

# Portfolio Backtesting

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This vignette illustrates the usage of the package `portfolioBacktest` for automated portfolio backtesting. It can be used by a researcher/practitioner to check a set of different portfolios, as well as by a course instructor to evaluate the students in their portfolio design in a fully automated and convenient manner.

## 1 Installation

The package can currently be installed from GitHub:

```
# install.packages("devtools")
devtools::install_github("dppalomar/portfolioBacktest")

# Getting help
library(portfolioBacktest)
help(package = "portfolioBacktest")
package?portfolioBacktest
?portfolioBacktest
```

## 2 Usage of the package

### 2.1 Loading data

We start by loading the package and some random sets of stock market data:

```
library(xts)
library(portfolioBacktest)
data(prices) # you may want to specify data(prices, package = "portfolioBacktest")
              # in case there is any conflict with the package PerformanceAnalytics
```

The dataset `prices` is a list of objects `xts` that contains the prices of random sets of stock market data from the S&P 500, HSI, NKY, SHZ, and UKC, over random periods of two years with a random selection of 50 stocks of each universe.

```
length(prices)
#> [1] 100
str(prices[[1]])
#> An 'xts' object on 2013-01-23/2014-12-29 containing:
#>   Data: num [1:474, 1:46] 128 130 130 129 128 ...
#>   - attr(*, "dimnames")=List of 2
#>    ..$ : NULL
#>    ..$ : chr [1:46] "1 HK Equity" "101 HK Equity" "1038 HK Equity" "1044 HK Equity" ...
#>   Indexed by objects of class: [Date] TZ: UTC
#>   xts Attributes:
#>    NULL

colnames(prices[[1]])
#> [1] "1 HK Equity"      "101 HK Equity"    "1038 HK Equity"   "1044 HK Equity"
#> [5] "1088 HK Equity"    "1093 HK Equity"   "11 HK Equity"     "1109 HK Equity"
#> [9] "1177 HK Equity"    "12 HK Equity"     "1299 HK Equity"   "1398 HK Equity"
#> [13] "151 HK Equity"     "16 HK Equity"     "17 HK Equity"     "175 HK Equity"
#> [17] "19 HK Equity"      "1928 HK Equity"   "2 HK Equity"       "2007 HK Equity"
#> [21] "2018 HK Equity"    "2313 HK Equity"   "2318 HK Equity"   "2319 HK Equity"
#> [25] "2382 HK Equity"    "2388 HK Equity"   "2628 HK Equity"   "267 HK Equity"
#> [29] "27 HK Equity"      "3 HK Equity"       "3328 HK Equity"   "386 HK Equity"
#> [33] "388 HK Equity"     "3988 HK Equity"   "5 HK Equity"       "6 HK Equity"
#> [37] "66 HK Equity"      "688 HK Equity"     "762 HK Equity"     "823 HK Equity"
#> [41] "83 HK Equity"      "836 HK Equity"     "857 HK Equity"     "883 HK Equity"
#> [45] "939 HK Equity"     "941 HK Equity"
```

