, indices of the selected p factors
alpha	scalar, value of the confidence level α
model	scalar, model to measure the risk 1 for the volatility 2 for the expected shortfall 3 for the Cornish-Fisher value-at-risk

■ Output

x	matrix $n \times 1$, portfolio weights
y	matrix $n \times 1$, factor weights
mr	matrix $n \times 1$, marginal risks
rc	matrix $n \times 1$, risk contributions
prc	matrix $n \times 1$, risk contributions expressed in %

■ Globals

■ Remarks

The risk budgeting optimization problem with respect to risk factors is defined on pages 144-145. To use the CO library instead of the SQP algorithm, we have to define the compiler directive `#define use_co 1` at the top of the program.

■ Source

rpb-rb-ng.src

Compute_RB_NG

Purpose

Computes the risk budgeting portfolio (non-Gaussian risk measure).

Format

{x,risk,mr,rc,prc} = Compute_RB_NG(sv,R,b,alpha,model);

Input

sv	matrix $n \times 1$, initial values of the optimization problem
R	matrix $T \times n$, data matrix of asset returns
b	matrix $n \times 1$, vector of risk budgets
alpha	scalar, value of the confidence level α
model	scalar, model to measure the risk 1 for the volatility 2 for the expected shortfall 3 for the Cornish-Fisher value-at-risk

Output

x	matrix $n \times 1$, weights of the RB portfolio
risk	scalar, portfolio risk
mr	matrix $n \times 1$, marginal risks
rc	matrix $n \times 1$, risk contributions
prc	matrix $n \times 1$, risk contributions expressed in %

Globals

Remarks

The risk budgeting optimization problem is defined on pages 98-102. To use the CO library instead of the SQP algorithm, we have to define the compiler directive `#define use_co 1` at the top of the program.

Source

rpb-rb-ng.src

Compute_RB_Portfolio

Purpose

Computes the risk budgeting portfolio (volatility risk measure).

Format

{x,vol,mr,rc,prc} = Compute_RB_Portfolio(sv,Sigma,b);

Input

sv	matrix $n \times 1$, initial values of the optimization problem
Sigma	matrix $n \times n$, covariance matrix of asset returns
b	matrix $n \times 1$, vector of risk budgets

Output

x	matrix $n \times 1$, weights of the RB portfolio
vol	scalar, portfolio volatility
mr	matrix $n \times 1$, marginal risks
rc	matrix $n \times 1$, risk contributions
prc	matrix $n \times 1$, risk contributions expressed in %

Globals

_rpb_algorithm	scalar, choice of the numerical algorithm 1 for the CCD algorithm (default) 2 for the SQP algorithm 3 for the Newton algorithm

Remarks

The risk budgeting optimization problem is defined on pages 98-102.

Source

rpb-rb.src

Compute_RB_SD

■ Purpose

Computes the risk budgeting portfolio (standard deviation-based risk measure).

■ Format

{x,risk,mr,rc,prc} = Compute_RB_SD(sv,mu,Sigma,c,b);

■ Input

sv	matrix $n \times 1$, initial values of the optimization problem
mu	matrix $n \times 1$, vector of expected returns
Sigma	matrix $n \times n$, covariance matrix of asset returns
c	scalar, value of parameter c
b	matrix $n \times 1$, vector of risk budgets

■ Output

x	matrix $n \times 1$, weights of the RB portfolio
risk	scalar, portfolio risk
mr	matrix $n \times 1$, marginal risks
rc	matrix $n \times 1$, risk contributions
prc	matrix $n \times 1$, risk contributions expressed in %

■ Globals

_rpb_algorithm	scalar, choice of the numerical algorithm 1 for the CCD algorithm (default) 2 for the SQP algorithm 3 for the Newton algorithm

■ Remarks

The risk budgeting optimization problem is defined on pages 98-102.

■ Source

rpb-rb.src

Compute_RB_Turnover

■ **Purpose**

Computes the risk budgeting portfolio with turnover constraints.

■ **Format**

{x,vol,mr,rc,prc,tau} = Compute_RB_Turnover(sv,x0,Sigma,b,tau_max);

■ **Input**

sv	matrix $n \times 1$, initial values of the optimization problem
x0	matrix $n \times 1$, current portfolio
Sigma	matrix $n \times n$, covariance matrix of asset returns
b	matrix $n \times 1$, vector of risk budgets
tau_max	scalar, value of the maximum turnover τ^+

■ **Output**

x	matrix $n \times 1$, weights of the RB portfolio
vol	scalar, portfolio volatility
mr	matrix $n \times 1$, marginal risks
rc	matrix $n \times 1$, risk contributions
prc	matrix $n \times 1$, risk contributions expressed in %
tau	scalar, value of the turnover $\tau(x)$

■ **Globals**

■ **Remarks**

The risk budgeting optimization problem with turnover constraints is defined on page 265.

■ **Source**

rpb-turnover.src

Compute_RB_VaR

■ Purpose
Computes the risk budgeting portfolio (Gaussian value-at-risk).

■ Format
{x,var,mr,rc,prc} = Compute_RB_VaR(sv,mu,Sigma,alpha,b);

■ Input

sv	matrix $n \times 1$, initial values of the optimization problem
mu	matrix $n \times 1$, vector of expected returns
Sigma	matrix $n \times n$, covariance matrix of asset returns
alpha	scalar, value of the confidence level α
b	matrix $n \times 1$, vector of risk budgets

■ Output

x	matrix $n \times 1$, weights of the RB portfolio
var	scalar, value-at-risk of the portfolio
mr	matrix $n \times 1$, marginal risks
rc	matrix $n \times 1$, risk contributions
prc	matrix $n \times 1$, risk contributions expressed in %

■ Globals

_rpb_algorithm	scalar, choice of the numerical algorithm 1 for the CCD algorithm (default) 2 for the SQP algorithm 3 for the Newton algorithm

■ Remarks
The risk budgeting optimization problem is defined on pages 98-102.

■ Source
rpb-rb.src

Compute_RB_Vol

■ Purpose

Computes the risk budgeting portfolio (volatility risk measure).

■ Format

{x,vol,mr,rc,prc} = Compute_RB_Vol(sv,Sigma,b);

■ Input

sv	matrix $n \times 1$, initial values of the optimization problem
Sigma	matrix $n \times n$, covariance matrix of asset returns
b	matrix $n \times 1$, vector of risk budgets

■ Output

x	matrix $n \times 1$, weights of the RB portfolio
vol	scalar, portfolio volatility
mr	matrix $n \times 1$, marginal risks
rc	matrix $n \times 1$, risk contributions
prc	matrix $n \times 1$, risk contributions expressed in %

■ Globals

_rpb_algorithm	scalar, choice of the numerical algorithm 1 for the CCD algorithm (default) 2 for the SQP algorithm 3 for the Newton algorithm

■ Remarks

The risk budgeting optimization problem is defined on pages 98-102.

■ Source

rpb-rb.src

Compute_RC_CF

■ Purpose

Computes the risk contributions of a portfolio (Cornish-Fisher value-at-risk).

■ Format

{var,mr,rc,prc} = Compute_RC_CF(x,M1,M2,M3,M4,alpha);

■ Input

x	matrix $n \times 1$, weights of the portfolio
M1	matrix $n \times 1$, first moment matrix
M2	matrix $n \times n$, covariance matrix
M3	matrix $n \times n^2$, co-skewness matrix
M4	matrix $n \times n^3$, co-kurtosis matrix
alpha	scalar, value of confidence level α

■ Output

var	scalar, Cornish-Fisher value-at-risk of the portfolio
mr	matrix $n \times 1$, marginal risks
rc	matrix $n \times 1$, risk contributions
prc	matrix $n \times 1$, risk contributions expressed in %

■ Globals

■ Remarks

The risk contributions with the Cornish-Fisher value-a-risk are defined on pages 94-95.

■ Source

rpb-rb-ng.src

Compute_RC_Credit

■ **Purpose**

Computes the risk contributions of a credit portfolio.

■ **Format**

{VaR,RC_VaR,ES,RC_ES} = Compute_RC_Credit(x,mu_G,p,rho,alpha);

■ **Input**

x	matrix $n \times 1$, vector of exposures at default
mu_G	matrix $n \times 1$, vector of expected losses given default
p	matrix $n \times 1$, vector of default probabilities
rho	scalar, value of the uniform correlation
alpha	scalar, value of the confidence level α

■ **Output**

VaR	scalar, value-at-risk of the portfolio
RC_VaR	matrix $n \times 1$, risk contributions with respect to the value-at-risk
ES	scalar, expected shortfall of the portfolio
RC_ES	matrix $n \times 1$, risk contributions with respect to the expected shortfall

■ **Globals**

■ **Remarks**

The risk contributions are computed using formulas described on pages 212-214.

■ **Source**

rpb-bond.src

Compute_RC_ES

■ Purpose

Computes the risk contributions of a portfolio (Gaussian expected shortfall).

■ Format

{es,mr,rc,prc} = Compute_RC_ES(x,mu,Sigma,alpha);

■ Input

x	matrix $n \times 1$, weights of the portfolio
mu	matrix $n \times 1$, vector of expected returns
Sigma	matrix $n \times n$, covariance matrix of asset returns
alpha	scalar, value of confidence level α

■ Output

es	scalar, expected shortfall of the portfolio
mr	matrix $n \times 1$, marginal risks
rc	matrix $n \times 1$, risk contributions
prc	matrix $n \times 1$, risk contributions expressed in %

■ Globals

■ Remarks

The risk contributions with the expected shortfall are defined on page 80.

■ Source

rpb-rb.src

Compute_RC_Factor

■ **Purpose**

Computes the risk contributions of a portfolio with respect to linear factors.

