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)
```

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.

```r
length(prices)
#> [1] 50
str(prices[[1]])
#> An 'xts' object on 2008-11-27/2010-11-02 containing:
#>   Data: num [1:504, 1:50] 15.7 15.4 14.7 14.9 15.8 ...
#>  - attr(*, "dimnames")=List of 2
#>   ..$ : NULL
#>   ..$ : chr [1:50] "MSCI UN Equity" "MNST UW Equity" "LKQ UW Equity" "UDR UN Equity" ...
#>   Indexed by objects of class: [Date] TZ: UTC
#>   xts Attributes:
#>  NULL

colnames(prices[[1]])
#>  [1] "MSCI UN Equity" "MNST UW Equity" "LKQ UW Equity"  "UDR UN Equity"
#>  [5] "LB UN Equity"   "MS UN Equity"   "IFF UN Equity"  "TMO UN Equity"
#>  [9] "BIIB UW Equity" "NOC UN Equity"  "CPB UN Equity"  "VMC UN Equity"
#> [13] "ULTA UW Equity" "NVDA UW Equity" "FAST UW Equity" "WMB UN Equity"
#> [17] "VRTX UW Equity" "EBAY UW Equity" "RHI UN Equity"  "XRAY UW Equity"
#> [21] "GRMN UW Equity" "ALGN UW Equity" "FTI UN Equity"  "NBL UN Equity"
#> [25] "LLY UN Equity"  "FIS UN Equity"  "L UN Equity"    "STT UN Equity"
#> [29] "CVX UN Equity"  "IR UN Equity"   "PKG UN Equity"  "CDNS UW Equity"
#> [33] "XLNX UW Equity" "JCI UN Equity"  "IBM UN Equity"  "VRSN UW Equity"
#> [37] "WFC UN Equity"  "SIVB UW Equity" "PM UN Equity"   "ZBH UN Equity"
#> [41] "RTN UN Equity"  "CINF UW Equity" "ALXN UW Equity" "UTX UN Equity"
#> [45] "AAPL UW Equity" "ADM UN Equity"  "BBY UN Equity"  "AMZN UW Equity"
#> [49] "MRO UN Equity"  "IPGP UW Equity"
```

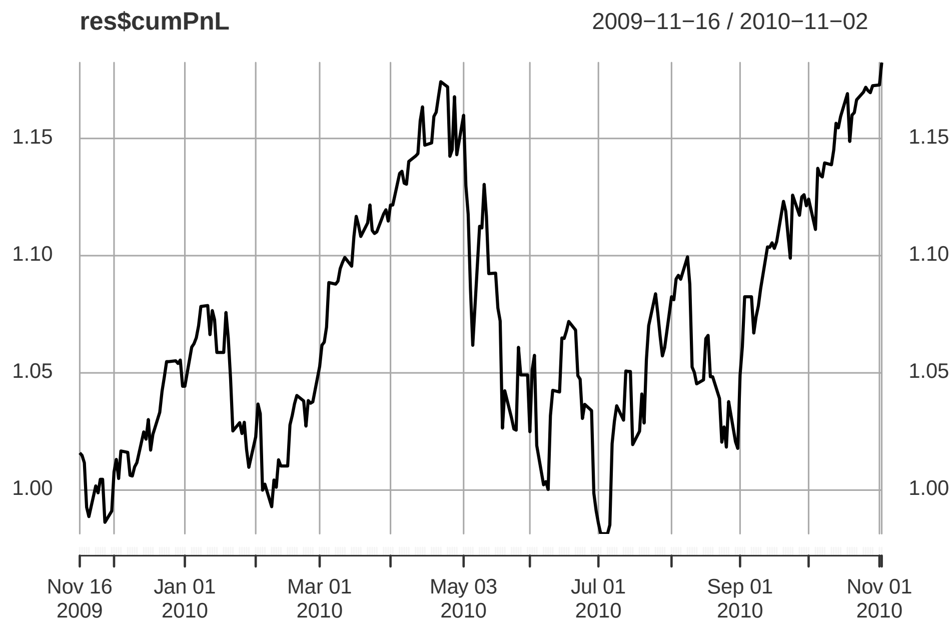
2.2 Backtesting a single portfolio

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`:

```r
uniform_portfolio_fun <- function(prices) {
  N <- ncol(prices)
  w <- rep(1/N, N)  # satisfies the constraints w>=0 amd 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:

```r
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 expected return       volatility
#>        0.9281714        0.1641935        0.1823414        0.1964523
```

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$cpu_time
#> [1] 0.023
res$performance
#>     sharpe ratio     max drawdown expected return       volatility
#>       0.90688642       0.02956825       0.04228335       0.04662475
```

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$cpu_time
#> [1] 12.628
res$performance
#>    sharpe ratio    max drawdown expected return      volatility
#>      0.27286028      0.20343573      0.09486546      0.34767045
```

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$cpu_time
#> [1] 12.706 12.732 12.018 12.702 12.394
res$performance
#>                  dataset 1 dataset 2 dataset 3 dataset 4 dataset 5
#> sharpe ratio    0.27286028 1.1835509 1.3178749 1.1930983 1.9920024
#> max drawdown    0.20343573 0.3391357 0.1601892 0.2096279 0.2164856
#> expected return 0.09486546 0.5625267 0.3475473 0.3705347 0.5972125
#> volatility      0.34767045 0.4752873 0.2637180 0.3105651 0.2998051
```

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

```
res$cpu_time_average
#> [1] 12.5104
res$performance_summary
#>    sharpe ratio (median)    max drawdown (median) expected return (median)
#>                1.1930983                0.2096279                0.3705347
```

```
#>      volatility (median)
#>                0.3105651
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)
#> 2018-09-20 23:12:47 - Execute func1
#> 2018-09-20 23:12:47 - Execute func2
res
#> $performance_summary
#>       sharpe ratio  (median) max drawdown  (median)
#> func1              1.6113535             0.10145617
#> func2              0.9221429             0.03029658
#>       expected return  (median) volatility  (median)
#> func1                  0.18234136           0.14552105
#> func2                  0.04228335           0.04621708
#>
#> $cpu_time_average
#>  func1  func2
#> 0.0014 0.0130
#>
#> $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])
#> 2018-09-20 13:40:26 - Execute code from Firstname1 Surname1 (00000001)
#> 2018-09-20 13:40:28 - Execute code from Firstname2 Surname2 (00000002)
#> 2018-09-20 13:40:35 - Execute code from Firstname3 Surname3 (00000003)
res_all_students$performance_summary
```

```r
#>          sharpe ratio  (median) max drawdown  (median)
#> 00000001               1.5003370             0.1591520
#> 00000002              -0.5376190             0.3260651
#> 00000003               0.4112669             0.1084156
#>          expected return  (median) volatility  (median)
#> 00000001                0.36604788            0.2319558
#> 00000002               -0.11097632            0.2064219
#> 00000003                0.06697449            0.1515797
res_all_students$cpu_time_average
#>  00000001  00000002  00000003
#> 0.6096667 2.2643333 0.5916667
res_all_students$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:

```r
leaderboard <- portfolioLeaderboard(res_all_students)

# show leaderboard
library(gridExtra)
grid.table(formatC(leaderboard$leaderboard, digits = 3))
```

	sharpe ratio score	max drawdown score	cpu time score	failure ratio score	final score
00000003	50	100	100	100	95
00000001	100	50	50	100	90
00000002	0	0	0	100	70

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()`):

```r
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)))
}
```