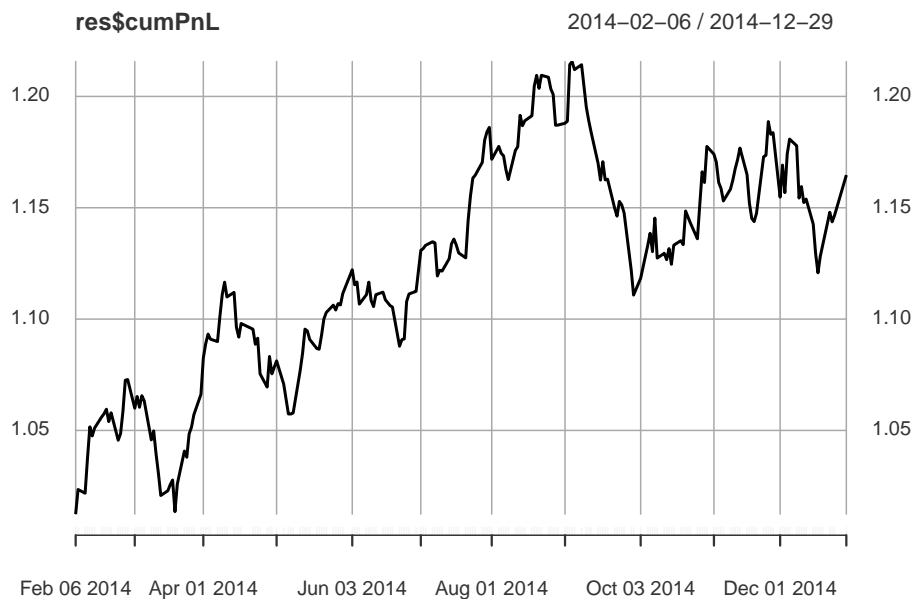
## 2.2 Backtesting a single portfolio

We start by defining a simple portfolio design in the form of a function that takes as input the prices and outputs the portfolio vector `w`:

```
uniform_portfolio_fun <- function(prices) {
  N <- ncol(prices)
  w <- rep(1/N, N) # satisfies the constraints w>=0 and sum(w)=1
  return(w)
}
```

Now we are ready to use the function `backtestPortfolio()` that will execute and evaluate the portfolio design function on a rolling-window basis:

```
res <- portfolioBacktest(uniform_portfolio_fun, prices[[1]])
names(res)
#> [1] "returns"      "cumPnL"        "performance"    "cpu_time"
#> [5] "error"        "error_message"
plot(res$cumPnL)
```



```
res$performance
#>      Sharpe ratio      max drawdown      annual return annual volatility
#>      1.466254e+00      8.627088e-02      1.889171e-01      1.288433e-01
#>      Sterling ratio      Omega ratio      ROT bps
#>      2.189813e+00      1.257056e+00      2.589679e+03
```

Let's try with a slightly more sophisticated portfolio design, like the global minimum variance portfolio (GMVP):

```
GMVP_portfolio_fun <- function(prices) {
  X <- diff(log(prices))[-1] # compute log returns
  Sigma <- cov(X) # compute SCM
  # design GMVP
  w <- solve(Sigma, rep(1, nrow(Sigma)))
  w <- w/sum(abs(w)) # it may not satisfy w>=0
  return(w)
}
res <- portfolioBacktest(GMVP_portfolio_fun, prices[[1]])
res$error
#> [1] TRUE
res$error_message
#> [1] "No-shortselling constraint not satisfied."
```

Indeed, the GMVP does not satisfy the no-shortselling constraint. We can repeat the backtesting indicating that shortselling is allowed:

```
res <- portfolioBacktest(GMVP_portfolio_fun, prices[[1]], shortselling = TRUE)
res$error
#> [1] FALSE
res$error_message
#> NULL
res$cpu_time
#> [1] 0.04
```

```
res$performance
#>      Sharpe ratio      max drawdown      annual return annual volatility
#>      1.64718707      0.02471534      0.05919997      0.03594004
#>      Sterling ratio      Omega ratio      ROT bps
#>      2.39527214      1.30331447      173.12764544
```

We could be more sophisticated and design a Markowitz mean-variance portfolio satisfying the no-shortselling constraint:

```
library(CVXR) #install.packages("CVXR")

Markowitz_portfolio_fun <- function(prices) {
  X <- diff(log(prices))[-1] # compute log returns
  mu <- colMeans(X) # compute mean vector
  Sigma <- cov(X) # compute the SCM
  # design mean-variance portfolio
  w <- Variable(nrow(Sigma))
  prob <- Problem(Maximize(t(mu) %*% w - 0.5*quad_form(w, Sigma)),
                  constraints = list(w >= 0, sum(w) == 1))
  result <- solve(prob)
  return(as.vector(result$getValue(w)))
}
```