■ **Format**

{vol,y,mr_y,rc_y,prc_y} = Compute_RC_Factor(x,Sigma,A,Omega,D);

■ **Input**

x	matrix $n \times 1$, weights of the portfolio
Sigma	matrix $n \times n$, covariance matrix of asset returns
A	matrix $n \times m$, factor loading matrix A
Omega	matrix $m \times m$, covariance matrix of risk factors Ω
D	matrix $n \times n$, covariance matrix of specific risks D

■ **Output**

vol	scalar, portfolio volatility
y	matrix $n \times 1$, factor weights
mr_y	matrix $n \times 1$, marginal risks
rc_y	matrix $n \times 1$, risk contributions
prc_y	matrix $n \times 1$, risk contributions expressed in %

■ **Globals**

■ **Remarks**

The risk contributions with respect to risk factors are defined on pages 141-142. The output variables contain both statistics with respect to risk factors (the first m rows) and residual risk factors (the last $n - m$ rows).

■ **Source**

rpb-rb-factor.src

Compute_RC_Factor_NG

Purpose

Computes the risk contributions of a portfolio with respect to linear factors (non-Gaussian risk measures).

Format

{y,risk_y,mr_y,rc_y,prc_y} = Compute_RC_Factor_NG(x,risk_x,mr_x,A,Omega,D);

Input

x	matrix $n \times 1$, weights of the portfolio
risk_x	scalar, portfolio risk
mr_x	matrix $n \times 1$, marginal risks
A	matrix $n \times m$, factor loading matrix A
Omega	matrix $m \times m$, covariance matrix of risk factors Ω
D	matrix $n \times n$, covariance matrix of specific risks D

Output

y	matrix $n \times 1$, factor weights
risk_y	scalar, portfolio risk
mr_y	matrix $n \times 1$, marginal risks
rc_y	matrix $n \times 1$, risk contributions
prc_y	matrix $n \times 1$, risk contributions expressed in %

Globals

Remarks

The risk contributions with respect to risk factors are defined on pages 141-142. The output variables contain both statistics with respect to risk factors (the first m rows) and residual risk factors (the last $n - m$ rows).

Source

rpb-rb-factor.src

Compute_RC_LS

■ **Purpose**

Computes the risk contributions of a long/short portfolio (volatility risk measure).

■ **Format**

{vol,mr,rc,prc} = Compute_RC_Vol(x,Sigma);

■ **Input**

x	matrix $2n \times 1$, weights of the portfolio
Sigma	matrix $2n \times 2n$, covariance matrix of asset returns

■ **Output**

vol	scalar, portfolio volatility
mr	matrix $n \times 1$, marginal risks
rc	matrix $n \times 1$, risk contributions
prc	matrix $n \times 1$, risk contributions expressed in %

■ **Globals**

■ **Remarks**

The risk contributions with the volatility risk measure are defined on page 80.

■ **Source**

rpb-ls.src

Compute_RC_NG

Purpose
Computes the risk contributions of a portfolio (non-Gaussian risk measure).

Format
{risk,mr,rc,prc} = Compute_RC_NG(x,R,alpha,model);

Input

x	matrix $n \times 1$, weights of the portfolio
R	matrix $T \times n$, data matrix of asset returns
alpha	scalar, value of the confidence level α
model	scalar, model to measure the risk 1 for the volatility 2 for the expected shortfall 3 for the Cornish-Fisher value-at-risk

Output

risk	scalar, portfolio risk
mr	matrix $n \times 1$, marginal risks
rc	matrix $n \times 1$, risk contributions
prc	matrix $n \times 1$, risk contributions expressed in %

Globals

Remarks
The risk contributions are defined on page 78.

Source
rpb-rb-ng.src

Compute_RC_SD

■ **Purpose**

Computes the risk contributions of a portfolio (standard deviation-based risk measure).

■ **Format**

{risk,mr,rc,prc} = Compute_RC_SD(x,mu,Sigma,c);

■ **Input**

x	matrix $n \times 1$, weights of the portfolio
mu	matrix $n \times 1$, vector of expected returns
Sigma	matrix $n \times n$, covariance matrix of asset returns
c	scalar, value of parameter c

■ **Output**

risk	scalar, portfolio risk
mr	matrix $n \times 1$, marginal risks
rc	matrix $n \times 1$, risk contributions
prc	matrix $n \times 1$, risk contributions expressed in %

■ **Globals**

■ **Remarks**

The risk contributions with the standard deviation-based risk measure are defined on pages 73 and 80.

■ **Source**

rpb-rb.src

Compute_RC_VaR

■ Purpose

Computes the risk contributions of a portfolio (Gaussian value-at-risk).

■ Format

{var,mr,rc,prc} = Compute_RC_VaR(x,mu,Sigma,alpha);

■ Input

x	matrix $n \times 1$, weights of the portfolio
mu	matrix $n \times 1$, vector of expected returns
Sigma	matrix $n \times n$, covariance matrix of asset returns
alpha	scalar, value of confidence level α

■ Output

var	scalar, value-at-risk of the portfolio
mr	matrix $n \times 1$, marginal risks
rc	matrix $n \times 1$, risk contributions
prc	matrix $n \times 1$, risk contributions expressed in %

■ Globals

■ Remarks

The risk contributions with the value-at-risk are defined on page 80.

■ Source

rpb-rb.src

Compute_RC_Vol

Purpose

Computes the risk contributions of a portfolio (volatility risk measure).

Format

{vol,mr,rc,prc} = Compute_RC_Vol(x,Sigma);

Input

x	matrix $n \times 1$, weights of the portfolio
Sigma	matrix $n \times n$, covariance matrix of asset returns

Output

vol	scalar, portfolio volatility
mr	matrix $n \times 1$, marginal risks
rc	matrix $n \times 1$, risk contributions
prc	matrix $n \times 1$, risk contributions expressed in %

Globals

Remarks

The risk contributions with the volatility risk measure are defined on page 80.

Source

rpb-rb.src

Compute_Risk_Contribution

■ Purpose

Computes the risk contributions of a portfolio (volatility risk measure).

■ Format

{vol,mr,rc,prc} = Compute_Risk_Contribution(x,Sigma);

■ Input

x	matrix $n \times 1$, weights of the portfolio
Sigma	matrix $n \times n$, covariance matrix of asset returns

■ Output

vol	scalar, portfolio volatility
mr	matrix $n \times 1$, marginal risks
rc	matrix $n \times 1$, risk contributions
prc	matrix $n \times 1$, risk contributions expressed in %

■ Globals

■ Remarks

The risk contributions with the volatility risk measure are defined on page 80.

■ Source

rpb-rb.src

Compute_Sampling_Portfolio

Purpose

Computes the sampling optimized portfolio.

Format

{x,mu_x,sigma_x,gamma_x,retcode} = Compute_Sampling_Portfolio(
benchmark,mu,Sigma,A,B,C,D,Bounds,Active);

Input

benchmark	matrix $n \times 1$, benchmark portfolio b
mu	matrix $n \times 1$, vector of expected returns
Sigma	matrix $n \times n$, covariance matrix of asset returns
A	matrix $m \times n$, A matrix
B	matrix $m \times 1$, B vector
C	matrix $p \times n$, C matrix
D	matrix $p \times 1$, D vector
Bounds	matrix $n \times 2$, lower and upper bounds
Active	matrix $n \times 1$, vector of active assets (0 or 1)

Output

x	matrix $n \times 1$, optimal portfolio x
mu_x	scalar, expected excess return $\mu(x \mid b)$ of the optimal portfolio
sigma_x	scalar, tracking error volatility $\sigma(x \mid b)$ of the optimal portfolio
gamma_x	scalar, implied value of γ
retcode	scalar, return code of the QP algorithm

Globals

Remarks

The sampling optimization problem is defined on page 61. The constraints are defined as follows:

$$\left\{ \begin{array}{l} Ax = B \\ Cx \geq D \end{array} \right.$$

This procedure can be used to solve the sampling problem using the heuristic algorithm, the backward elimination algorithm and the forward selection algorithm (pages 60-64).

Source

rpb-markowitz.src

Compute_Tangency_Portfolio

Purpose

Computes the tangency portfolio.

Format

{x,mu_x,sigma_x,gamma_x,SR_x} = Compute_Tangency_Portfolio(mu,Sigma,
A,B,C,D,Bounds,rfr,vol_min);

Input

mu	matrix $n \times 1$, vector of expected returns
Sigma	matrix $n \times n$, covariance matrix of asset returns
A	matrix $m \times n$, A matrix
B	matrix $m \times 1$, B vector
C	matrix $p \times n$, C matrix
D	matrix $p \times 1$, D vector
Bounds	matrix $n \times 2$, lower and upper bounds
rfr	scalar, value of the risk-free rate
vol_min	scalar, minimum volatility

Output

x	matrix $n \times 1$, tangency portfolio
mu_x	scalar, expected return of the tangency portfolio
sigma_x	scalar, volatility of the tangency portfolio
gamma_x	scalar, implied value of γ
SR_x	scalar, Sharpe ratio of the tangency portfolio

Globals

Remarks

The tangency portfolio problem is defined on pages 12-15. The constraints are defined as follows:

$$\left\{ \begin{array}{l} Ax = B \\ Cx \geq D \end{array} \right.$$

Source

rpb-sharpe.src

Compute_TE_Maximum

Purpose

Computes the portfolio with the maximum tracking error volatility.

Format

{x,mu_x,sigma_x,gamma_x,retcode} = Compute_TE_Maximum(benchmark, mu,Sigma,A,B,C,D,Bounds);

Input

benchmark	matrix $n \times 1$, benchmark portfolio b
mu	matrix $n \times 1$, vector of expected returns
Sigma	matrix $n \times n$, covariance matrix of asset returns
A	matrix $m \times n$, A matrix
B	matrix $m \times 1$, B vector
C	matrix $p \times n$, C matrix
D	matrix $p \times 1$, D vector
Bounds	matrix $n \times 2$, lower and upper bounds

Output

x	matrix $n \times 1$, optimal portfolio x
mu_x	scalar, expected excess return $\mu(x \mid b)$ of the optimal portfolio
sigma_x	scalar, tracking error volatility $\sigma(x \mid b)$ of the optimal portfolio
gamma_x	scalar, implied value of γ
retcode	scalar, return code of the SQP algorithm

Globals

Remarks

The tracking error optimization problem is defined on pages 19-22. The constraints are defined as follows:

$$\left\{ \begin{array}{l} Ax = B \\ Cx \geq D \end{array} \right.$$

Source

rpb-markowitz.src

Compute_TE_Minimum

■ Purpose

Computes the portfolio with the minimum tracking error volatility.

■ Format

{x,mu_x,sigma_x,gamma_x,retcode} = Compute_TE_Minimum(benchmark,
mu,Sigma,A,B,C,D,Bounds);

■ Input

benchmark	matrix $n \times 1$, benchmark portfolio b
mu	matrix $n \times 1$, vector of expected returns
Sigma	matrix $n \times n$, covariance matrix of asset returns
A	matrix $m \times n$, A matrix
B	matrix $m \times 1$, B vector
C	matrix $p \times n$, C matrix
D	matrix $p \times 1$, D vector
Bounds	matrix $n \times 2$, lower and upper bounds

■ Output

x	matrix $n \times 1$, optimal portfolio x
mu_x	scalar, expected excess return $\mu(x \mid b)$ of the optimal portfolio
sigma_x	scalar, tracking error volatility $\sigma(x \mid b)$ of the optimal portfolio
gamma_x	scalar, implied value of γ
retcode	scalar, return code of the SQP algorithm

■ Globals

■ Remarks

The tracking error optimization problem is defined on pages 19-22. The constraints are defined as follows:

$$\begin{cases} Ax = B \\ Cx \geq D \end{cases}$$

■ Source

rpb-markowitz.src

Compute_TE_Portfolio

Purpose

Computes the tracking error optimized portfolio.

Format

{x,mu_x,sigma_x,gamma_x,retcode} = Compute_TE_Portfolio(benchmark, mu,Sigma,A,B,C,D,Bounds,Targets,Method);

Input

benchmark	matrix $n \times 1$, benchmark portfolio b
mu	matrix $n \times 1$, vector of expected returns
Sigma	matrix $n \times n$, covariance matrix of asset returns
A	matrix $m \times n$, A matrix
B	matrix $m \times 1$, B vector
C	matrix $p \times n$, C matrix
D	matrix $p \times 1$, D vector
Bounds	matrix $n \times 2$, lower and upper bounds
Targets	matrix $k \times 1$, vector of targets (γ, $\mu^\star$ or $\sigma^\star$)
Method	scalar 0 for the γ-problem 1 for the μ-problem 2 for the σ-problem

Output

x	matrix $n \times k$, optimal portfolios x
mu_x	matrix $k \times 1$, expected excess return $\mu(x \mid b)$ of optimal portfolios
sigma_x	matrix $k \times 1$, tracking error volatility $\sigma(x \mid b)$ of optimal portfolios
gamma_x	matrix $k \times 1$, implied value of γ
retcode	matrix $k \times 1$, return code of the QP algorithm

Globals

Remarks

The tracking error optimization problem is defined on pages 19-22. The constraints are defined as follows:

$$\begin{cases} Ax = B \\ Cx \geq D \end{cases}$$

Source

rpb-markowitz.src

Generate_Turnover_Matrices

■ Purpose

Computes the matrices of the quadratic problem to compute the mean-variance optimized portfolio with a turnover constraint.

■ Format

{mu_tilde,Sigma_tilde,A_tilde,B_tilde,C_tilde,D_tilde,Bounds_tilde} =
Generate_Turnover_Matrices(x0,mu,Sigma,tau,Bounds);

■ Input

x0	matrix $n \times 1$, current portfolio
mu	matrix $n \times 1$, vector of expected returns
Sigma	matrix $n \times n$, covariance matrix of asset returns
tau	scalar, maximum turnover τ^+
Bounds	matrix $n \times 2$, lower and upper bounds

■ Output

mu_tilde	matrix $3n \times 1$, vector of expected returns
Sigma_tilde	matrix $3n \times 3n$, covariance matrix of asset returns
A_tilde	matrix $(m+1) \times 3n$, A matrix
B_tilde	matrix $(m+1) \times 1$, B vector
C_tilde	matrix $1 \times 3n$, C matrix
D_tilde	matrix 1×1, D vector
Bounds_tilde	matrix $3n \times 2$, lower and upper bounds

■ Globals

■ Remarks

The mean-variance optimized portfolio is obtained by solving an augmented QP problem (see page 59).

■ Source

rpb-markowitz.src

Implied_Risk_Premium

- **Purpose**

  Computes the implied risk premia.

- **Format**

  {mu_x,pi_x,pc,ppc} = Implied_Risk_Premium(x,Sigma,SR);

- **Input**

x	matrix $n \times 1$, portfolio x
Sigma	matrix $n \times n$, covariance matrix of asset returns
SR	scalar, Sharpe ratio of portfolio x

- **Output**

mu_x	scalar, expected return of portfolio x
pi_x	matrix $n \times 1$, implied risk premia
pc	matrix $n \times 1$, performance contributions
ppc	matrix $n \times 1$, performance contributions expressed in %

- **Globals**

- **Remarks**

  The implied risk premia and performance contributions associated to a portfolio are defined on pages 114-115.

- **Source**

  rpb-rp.src

Implied_Risk_Premium2

■ Purpose
Computes the implied risk premia (two-asset case).

■ Format
{pi1,pi2} = Implied_Risk_Premium2(x,sigma1,sigma2,rho,SR);

■ Input

x	matrix $n \times 1$, weight of the first asset
sigma1	matrix $n \times 1$, volatility of the first asset
sigma2	matrix $n \times 1$, volatility of the second asset
rho	matrix $n \times 1$, cross-correlation
SR	matrix $n \times 1$, Sharpe ratio

■ Output

pi1	matrix $n \times 1$, implied risk premium of the first asset
pi2	matrix $n \times 1$, implied risk premium of the second asset

■ Globals

■ Remarks
The implied risk premium for the two-asset case is defined on page 277.

■ Source
rpb-rp.src

Risky_Bond_Price

Purpose

Computes the price of a risky bond.

Format

P = Risky_Bond_Price(t,Ct,Notional,Maturity,RR,IR_fn,Survival_fn,Density_fn);

Input

t	matrix $m \times 1$, vector of fixing dates
Ct	matrix $m \times 1$, vector of coupons
Notional	scalar, notional of the bond
Maturity	scalar, maturity of the bond
RR	scalar, recovery rate
IR_fn	scalar, pointer to the procedure that computes the zero-coupon interest rates
Survival_fn	scalar, pointer to the procedure that computes the survival function of the default time
Density_fn	scalar, pointer to the procedure that computes the density function of the default time

Output

P	scalar, price of the risky bond

Globals

_Bond_Continuous_Time	scalar 0 for the actuarial method 1 for the continuous method

Remarks

We use the formula on page 200 to compute the price of the risky bond.

Source

rpb-bond.src

Risky_Bond_Price_EDT

■ Purpose

Computes the price of a risky bond (exponential default time).

■ Format

P = Risky_Bond_Price_EDT(t,Ct,Rt,Notional,Maturity,RR,lambda);

■ Input

t	matrix $m \times 1$, vector of fixing dates
Ct	matrix $m \times 1$, vector of coupons
Rt	matrix $m \times 1$, vector of zero-coupon interest rates
Notional	scalar, notional of the bond
Maturity	scalar, maturity of the bond
RR	scalar, recovery rate
lambda	scalar, parameter λ of the exponential default time

■ Output

P	scalar, price of the risky bond

■ Globals

_Bond_Continuous_Time	scalar 0 for the actuarial method 1 for the continuous method

■ Remarks

We use the formula on page 200 to compute the price of the risky bond.

■ Source

rpb-bond.src

Rolling_Covariance

■ Purpose

Estimates the covariance matrix with a rolling window.

■ Format

{cov,vol,cor} = Rolling_Covariance(dates,data,dt,mtd);

■ Input

dates	matrix $T \times 1$, vector of dates
data	matrix $T \times n$, data matrix containing the price dynamics
dt	scalar, lag window (in days)
mtd	scalar, method to treat missing values 1 for the listwise deletion 2 for the pairwise deletion

■ Output

cov	array $T \times n \times n$, array containing the covariance matrices
vol	matrix $T \times n$, matrix containing the volatilities
cor	array $T \times n \times n$, array containing the correlation matrices

■ Globals

■ Remarks

■ Source

rpb-cov-vol.src

vcx2

■ Purpose

Estimates the covariance matrix when the data contain missing values.

■ Format

{Sigma,mu} = vcx2(x,mtd);

■ Input

x	matrix $T \times n$, data matrix
mtd	scalar, method to treat missing values
	0 if no missing data
	1 for a listwise deletion
	2 for a pairwise deletion
	3 for a complete pairwise deletion
	4 for a modified listwise deletion
	5 for a modified complete pairwise deletion

■ Output

Sigma	matrix $n \times n$, covariance matrix
mu	matrix $n \times 1$, vector of means

■ Globals

■ Remarks

■ Source

rpb-cov-vol.src

VCX_CC

■ **Purpose**

Estimates the covariance matrix by assuming a uniform correlation.