We can now backtest it:

```
res <- portfolioBacktest(Markowitz_portfolio_fun, prices[[1]])
res$error
#> [1] FALSE
res$error_message
#> NULL
res$cpu_time
#> [1] 3.59
res$performance
#>      Sharpe ratio      max drawdown      annual return annual volatility
#>      -0.4187583      0.3460377      -0.1295226      0.3093016
#>      Sterling ratio      Omega ratio      ROT bps
#>      -0.3743020      0.9534549      -88.4547661
```

Instead of backtesting a portfolio on a single `xts` dataset, it is more meaningful to backtest it on multiple datasets. This can be easily done simply by passing a list of `xts` objects:

```
res <- portfolioBacktest(Markowitz_portfolio_fun, prices[1:5])
names(res)
#> [1] "returns"      "cumPnL"      "performance"
#> [4] "performance_summary" "cpu_time"      "cpu_time_average"
#> [7] "failure_ratio" "error"        "error_message"
res$cpu_time
#> [1] 3.08 2.52 2.53 2.67 2.48
res$performance
#>      dataset 1      dataset 2      dataset 3      dataset 4
#> Sharpe ratio      -0.4187583      -0.5146592      1.2704831      1.8411582
#> max drawdown      0.3460377      0.4686311      0.4126044      0.1817962
#> annual return      -0.1295226      -0.2614145      0.6155478      0.5834570
#> annual volatility  0.3093016      0.5079371      0.4844990      0.3168967
```

```

#> Sterling ratio      -0.3743020   -0.5578257    1.4918593    3.2094019
#> Omega ratio         0.9534549    0.9417655    1.2301029    1.3361718
#> ROT bps             -88.4547661 -174.8816536  482.4063915  296.5086680
#>                      dataset 5
#> Sharpe ratio        0.04438826
#> max drawdown        0.19730661
#> annual return       0.01703249
#> annual volatility   0.38371610
#> Sterling ratio      0.08632498
#> Omega ratio         1.04278734
#> ROT bps             97.70912146

```

In particular, note the additional elements in the returned list:

```

res$cpu_time_average
#> [1] 2.656
res$performance_summary
#>      Sharpe ratio (median)      max drawdown (median)
#>      0.04438826              0.34603766
#>      annual return (median) annual volatility (median)
#>      0.01703249              0.38371610
#>      Sterling ratio (median)  Omega ratio (median)
#>      0.08632498              1.04278734
#>      ROT bps (median)
#>      97.70912146
res$failure_ratio
#> [1] 0

```

## 2.3 Backtesting multiple portfolios

Backtesting multiple portfolios is equally simple. It suffices to pass a list of functions to the backtesting function `multiplePortfolioBacktest()`:

```

res <- multiplePortfolioBacktest(portfolio_fun_list = list(uniform_portfolio_fun,
                                                         GMVP_portfolio_fun),
                               prices = prices[1:5], shortselling = TRUE)
#> 2018-11-13 21:19:05 - Execute func1
#> 2018-11-13 21:19:05 - Execute func2
res
#> $performance_summary
#>      Sharpe ratio (median) max drawdown (median)
#> func1      1.178459      0.15771401
#> func2      1.583984      0.04479846
#>      annual return (median) annual volatility (median)
#> func1      0.18891706      0.20705821
#> func2      0.06276355      0.05739085
#>      Sterling ratio (median) Omega ratio (median) ROT bps (median)
#> func1      1.776008      1.211860      2589.6794
#> func2      2.395272      1.303314      173.1276
#>
#> $cpu_time_average
#> func1 func2
#> 0.016 0.030
#>

```

```

#> $failure_ratio
#> func1 func2
#>      0      0
#>
#> $error_message
#> $error_message$func1
#> list()
#>
#> $error_message$func2
#> list()