■ **Format**

{Sigma,rho} = vcx_cc(x);

■ **Input**

x	matrix $T \times n$, data matrix

■ **Output**

Sigma	matrix $n \times n$, covariance matrix
rho	scalar, uniform correlation

■ **Globals**

■ **Remarks**

■ **Source**

rpb-cov-vol.src

vcx_factor

■ **Purpose**

Estimates the covariance matrix using m risk factors.

■ **Format**

{Sigma,f} = vcx_factor(x,m);

■ **Input**

x	matrix $T \times n$, data matrix
m	scalar, number of factors

■ **Output**

Sigma	matrix $n \times n$, covariance matrix
f	matrix $T \times m$, PCA factor matrix

■ **Globals**

■ **Remarks**

We use the linear factor model on page 38 to compute the covariance matrix. The factors are estimated using principal component analysis (see page 47 for the expression of PCA factors).

■ **Source**

rpb-cov-vol.src

vcx_rmt

- **Purpose**

  Estimates the covariance matrix using the random matrix theory.

- **Format**

  {Sigma,f} = vcx_factor(x);

- **Input**

x	matrix $T \times n$, data matrix

- **Output**

Sigma	matrix $n \times n$, covariance matrix
f	matrix $T \times m$, PCA factor matrix

- **Globals**

- **Remarks**

  The number of PCA factors is estimated using the formula given on page 48.

- **Source**

  rpb-cov-vol.src

Chapter 3

Programs

Remark 2 *The numerical programs marked ($\star$) are not distributed. Most of databases (SX5E, EGBI, DJCS, etc.) are also not available because of the data copyright.*

3.1 Appendix A

1. **app1-2-1-1.prg**
   Reproduces Figure A.1 on Page 309.

2. **app1-2-1-2.prg**
   Reproduces Figure A.2 on Page 311.

3. **app1-2-1-3.prg**
   Reproduces Figure A.3 on Page 311.

4. **app1-2-2-1.prg**
   Reproduces Figure A.4 on Page 313.

5. **app1-2-4-1.prg**
   Reproduces Figure A.5 on Page 318.

6. **app1-2-4-2.prg**
   Reproduces Figure A.6 on Page 318.

7. **app1-3-3-1.prg**
   Reproduces Table A.2 on Page 328.

8. **app1-3-3-2.prg**
   Reproduces Table A.3 on Page 328.

9. **app1-3-3-3.prg**
   Reproduces Figure A.7 on Page 329.

10. **app1-3-3-4.prg**
    Reproduces Figure A.8 on Page 332.

11. **app1-3-3-5.prg**
    Reproduces Figure A.9 on Page 335.

12. **app1-3-3-6.prg**
    Reproduces Figure A.10 on Page 335.

3.2 Appendix B

1. **app2-1-1-1.prg**
   Solves Exercise B.1.1 on Page 337.

2. **app2-1-2-1.prg**
   Solves Exercise B.1.2 on Page 338.

3. **app2-1-3-1.prg**
   Solves Exercise B.1.3 on Page 339.

4. **app2-1-4-1.prg**
   Solves Exercise B.1.4 on Page 341.

5. **app2-1-5-1.prg**
   Solves Exercise B.1.5 on Page 342.

6. **app2-1-6-1.prg**
   Solves Exercise B.1.6 on Page 343.

7. **app2-1-7-1.prg**
   Solves Exercise B.1.7 on Page 344.

8. **app2-1-8-1.prg**
   Solves Exercise B.1.8 on Page 345.

9. **app2-1-9-1.prg**
   Solves Exercise B.1.9 on Page 346.

10. **app2-1-10-1.prg**
    Solves Exercise B.1.10 on Page 347.

11. **app2-1-11-1.prg**
    Solves Exercise B.1.11 on Page 348.

12. **app2-1-12-1.prg**
    Solves Exercise B.1.12 on Page 349.

13. **app2-2-1-1.prg**
    Solves Exercise B.2.1 on Page 351.

14. **app2-2-2-1.prg**
    Solves Exercise B.2.2 on Page 352.

15. **app2-2-3-1.prg**
    Solves Exercise B.2.3 on Page 353.

16. **app2-2-4-1.prg**
    Solves Exercise B.2.4 on Page 354.

17. **app2-2-5-1.prg**
    Solves Exercise B.2.5 on Page 355.

18. **app2-2-6-1.prg**
    Solves Exercise B.2.6 on Page 356.

19. **app2-2-7-1.src**
    Procedures for solving Exercise B.2.7 on Page 358.

20. **app2-2-7-1.prg**
    Solves Exercise B.2.7 on Page 358.

21. **app2-2-8-1.prg**
    Solves Exercise B.2.8 on Page 359.

22. **app2-2-9-1.prg**
    Solves Exercise B.2.9 on Page 360.

23. **app2-2-9-2.prg**
    Solves Exercise B.2.9 on Page 360.

24. **app2-3-1-1.prg**
    Solves Exercise B.3.1 on Page 362.

25. **app2-3-2-1.prg**
    Solves Exercise B.3.2 on Page 362.

26. **app2-3-3-1.prg**
    Solves Exercise B.3.3 on Page 363.

27. **app2-3-4-1.prg**
    Solves Exercise B.3.4 on Page 365.

28. **app2-3-5-1.prg**
    Solves Exercise B.3.5 on Page 366.

29. **app2-3-6-1.prg**
    Solves Exercise B.3.6 on Page 368.

30. **app2-3-7-1.prg**
    Solves Exercise B.3.7 on Page 370.

31. **app2-3-8-0.prg**
    Solves Exercise B.3.8 on Page 371.

32. **app2-3-8-1.prg**
    Solves Exercise B.3.8 on Page 371.

33. **app2-3-9-1.prg**
    Solves Exercise B.3.9 on Page 372.

34. **app2-3-10-1.prg**
    Solves Exercise B.3.10 on Page 374.

3.3 Chapter 1

1. **chap1-1-1-1.prg**
   Reproduces Figure 1.1 on Page 6.

2. **chap1-1-1-2.prg**
   Reproduces Figure 1.2 on Page 8.

3. **chap1-1-1-3.prg**
   Reproduces Tables 1.1, 1.2 and 1.3 on Pages 7 and 8.

4. **chap1-1-1-4.prg**
   Reproduces Figure 1.3 and Table 1.4 on Page 10.

5. **chap1-1-1-5.prg**
   Tests Equation (1.6) on Page 11.

6. **chap1-1-2-1.prg**
   Reproduces Figure 1.4 on Page 13.

7. **chap1-1-2-2.prg**
   Reproduces Figure 1.5 on Page 15.

8. **chap1-1-3-1.prg**
   Reproduces Tables 1.5 and 1.6 on Pages 17 and 18.

9. **chap1-1-4-1.prg**
   Reproduces Figure 1.6 on Page 20.

10. **chap1-1-4-2.prg**
    Reproduces Figure 1.7 on Page 21.

11. **chap1-1-5-1.prg**
    Computes the implied expected returns on Page 24.

12. **chap1-1-5-2.prg**
Computes the sensitivity of $\bar{\mu}$ with respect to the matrix Q.

13. **chap1-1-5-3.prg**
Reproduces Table 1.7 on Page 26.

14. **chap1-1-5-4.prg**
Computes the optimal value of τ and the corresponding Black-Litterman portfolio x^* (Page 26).

15. **chap1-2-1-1.prg**
Computes the correlation matrix (1.16) on Page 28.

16. **chap1-2-1-2.prg**
Reproduces Figure 1.9 on Page 31.

17. **chap1-2-1-3.prg**
Reproduces Figure 1.10 on Page 33.

18. **chap1-2-1-4.prg**
Reproduces Figure 1.11 on Page 35.

19. **chap1-2-1-5.prg**
Reproduces Figure 1.12 on Page 36.

20. **chap1-2-1-6.prg**
Reproduces Figure 1.13 on Page 38.

21. **chap1-2-1-7.prg**
Computes the correlation matrices (1.19) and (1.21) on Page 39.

22. **chap1-2-3-1.prg**
Reproduces Table 1.8 on Page 45.

23. **chap1-2-3-2.prg**
Reproduces Figure 1.16 on Page 46.

24. **chap1-2-3-3.prg**
Illustrates the resampling technique (Page 47).

25. **chap1-2-3-4.prg**
Reproduces Figure 1.17 on Page 48.

26. **chap1-2-3-5.prg**
Computes the correlation matrix (1.23) on Page 49.

27. **chap1-2-3-6.prg**
Computes the correlation matrix (1.24) on Page 51.

28. **chap1-2-3-7.prg**
Reproduces Table 1.9 on Page 53.

29. **chap1-2-3-8.prg**
    Reproduces Figure 1.18 on Page 54.

30. **chap1-2-4-1.prg**
    Reproduces Tables 1.10 and 1.11 on Page 55.

31. **chap1-2-4-2.prg**
    Reproduces Figure 1.19 on Page 56.

32. **chap1-2-4-3.prg**
    Reproduces Table 1.12 on Page 57.

33. **chap1-2-4-4.prg**
    Illustrates the effect of deleting a PCA factor (Page 56).

34. **chap1-2-4-5.prg**
    Reproduces Table 1.13 on Page 60.

35. **chap1-2-4-6.prg**
    Reproduces Tables 1.14, 1.15 and 1.16 on Pages 63 and 64.

36. **chap1-2-4-7.prg**
    Calculates the number of solved QP problems (Page 62).

37. **chap1-2-4-8.prg**
    Computes the sampling of the SPX index (Page 64).

38. **chap1-2-4-9.prg**
    Reproduces Figure 1.20 on Page 65.

39. **chap1-2-4-10.prg**
    Reproduces Table 1.17 on Page 68.