```

### 3 Usage for grading students in a course

If an instructor wants to evaluate the students of a course in their portfolio design, it can also be done very easily. It suffices to ask each student to submit a .R script (named LASTNAME-firstname-STUDENTNUMBER-XXXX.R) containing the portfolio function called exactly `portfolio_fun()` as well as any other auxiliary functions that it may require (needless to say that the required packages should be loaded in that script with `library()`). Then the instructor can put all those files in a folder and evaluate all of them at once.

```

res_all_students <- multiplePortfolioBacktest(folder_path = "folder_path",
                                              prices = prices[1:3])
#> 2018-11-13 21:19:06 - Execute code from Firstname1 Surname1 (00000001)
#> 2018-11-13 21:19:09 - Execute code from Firstname2 Surname2 (00000002)
#> 2018-11-13 21:19:18 - Execute code from Firstname3 Surname3 (00000003)
res_all_students$performance_summary
#>           Sharpe ratio (median) max drawdown (median)
#> 00000001      2.3098857           0.1119180
#> 00000002      0.5823419           0.2506662
#> 00000003      0.6569324           0.1431620
#>           annual return (median) annual volatility (median)
#> 00000001      0.3841061           0.2054775
#> 00000002      0.1417214           0.3545257
#> 00000003      0.1348055           0.2229336
#>           Sterling ratio (median) Omega ratio (median) ROT bps (median)
#> 00000001      5.5126225           1.394246           921.8511
#> 00000002      0.8236259           1.124574           1396.9909
#> 00000003      1.0377623           1.122605           267.2722
res_all_students$cpu_time_average
#> 00000001 00000002 00000003
#> 0.7500000 2.9900000 0.7233333
res_all_students$failure_ratio
#> 00000001 00000002 00000003
#>      0      0      0

```

Now we can rank the different portfolios/students based on a weighted combination of the rank percentiles (termed scores) of the performance measures:

```

leaderboard <- portfolioLeaderboard(res_all_students, weights = list(Sharpe_ratio = 7, max_drawdown = 1)

# show leaderboard
library(gridExtra)
grid.table(leaderboard$leaderboard_scores)

```

	Sharpe ratio score	max drawdown score	annual return score	ROT score	final score
00000001	100	100	100	50	95
00000003	50	50	0	0	40
00000002	0	0	50	100	15

### 3.1 Example of a script file to be submitted by a student

Consider the student Mickey Mouse with id number 666. Then the script file should be named Mickey-Mouse-666.R and should contain the portfolio function called exactly `portfolio_fun()` as well as any other auxiliary functions that it may require (needless to say that the required packages should be loaded in that script with `library()`):

```
library(CVXR)

auxiliary_function <- function(x) {
  # here whatever code
}

portfolio_fun <- function(prices) {
  X <- diff(log(prices))[-1] # compute log returns
  mu <- colMeans(X) # compute mean vector
  Sigma <- cov(X) # compute the SCM
  # design mean-variance portfolio
  w <- Variable(nrow(Sigma))
  prob <- Problem(Maximize(t(mu) %*% w - 0.5*quad_form(w, Sigma)),
                  constraints = list(w >= 0, sum(w) == 1))
  result <- solve(prob)
  return(as.vector(result$getValue(w)))
}
```

## 4 Appendix

### 4.1 Performance criteria

The definition of performance criteria used in this package is listed as below

- **expeted return:** the annualized return
- **volatility:** the annualized standard deviation of returns
- **max drawdown:** the maximum loss from a peak to a trough of a portfolio, see also here
- **Sharpe ratio:** annualized Sharpe ratio, the ratio between **annualized return** and **annualized standard deviation**
- **Sterling ratio:** the return over average drawdown, see here for complete definition. In the package, we use

$$\text{Sterling ratio} = \frac{\text{annualized return}}{\text{max drawdown}}$$

- **Omega ratio:** the probability weighted ratio of gains over losses for some threshold return target, see [here](#) for complete definition. The ratio is calculated as:

$$\Omega(r) = \frac{\int_r^\infty (1 - F(x))dx}{\int_{-\infty}^r F(x)dx}$$

In the package, we use  $\Omega(0)$ , which is also known as Gain-Loss-Ratio.

- **Return over Turnover (ROT):** the sum of cumulative return over the sum of turnover.