40. **chap1-2-4-11.prg**
    Reproduces Table 1.18 on Page 69.

41. **chap1-2-4-12.prg**
    Reproduces Table 1.19 on Page 69.

42. **chap1-2-4-13.prg**
    Reproduces Table 1.20 on Page 70.

3.4 Chapter 2

1. **chap2-0-0-1.prg**
   Reproduces Figure 2.1 on Page 72.

2. **chap2-1-1-1.prg**
   Reproduces Table 2.1 on Page 76.
3. **chap2-1-2-1.prg**
   Reproduces Tables 2.2, 2.3 and 2.4 on Pages 81 and 82.
4. **chap2-1-2-2.prg**
   Reproduces Tables 2.5 and 2.6 on Page 84.
5. **chap2-1-3-1.prg**
   Checks the results on Pages 86 and 87.
6. **chap2-1-3-2.prg**
   Computes the risk contributions of Example 8 (Pages 88-90).
7. **chap2-1-3-3.prg**
   Reproduces Figure 2.2 on Page 90.
8. **chap2-1-3-4.prg**
   Computes the Monte Carlo simulation on Page 91.
9. **chap2-1-3-5.prg**
   Computes the numerical results used in Remark 24 on Page 91.
10. **chap2-1-3-6.prg**
    Checks the results on Page 92.
11. **chap2-1-3-7.prg**
    Checks the formulas given on Pages 94 and 95.
12. **chap2-1-3-8.prg**
    Tests the Cornish-Fisher value-at-risk (Page 94).
13. **chap2-1-3-9.prg**
    Reproduces Table 2.7 and Figure 2.3 on Pages 96 and 97.
14. **chap2-1-3-10.prg**
    Reproduces the numerical results of Example 10 and Table 2.8 on Pages 96-98.
15. **chap2-2-1-1.prg**
    Reproduces Tables 2.9 and 2.10 on Pages 99 and 100.
16. **chap2-2-1-2.prg**
    Illustrates the uniqueness problem of the RB portfolio (Page 101).
17. **chap2-2-2-1.prg**
    Reproduces Figure 2.4 on Page 104.
18. **chap2-2-2-2.prg**
    Reproduces Table 2.11 on Page 103.

19. **chap2-2-2-3.prg**
    Reproduces Figure 2.5 on Page 107.
20. **chap2-2-2-4.prg**
    Reproduces Table 2.12 and Figure 2.6 on Page 112.
21. **chap2-2-2-5.prg**
    Reproduces Table 2.13 on Page 113.
22. **chap2-2-2-6.prg**
    Another illustration of the uniqueness problem (Page 111).
23. **chap2-2-3-1.prg**
    Reproduces Tables 2.14 and 2.15 on Page 116.
24. **chap2-2-4-1.prg**
    Reproduces Tables 2.16 and 2.17 on Page 117.
25. **chap2-2-4-2.prg**
    Computes the ERC Shrinkage covariance matrix (Page 118).
26. **chap2-2-4-3.prg**
    Reproduces Tables 2.18 and 2.19 on Pages 118 and 119.
27. **chap2-2-4-4.prg**
    Computes numerically the shrinkage covariance matrix (Pages 117 and 118).
28. **chap2-3-1-1.prg**
    Reproduces Table 2.20 on Page 121.
29. **chap2-3-2-1.prg**
    Reproduces Table 2.21 on Page 123.
30. **chap2-3-3-1.prg**
    Reproduces Figure 2.7 on Page 124.
31. **chap2-3-3-2.prg**
    Reproduces Figure 2.8 on Page 125.
32. **chap2-3-4-1.prg**
    Reproduces Figure 2.9 on Page 128.
33. **chap2-3-4-2.prg**
    Reproduces Table 2.22 on Page 129.
34. **chap2-4-1-1.prg**
    Reproduces Table 2.23 on Page 132.
35. **chap2-4-2-1.prg**
    Reproduces Table 2.24 and Figure 2.10 on Page 134.

36. **chap2-5-1-1.prg**
    Illustrates the duplication invariance property (Page 135).

37. **chap2-5-1-2.prg**
    Illustrates the polico invariance property (Page 137).

38. **chap2-5-1-3.prg**
    Reproduces Tables 2.25, 2.26, 2.27, 2.28 and Figure 2.11 on Pages 139-140.

39. **chap2-5-2-1.prg**
    Computes A^+ and $\tilde{B}$ and reproduces Tables 2.29 and 2.30 on Page 143

40. **chap2-5-3-1.prg**
    Reproduces Tables 2.31 and 2.32 on Pages 144 and 145.

41. **chap2-5-3-2.prg**
    Illustrates the duplication invariance property and solves it with the risk factor approach (Page 144).

42. **chap2-5-3-3.prg**
    Reproduces Tables 2.33 and 2.34 on Pages 145 and 146.

43. **chap2-5-3-4.prg**
    Reproduces Table 2.35 on Page 146.

44. **chap2-5-3-5.prg**
    Solves the duplication invariance property with the risk factor approach (Pages 146-147).

45. **chap2-5-3-6.prg**
    Solves the polico invariance property with the risk factor approach (Pages 146-147).

3.5 Chapter 3

1. **chap3-1-3-1.prg**
   Reproduces Table 3.1 and Figure 3.1 on Page 158.

2. **chap3-2-2-1.prg**
   Reproduces Figure 3.2 on Page 162.

3. **chap3-2-3-1.prg**
   Reproduces Figure 3.3 on Page 163.

4. **chap3-2-3-2.prg**
   Reproduces Tables 3.1, 3.2 and Figure 3.3 on Pages 165 and 166.

5. **chap3-2-3-3.prg**
   Reproduces Table 3.4 on Page 169.

6. **chap3-2-3-4.prg**
   Reproduces Table 3.5 on Page 171.

7. **chap3-2-3-5.prg**
   Solves Example 26 on Page 175.

8. **chap3-2-3-6.prg**
   Solves Example 27 on Page 176.

9. **chap3-2-3-7.prg**
   Solves Example 28 on Page 176.

10. **chap3-2-3-8.prg**
    Solves Example 29 on Page 177.

11. **chap3-2-3-9.prg**
    Solves Example 30 on Page 178.

12. **chap3-2-3-10.prg**
    Solves Example 31 on Page 178.

13. **chap3-2-3-11.prg**
    Solves Example 32 on Page 179.

14. **chap3-3-1-1.prg** ($\star$)
    Simulates risk-based portfolios (Page 181).

15. **chap3-3-1-2.prg** ($\star$)
    Simulates risk-based portfolios with different lag windows for estimating the covariance matrix (Page 184).

16. **chap3-3-1-3.prg** ($\star$)
    Simulates risk-based portfolios with shrinkage covariance matrices (Page 186).

17. **chap3-3-1-4.prg**
    Reproduces Table 3.11 on Page 182.

18. **chap3-3-1-5.prg**
    Reproduces Table 3.12 on Page 182.

19. **chap3-3-1-6.prg**
    Reproduces Figure 3.7 on Page 183.

20. **chap3-3-2-1.prg**
    Computes the composition of risk-based portfolios for a given date (Page 183).

21. **chap3-3-2-2.prg**
    Reproduces Table 3.13 on Page 184.
22. **chap3-3-2-3.prg**
    Reproduces Figure 3.8 on Page 185.
23. **chap3-3-2-4.prg**
    Reproduces Table 3.14 on Page 185.
24. **chap3-3-2-5.prg**
    Reproduces Table 3.15 on Page 187.

3.6 Chapter 4

1. **chap4-2-1-1.prg**
   Reproduces Figure 4.1 on Page 196.
2. **chap4-2-1-2.prg**
   Reproduces Figure 4.2 on Page 197.
3. **chap4-2-2-1.prg**
   Reproduces Figure 4.3 on Page 199.
4. **chap4-2-2-2.prg**
   Reproduces Table 4.1 on Page 199.
5. **chap4-2-2-3.prg**
   Reproduces Table 4.2 on Page 200.
6. **chap4-2-2-4.prg**
   Solves Example 34 on Page 201.
7. **chap4-2-2-5.prg**
   Solves Example 34 on Page 201 (with Nelson-Siegel yield curve).
8. **chap4-2-2-6.prg**
   Reproduces Table 4.3 on Page 202.
9. **chap4-2-3-1.prg**
   Reproduces Table 4.4 and Figure 4.6 on Page 206.
10. **chap4-2-3-2.prg**
    Reproduces Table 4.5 on Page 206.
11. **chap4-2-3-3.prg**
    Computes the risk decomposition of a bond portfolio (Page 205).

12. **chap4-2-3-4.prg**
    Reproduces Table 4.6 on Page 208.
13. **chap4-2-3-5.prg**
    Reproduces Table 4.7 on Page 208.
14. **chap4-2-3-6.prg**
    Reproduces Figure 4.7 on Page 210.
15. **chap4-2-3-7.prg**
    Reproduces Tables 4.8 and 4.9 on Page 215.
16. **chap4-3-1-1.prg**
    Reproduces Figure 4.8 on Page 218.
17. **chap4-3-1-2.prg**
    Reproduces Figure 4.9 on Page 218.
18. **chap4-3-1-3.prg**
    Reproduces Figure 4.10 on Page 219.
19. **chap4-3-1-4.prg**
    Reproduces Figure 4.11 on Page 219.
20. **chap4-3-1-5.prg**
    Computes the maximum value of the risk contribution (Remark 54 on Page 217).
21. **chap4-3-1-6.prg**
    Reproduces Table 4.10 and Figure 4.12 on Pages 220 and 221.
22. **chap4-3-1-7.prg**
    Reproduces Figure 4.13 on Page 221.
23. **chap4-3-2-2.prg**
    Reproduces Table 4.12 on Page 224.
24. **chap4-3-2-3.prg**
    Reproduces Tables 4.13 and 4.14 on Pages 225 and 226.
25. **chap4-3-2-4.prg**
    Reproduces Figure 4.14 on Page 226.
26. **chap4-3-2-5.prg**
    Reproduces Tables 4.16, 4.17, 4.18 and 4.19 on Pages 228 and 229.
27. **chap4-3-2-6.prg**
    Computes the risk contributions of the EGBI portfolio (Page 229).
28. **chap4-3-2-7.prg** ($\star$)
    Simulates the GDP-WB index (Page 231).

29. **chap4-3-2-8.prg** ($\star$)
Simulates the DEBT-WB index (Page 231).

30. **chap4-3-2-9.prg** ($\star$)
Simulates the EGBI-RB index (Page 235).

31. **chap4-3-2-10.prg** ($\star$)
Simulates the GDP-RB index (Page 235).

32. **chap4-3-2-11.prg** ($\star$)
Simulates the DEBT-RB index (Page 235).

33. **chap4-3-2-12.prg**
Reproduces Table 4.20 on Page 230.

34. **chap4-3-2-13.prg**
Reproduces Table 4.21 on Page 232.

35. **chap4-3-2-14.prg**
Reproduces Table 4.22 on Page 233.

36. **chap4-3-2-15.prg**
Reproduces Table 4.23 on Page 236.

37. **chap4-3-2-16.prg**
Reproduces Table 4.24 on Page 237.

38. **chap4-3-2-17.prg**
Reproduces Figure 4.20 on Page 239.

39. **chap4-3-2-18.prg**
Reproduces Figure 4.21 on Page 239.

40. **chap4-3-2-19.prg**
Reproduces Table 4.25 and Figure 4.22 on Pages 238 and 240.

41. **chap4-3-2-20.prg**
Reproduces Figure 4.23 on Page 241.

42. **chap4-3-2-21.prg**
Reproduces Figure 4.24 on Page 241.

3.7 Chapter 5

1. **chap5-1-1-1.prg**
Reproduces Figure 5.1 on Page 245.

2. **chap5-1-1-2.prg**
   Reproduces Figure 5.2 on Page 246.

3. **chap5-1-2-1.prg**
   Reproduces Tables 5.1 and 5.2 on Page 252.

4. **chap5-1-2-2.prg** ($\star$)
   Reproduces Table 5.3 and Figure 5.3 on Page 253.

5. **chap5-2-1-1.prg**
   Reproduces Table 5.4 on Page 257.

6. **chap5-2-2-1.prg**
   Reproduces Table 5.5 on Page 259.

7. **chap5-2-2-3.prg**
   Simulates ERC allocations (Pages 258 and and 262).

8. **chap5-2-2-4.prg**
   Tests the convergence of ERC optimization problems (Pages 258 and and 262).

9. **chap5-2-2-5.prg**
   Reproduces Table 5.6 and Figures 5.4, 5.5, 5.6 & 5.7 on Pages 259-262.

10. **chap5-2-2-6.prg**
    Reproduces Table 5.7 and Figures 5.8, 5.9, 5.10 & 5.11 on Pages 263-265.

11. **chap5-2-3-1.prg**
    Illustrates the turnover problem (Page 266).

12. **chap5-2-3-2.prg**
    Illustrates the turnover problem (Page 266).

13. **chap5-2-3-3.prg**
    Reproduces Tables 5.8, 5.9, 5.10 and 5.11 on Page 267.

14. **chap5-2-3-4.prg**
    Reproduces Tables 5.12 and 5.13 on Page 268.

3.8 Chapter 6

1. **chap6-1-1-1.prg**
   Reproduces Figure 6.1 on Page 272.

2. **chap6-1-1-2.prg**
   Reproduces Figure 6.2 on Page 273.

3. **chap6-1-1-3.prg**
   Reproduces Figure 6.3 on Page 274.

4. **chap6-1-2-1.prg**
   Reproduces Table 6.1 and Figure 6.4 on Pages 275 and 276.

5. **chap6-1-2-2.prg**
   Reproduces Figure 6.5 on Page 276.

6. **chap6-1-2-3.prg**
   Tests the analytical formula of the implied risk premium (Page 277).

7. **chap6-1-2-4.prg**
   Reproduces Figure 6.6 on Page 278.

8. **chap6-1-3-1.prg**
   Reproduces Table 6.2 and Figure 6.7 on Pages 279 and 280.

9. **chap6-1-4-1.prg**
   Reproduces Figure 6.8 on Page 283.

10. **chap6-1-4-2.prg**
    Reproduces Figure 6.9 on Page 283.

11. **chap6-2-1-1.prg**
    Reproduces Figure 6.10 on Page 286.

12. **chap6-2-2-1.prg**
    Reproduces Table 6.5 and Figure 6.12 on Pages 289 and 290.

13. **chap6-2-2-2.prg**
    Reproduces Table 6.6 and 6.7 on Pages 290 and 291.

14. **chap6-2-2-3.prg**
    Reproduces Table 6.8 and Figure 6.13 on Page 292.

15. **chap6-2-2-4.prg**
    Reproduces Figure 6.14 on Page 293.

16. **chap6-2-2-5.prg**
    Reproduces Figure 6.9 on Page 292.

17. **chap6-3-1-1.prg** ($\star$)
    Reproduces Table 6.10 and Figure 6.15 on Pages 296 and 297.

18. **chap6-3-1-2.prg** ($\star$)
    Reproduces Table 6.10 and Figure 6.16 on Pages 296 and 297.

3.9 Correspondence between the procedures and the programs

- **Barbell_Calibrate** — *chap4-3-1-6.prg*, *chap4-3-1-7.prg*.
- **Bond_Duration** — *chap4-2-2-2.prg*, *chap4-2-2-3.prg*, *chap4-3-1-6.prg*, *chap4-3-1-7.prg*.
- **Bond_Generate_Portfolio** — *chap4-2-3-3.prg*, *chap4-2-3-4.prg*, *chap4-2-3-5.prg*.
- **Bond_Portfolio_VaR** — *chap4-2-3-3.prg*, *chap4-2-3-4.prg*, *chap4-2-3-5.prg*, *chap4-2-3-6.prg*.
- **Bond_Portfolio_VaR_PCA** — *chap4-2-3-5.prg*.
- **Bond_Portfolio_VaR_RC** — *chap4-2-3-2.prg*, *chap4-2-3-3.prg*, *chap4-2-3-4.prg*.
- **Bond_Price** — *chap4-2-2-2.prg*, *chap4-2-2-3.prg*, *chap4-2-3-1.prg*, *chap4-2-3-2.prg*, *chap4-2-3-3.prg*, *chap4-2-3-4.prg*, *chap4-2-3-5.prg*, *chap4-2-3-6.prg*, *chap4-3-1-6.prg*, *chap4-3-1-7.prg*.
- **Bond_VaR** — *chap4-2-3-1.prg*, *chap4-2-3-2.prg*, *chap4-2-3-3.prg*.
- **Bond_VaR_RC** — *chap4-2-3-2.prg*.
- **Bond_YTM** — *chap4-2-2-2.prg*, *chap4-2-2-3.prg*, *chap4-2-2-6.prg*, *chap4-3-1-6.prg*, *chap4-3-1-7.prg*.
- **Capitalized_Libor** — *app2-3-10-1.prg*, *chap4-3-2-19.prg*, *chap4-3-2-21.prg*, *chap6-1-3-1.prg*, *chap6-3-1-1.prg*, *chap6-3-1-2.prg*.
- **cdfBeta** — *app1-2-1-1.prg*.
- **cdfCopulaNormal2** — *app1-2-4-1.prg*.
- **cdfCopulaStudent2** — *app1-2-4-2.prg*.
- **cdfIG** — *app1-2-1-1.prg*.
- **cdfSNi** — *chap2-1-3-9.prg*.
- **closest_Index** — *chap4-3-2-3.prg*, *chap4-3-2-4.prg*, *chap4-3-2-6.prg*, *chap4-3-2-7.prg*, *chap4-3-2-8.prg*, *chap4-3-2-9.prg*, *chap4-3-2-10.prg*, *chap4-3-2-11.prg*, *chap4-3-2-12.prg*, *chap4-3-2-13.prg*, *chap4-3-2-14.prg*, *chap4-3-2-15.prg*, *chap4-3-2-16.prg*.
- **Compute_BL_Portfolio** — *app2-1-9-1.prg*, *chap1-1-5-3.prg*, *chap1-1-5-4.prg*.

- **Compute_BL_Risk_Premium** — *chap1-1-5-2.prg*, *chap1-1-5-3.prg*.
- **Compute_Cornish_Fisher_VaR** — *app2-2-9-1.prg*, *chap2-1-3-7.prg*, *chap2-1-3-10.prg*.
- **Compute_Cornish_Fisher_z** — *chap2-1-3-8.prg*, *chap2-1-3-9.prg*, *chap2-1-3-10.prg*.
- **Compute_EMN_Portfolio** — *chap5-2-1-1.prg*.
- **Compute_Empirical_RC** — *chap2-1-3-3.prg*, *chap2-1-3-4.prg*, *chap2-1-3-5.prg*.
- **Compute_ERC_ES** — *app2-2-7-1.prg*.
- **Compute_ERC_LS** — *chap5-2-1-1.prg*.
- **Compute_ERC_Portfolio** — *app2-1-7-1.prg*, *app2-2-3-1.prg*, *app2-2-8-1.prg*, *app2-3-1-1.prg*, *app2-3-7-1.prg*, *app2-3-8-1.prg*, *app2-3-10-1.prg*, *chap2-3-1-1.prg*, *chap2-3-2-1.prg*, *chap2-3-2-2.prg*, *chap2-3-4-2.prg*, *chap2-5-1-1.prg*, *chap2-5-1-3.prg*, *chap3-2-3-5.prg*, *chap3-2-3-6.prg*, *chap3-2-3-7.prg*, *chap3-2-3-8.prg*, *chap3-2-3-9.prg*, *chap3-2-3-10.prg*, *chap3-2-3-11.prg*, *chap3-3-1-1.prg*, *chap3-3-1-2.prg*, *chap3-3-1-3.prg*, *chap5-1-2-2.prg*, *chap6-1-3-1.prg*, *chap6-3-1-1.prg*, *chap6-3-1-2.prg*.
- **Compute_ERC_VaR** — *app2-2-9-1.prg*.
- **Compute_Factor_Correlation** — *chap5-2-1-1.prg*.
- **Compute_Lasso_Portfolio** — *chap1-2-3-7.prg*, *chap1-2-3-8.prg*.
- **Compute_Lifestyle_Portfolio** — *app1-3-3-1.prg*, *app1-3-3-2.prg*, *app1-3-3-3.prg*.
- **Compute_MDP_Portfolio** — *app2-3-1-1.prg*, *app2-3-4-1.prg*, *chap2-3-4-2.prg*, *chap3-2-3-4.prg*, *chap3-2-3-5.prg*, *chap3-2-3-6.prg*, *chap3-2-3-7.prg*, *chap3-2-3-8.prg*, *chap3-2-3-9.prg*, *chap3-2-3-10.prg*, *chap3-2-3-11.prg*.
- **Compute_MV_Portfolio** — *app2-1-1-1.prg*, *app2-2-2-1.prg*, *app2-2-8-1.prg*, *app2-3-1-1.prg*, *app2-3-3-1.prg*, *app2-3-4-1.prg*, *chap1-1-1-3.prg*, *chap1-2-4-10.prg*, *chap1-2-4-11.prg*, *chap2-3-1-1.prg*, *chap2-3-4-2.prg*, *chap2-4-2-1.prg*, *chap2-5-1-2.prg*, *chap3-2-3-2.prg*, *chap3-2-3-3.prg*, *chap3-2-3-5.prg*, *chap3-2-3-6.prg*, *chap3-2-3-7.prg*, *chap3-2-3-8.prg*, *chap3-2-3-9.prg*, *chap3-2-3-10.prg*, *chap3-2-3-11.prg*, *chap3-3-1-1.prg*, *chap3-3-1-2.prg*, *chap3-3-1-3.prg*.

- **Compute_MVO_Portfolio** — *app2-1-1-1.prg*, *app2-1-2-1.prg*, *app2-1-5-1.prg*, *app2-1-9-1.prg*, *app2-1-10-1.prg*, *app2-1-11-1.prg*, *app2-3-9-1.prg*, *chap1-1-1-1.prg*, *chap1-1-1-2.prg*, *chap1-1-1-3.prg*, *chap1-1-1-4.prg*, *chap1-1-1-5.prg*, *chap1-1-2-1.prg*, *chap1-1-2-2.prg*, *chap1-1-3-1.prg*, *chap1-2-3-1.prg*, *chap1-2-3-2.prg*, *chap1-2-3-3.prg*, *chap1-2-3-4.prg*, *chap1-2-4-3.prg*, *chap1-2-4-4.prg*, *chap1-2-4-5.prg*, *chap1-2-4-12.prg*, *chap1-2-4-13.prg*, *chap2-2-3-1.prg*, *chap2-2-4-1.prg*, *chap2-3-3-1.prg*, *chap2-3-2-2.prg*, *chap3-2-3-2.prg*, *chap6-1-1-1.prg*, *chap6-1-4-1.prg*, *chap6-1-4-2.prg*, *chap6-2-2-1.prg*, *chap6-3-1-1.prg*, *chap6-3-1-2.prg*.
- **Compute_MSR_Portfolio** — *chap1-2-4-13.prg*.
- **Compute_RB_2A** — *chap2-2-2-1.prg*, *chap2-2-2-2.prg*.
- **Compute_RB_CC** — *chap2-2-2-3.prg*.
- **Compute_RB_CF** — *app2-2-9-1.prg*.
- **Compute_RB_ES** — *app2-2-7-1.prg*, *chap2-2-1-1.prg*, *chap2-4-1-1.prg*.
- **Compute_RB_Factor** — *app2-2-6-1.prg*, *chap2-5-3-1.prg*, *chap2-5-3-2.prg*, *chap2-5-3-3.prg*, *chap2-5-3-4.prg*, *chap4-3-1-5.prg*, *chap6-2-2-2.prg*.
- **Compute_RB_Factor_NG** — *chap5-2-2-3.prg*.
- **Compute_RB_NG** — *chap5-2-2-3.prg*.
- **Compute_RB_Portfolio** — *app2-2-5-1.prg*, *app2-3-6-1.prg*, *app2-3-8-1.prg*, *app2-3-10-1.prg*, *app2-3-10-1.prg*, *chap2-2-1-2.prg*, *chap2-2-2-3.prg*, *chap2-2-2-4.prg*, *chap2-2-2-5.prg*, *chap2-2-2-6.prg*, *chap2-2-3-1.prg*, *chap2-2-4-1.prg*, *chap2-2-4-2.prg*, *chap2-2-4-3.prg*, *chap2-4-2-1.prg*, *chap2-5-1-1.prg*, *chap2-5-1-2.prg*, *chap2-5-3-2.prg*, *chap2-5-3-4.prg*, *chap2-5-3-5.prg*, *chap2-5-3-6.prg*, *chap4-3-2-9.prg*, *chap4-3-2-10.prg*, *chap4-3-2-11.prg*, *chap5-2-3-1.prg*, *chap5-2-3-2.prg*, *chap5-2-3-3.prg*, *chap5-2-3-4.prg*, *chap6-2-2-1.prg*, *chap6-3-1-2.prg*.
- **Compute_RB_Turnover** — *chap5-2-3-1.prg*.
- **Compute_RB_Vol** — *chap2-2-1-2.prg*.
- **Compute_RC_Credit** — *chap4-2-3-7.prg*.
- **Compute_RC_ES** — *app2-2-7-1.prg*, *chap2-1-2-1.prg*, *chap2-1-3-1.prg*, *chap2-2-1-1.prg*, *chap2-4-1-1.prg*.
- **Compute_RC_Factor** — *app2-2-6-1.prg*, *app2-3-5-1.prg*, *chap2-5-2-1.prg*, *chap4-3-1-1.prg*, *chap4-3-1-2.prg*, *chap4-3-1-3.prg*, *chap4-3-1-4.prg*, *chap4-3-1-5.prg*, *chap4-3-1-7.prg*, *chap6-2-2-2.prg*, *chap6-2-2-3.prg*, *chap6-2-2-4.prg*, *chap6-2-2-5.prg*.

- **Compute_RC_NG** — *chap5-2-2-3.prg*.
- **Compute_RC_VaR** — *chap2-1-2-1.prg*, *chap2-1-3-1.prg*.
- **Compute_RC_Vol** — *chap2-1-2-1.prg*, *chap2-1-2-2.prg*, *chap2-1-3-1.prg*, *chap2-2-1-2.prg*.
- **Compute_Ridge_Portfolio** — *chap1-2-3-7.prg*, *chap1-2-3-8.prg*.
- **Compute_Risk_Contribution** — *app2-2-5-1.prg*, *app2-2-6-1.prg*, *app2-2-8-1.prg*, *app2-3-1-1.prg*, *app2-3-5-1.prg*, *app2-3-6-1.prg*, *app2-3-7-1.prg*, *app2-3-8-1.prg*, *app2-3-10-1.prg*, *chap2-2-1-2.prg*, *chap2-2-2-1.prg*, *chap2-2-2-4.prg*, *chap2-2-2-5.prg*, *chap2-2-2-6.prg*, *chap2-2-4-1.prg*, *chap2-3-1-1.prg*, *chap2-4-2-1.prg*, *chap2-5-1-2.prg*, *chap2-5-1-3.prg*, *chap2-5-2-1.prg*, *chap2-5-3-1.prg*, *chap2-5-3-2.prg*, *chap2-5-3-3.prg*, *chap2-5-3-4.prg*, *chap2-5-3-5.prg*, *chap2-5-3-6.prg*, *chap3-2-3-5.prg*, *chap3-2-3-6.prg*, *chap3-2-3-7.prg*, *chap3-2-3-8.prg*, *chap3-2-3-9.prg*, *chap3-2-3-10.prg*, *chap3-3-1-1.prg*, *chap3-3-1-2.prg*, *chap3-3-1-3.prg*, *chap4-3-1-1.prg*, *chap4-3-1-2.prg*, *chap4-3-1-3.prg*, *chap4-3-1-4.prg*, *chap4-3-1-5.prg*, *chap4-3-2-5.prg*, *chap4-3-2-6.prg*, *chap4-3-2-7.prg*, *chap4-3-2-8.prg*, *chap4-3-2-9.prg*, *chap4-3-2-10.prg*, *chap4-3-2-11.prg*, *chap5-1-2-2.prg*, *chap5-2-3-2.prg*, *chap5-2-3-3.prg*, *chap5-2-3-4.prg*, *chap6-1-1-2.prg*, *chap6-1-1-3.prg*, *chap6-1-2-1.prg*, *chap6-1-2-2.prg*, *chap6-1-2-3.prg*, *chap6-1-3-1.prg*, *chap6-2-2-1.prg*, *chap6-3-1-1.prg*, *chap6-3-1-2.prg*.
- **Compute_Sampling_Portfolio** — *chap1-2-4-6.prg*, *chap1-2-4-8.prg*.
- **Compute_Tangency_Portfolio** — *chap3-2-3-2.prg*.
- **Compute_TE_Maximum** — *app2-1-5-1.prg*, *app2-1-7-1.prg*.
- **Compute_TE_Minimum** — *app2-1-5-1.prg*.
- **Compute_TE_Portfolio** — *app2-1-5-1.prg*, *app2-1-7-1.prg*, *app2-1-9-1.prg*, *chap1-1-4-1.prg*, *chap1-1-4-2.prg*, *chap6-2-2-1.prg*, *chap6-3-1-1.prg*.
- **csspline** — *chap1-2-4-9.prg*, *chap2-5-1-3.prg*, *chap3-3-1-6.prg*, *chap3-3-2-3.prg*, *chap3-3-2-5.prg*, *chap4-2-1-2.prg*, *chap4-3-1-1.prg*, *chap5-1-1-2.prg*, *chap5-2-2-4.prg*, *chap5-2-2-5.prg*, *chap5-2-2-6.prg*.
- **delif_closed_points** — *chap1-2-1-5.prg*.
- **Diversification_ratio** — *chap3-2-3-5.prg*, *chap3-2-3-6.prg*, *chap3-2-3-7.prg*, *chap3-2-3-8.prg*, *chap3-2-3-9.prg*.
- **Entropy_Index** — *app2-2-8-1.prg*, *chap2-3-4-2.prg*, *chap2-5-3-4.prg*, *chap5-2-2-3.prg*.

- **Estimate_Kurtosis** — *app2-2-9-1.prg*, *chap2-1-3-7.prg*, *chap2-1-3-9.prg*, *chap2-1-3-10.prg*, *chap3-3-1-4.prg*, *chap3-3-2-4.prg*, *chap5-2-2-1.prg*.
- **Estimate_Maximum_Drawdown** — *chap5-2-2-1.prg*.
- **Estimate_Skewness** — *app2-2-9-1.prg*, *chap2-1-3-7.prg*, *chap2-1-3-9.prg*, *chap2-1-3-10.prg*, *chap3-3-1-4.prg*, *chap3-3-2-4.prg*, *chap5-2-2-1.prg*.
- **Estimate_Yearly_Statistics** — *chap3-3-1-5.prg*.
- **etdays2** — *chap4-3-2-2.prg*, *chap4-3-2-3.prg*.
- **EWMA_Volatility** — *chap1-2-1-5.prg*.
- **Fill_Miss** — *app2-3-10-1.prg*, *chap3-3-1-1.prg*, *chap3-3-1-2.prg*, *chap3-3-1-3.prg*, *chap5-1-2-1.prg*.
- **fspline** — *chap1-2-4-9.prg*, *chap2-5-1-3.prg*, *chap3-3-1-6.prg*, *chap3-3-2-3.prg*, *chap3-3-2-5.prg*, *chap4-2-1-2.prg*, *chap4-3-1-1.prg*, *chap5-1-1-2.prg*, *chap5-2-2-4.prg*, *chap5-2-2-5.prg*, *chap5-2-2-6.prg*.
- **Generate_Turnover_Matrices** — *app2-1-10-1.prg*.
- **Gini_Index** — *chap2-3-4-2.prg*, *chap2-5-3-4.prg*, *chap5-2-2-3.prg*.
- **Herfindahl_Index** — *app2-2-2-1.prg*, *chap2-3-4-2.prg*, *chap2-5-3-4.prg*, *chap3-2-3-5.prg*, *chap3-2-3-6.prg*, *chap3-2-3-7.prg*, *chap3-2-3-8.prg*, *chap3-2-3-9.prg*, *chap5-2-2-3.prg*.
- **Implied_Risk_Premimum2** — *chap6-1-2-3.prg*, *chap6-1-2-4.prg*.
- **indn_nomiss** — *app2-3-10-1.prg*, *chap3-3-1-1.prg*, *chap3-3-1-2.prg*, *chap3-3-1-3.prg*, *chap5-2-2-4.prg*, *chap5-2-2-5.prg*, *chap5-2-2-6.prg*, *chap6-3-1-2.prg*.
- **init_Sobol** — *chap1-1-1-1.prg*.
- **intspline** — *chap2-5-1-3.prg*, *chap3-3-2-5.prg*.
- **KendallCopulaFrank** — *app1-2-1-2.prg*.
- **KendallCopulaGumbel** — *app1-2-1-3.prg*.
- **Lorenz_Curve** — *chap3-1-3-1.prg*.
- **NelsonSiegel_Forward_Rate** — *chap4-2-1-1.prg*.
- **NelsonSiegel_Spot_Rate** — *chap4-2-1-1.prg*, *chap4-2-1-2.prg*, *chap4-2-2-1.prg*, *chap4-2-2-2.prg*, *chap4-2-2-3.prg*, *chap4-2-2-5.prg*, *chap4-2-2-6.prg*, *chap4-3-1-6.prg*, *chap4-3-1-7.prg*.

- **NelsonSiegel_ZC_Rate** — *chap4-2-2-2.prg*.
- **packr2** — *chap4-3-2-2.prg*, *chap4-3-2-3.prg*.
- **pdfBeta** — *app1-2-1-1.prg*.
- **pdfCopulaFrank** — *app1-2-1-2.prg*.
- **pdfCopulaGumbel** — *app1-2-1-3.prg*.
- **pdfCopulaNormal2** — *app1-2-1-1.prg*.
- **pdfIG** — *app1-2-1-1.prg*.
- **pdfSN** — *chap2-1-3-9.prg*.
- **qqUpperCopula** — *app1-2-4-1.prg*, *app1-2-4-2.prg*.
- **quadLegendre2** — *chap2-1-3-1.prg*.
- **regCorr1F** — *chap1-2-1-6.prg*, *chap1-2-1-7.prg*.
- **regCorrMF** — *chap1-2-1-7.prg*.
- **regGarch** — *chap1-2-1-5.prg*.
- **regKernelDensity** — *chap1-2-1-2.prg*, *chap1-2-1-6.prg*, *chap2-1-3-3.prg*, *chap4-2-3-6.prg*.
- **regLinearFactorModel** — *chap1-2-1-7.prg*.
- **regML** — *chap4-3-2-2.prg*.
- **regPCA** — *app2-3-5-1.prg*, *chap1-2-4-1.prg*, *chap1-2-4-2.prg*, *chap4-2-1-2.prg*, *chap4-3-1-1.prg*.
- **Reporting_Backtest** — *app2-3-10-1.prg*, *chap3-3-1-4.prg*, *chap3-3-2-4.prg*, *chap4-3-2-19.prg*, *chap5-1-2-2.prg*, *chap5-2-2-5.prg*, *chap5-2-2-6.prg*, *chap6-1-3-1.prg*, *chap6-3-1-1.prg*, *chap6-3-1-2.prg*.
- **Risky_Bond_Price** — *chap4-2-2-4.prg*, *chap4-2-2-5.prg*, *chap4-2-2-6.prg*.
- **Risky_Bond_Price_EDT** — *chap4-2-3-6.prg*.
- **rndCopulaClayton** — *chap2-1-3-3.prg*, *chap2-1-3-4.prg*, *chap2-1-3-7.prg*.
- **rndCopulaNormal** — *app2-2-7-1.src*.
- **rndCopulaNormal2** — *app1-2-2-1.prg*, *chap2-1-3-5.prg*.
- **rndCopulaSobol** — *app1-2-2-1.prg*.

- **rndCopulaStudent2** — *app1-2-2-1.prg*.
- **rndSN** — *chap2-1-3-9.prg*.
- **rndu_Sobol** — *chap1-1-1-1.prg*.
- **Rolling_Covariance** — *app2-3-10-1.prg*, *chap4-3-2-3.prg*, *chap5-1-2-2.prg*, *chap6-1-1-2.prg*, *chap6-1-1-3.prg*, *chap6-1-2-1.prg*, *chap6-1-2-2.prg*, *chap6-1-3-1.prg*, *chap6-3-1-1.prg*, *chap6-3-1-2.prg*.
- **Rolling_Return** — *chap5-1-2-1.prg*.
- **Rolling_Volatility** — *chap1-2-1-5.prg*, *chap4-3-2-3.prg*, *chap5-1-2-1.prg*.
- **Shrinkage_JM_MV** — *chap1-2-4-10.prg*, *chap1-2-4-11.prg*.
- **Shrinkage_JM_MVO** — *chap1-2-4-12.prg*.
- **Shrinkage_LW_CC** — *chap1-2-3-6.prg*, *chap3-3-1-3.prg*.
- **Shrinkage_LW_Factor** — *chap3-3-1-3.prg*.
- **simulate_Backtest** — *chap3-3-1-1.prg*, *chap3-3-1-2.prg*, *chap3-3-1-3.prg*, *chap3-3-1-4.prg*, *chap3-3-1-5.prg*, *chap3-3-2-4.prg*, *chap3-3-2-5.prg*.
- **simulate_GBM** — *chap4-2-3-1.prg*, *chap4-2-3-2.prg*, *chap4-2-3-3.prg*, *chap4-2-3-4.prg*, *chap4-2-3-5.prg*, *chap4-2-3-6.prg*.
- **simulate_GBM2** — *chap1-2-1-2.prg*.
- **Simulate_Monthly_Backtest** — *app2-3-10-1.prg*, *chap4-3-2-19.prg*, *chap4-3-2-21.prg*, *chap5-1-2-2.prg*, *chap6-1-3-1.prg*, *chap6-3-1-1.prg*, *chap6-3-1-2.prg*.
- **vcx_cc** — *chap3-3-1-3.prg*.
- **vcx_factor** — *chap3-3-1-3.prg*.
- **vcx_rmt** — *chap1-2-3-5.prg*, *chap3-3-1-3.prg*.