

Markets and Trading

FRE6871 & FRE7241, Fall 2024

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November 3, 2024



Downloading Treasury Bond Rates from *FRED*

The constant maturity Treasury rates are yields of hypothetical fixed-maturity bonds, interpolated from the market yields of actual Treasury bonds.

The *FRED* database contains current and historical constant maturity Treasury rates,

<https://fred.stlouisfed.org/series/DGS5>

`quantmod::getSymbols()` creates objects in the specified *environment* from the input strings (names).

It then assigns the data to those objects, without returning them as a *side effect*.

```
> # Symbols for constant maturity Treasury rates
> symbolv <- c("DGS1", "DGS2", "DGS5", "DGS10", "DGS20", "DGS30")
> # Create new environment for time series
> ratesenv <- new.env()
> # Download time series for symbolv into ratesenv
> quantmod::getSymbols(symbolv, env=ratesenv, src="FRED")
> # Remove NA values in ratesenv
> sapply(ratesenv, function(x) sum(is.na(x)))
> sapply(ls(ratesenv), function(namev) {
+   assign(x=namev, value=na.omit(get(namev, ratesenv)),
+   envir=ratesenv)
+ }) # end sapply
> sapply(ratesenv, function(x) sum(is.na(x)))
> # Get class of all objects in ratesenv
> sapply(ratesenv, class)
> # Get class of all objects in R workspace
> sapply(ls(), function(namev) class(get(namev)))
> # Save the time series environment into a binary .RData file
> save(ratesenv, file="/Users/jerzy/Develop/lecture_slides/data/rates_data.Rdata")
```



```
> # Get class of time series object DGS10
> class(get(x="DGS10", envir=ratesenv))
> # Another way
> class(ratesenv$DGS10)
> # Get first 6 rows of time series
> head(ratesenv$DGS10)
> # Plot dygraphs of 10-year Treasury rate
> dygraphs::dygraph(ratesenv$DGS10, main="10-year Treasury Rate")
+ dyOptions(colors="blue", strokeWidth=2)
> # Plot 10-year constant maturity Treasury rate
> x11(width=6, height=5)
> par(mar=c(2, 2, 0, 0), oma=c(0, 0, 0, 0))
> chart_Series(ratesenv$DGS10["1990/"], name="10-year Treasury Rate")
```

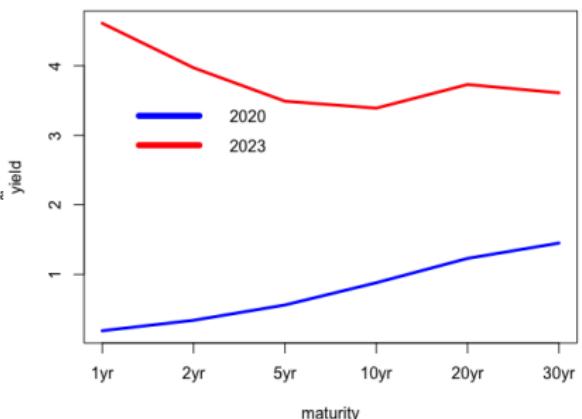
Treasury Yield Curve

The *yield curve* is a vector of interest rates at different maturities, on a given date.

The *yield curve* shape changes depending on the economic conditions: in recessions rates drop and the curve flattens, while in expansions rates rise and the curve steepens.

```
> # Load constant maturity Treasury rates
> load(file="/Users/jerzy/Develop/lecture_slides/data/rates_data.RData")
> # Get most recent yield curve
> ycnow <- eapply(ratesenv, xts::last)
> class(ycnow)
> ycnow <- do.call(cbind, ycnow)
> # Check if 2020-03-25 is not a holiday
> date2020 <- as.Date("2020-03-25")
> weekdays(date2020)
> # Get yield curve from 2020-03-25
> yc2020 <- eapply(ratesenv, function(x) x[date2020])
> yc2020 <- do.call(cbind, yc2020)
> # Combine the yield curves
> ycurves <- c(yc2020, ycnow)
> # Rename columns and rows, sort columns, and transpose into matrix
> colnames(ycurves) <- substr(colnames(ycurves), start=4, stop=11)
> ycurves <- ycurves[, order(as.numeric(colnames(ycurves)))]
> colnames(ycurves) <- paste0(colnames(ycurves), "yr")
> ycurves <- t(ycurves)
> colnames(ycurves) <- substr(colnames(ycurves), start=1, stop=4)
```

Yield Curves in 2020 and 2023



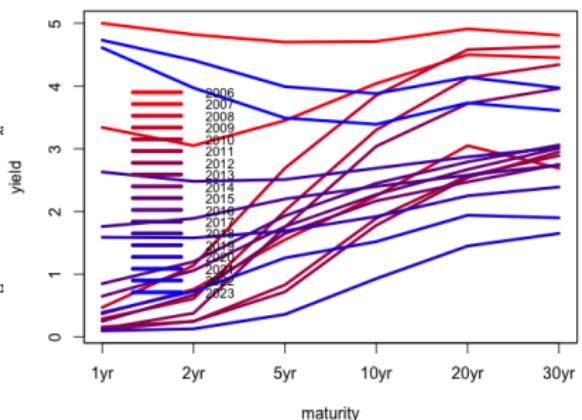
```
> # Plot using matplotlib()
> colvors <- c("blue", "red")
> matplot(ycurves, main="Yield Curves in 2020 and 2023", xaxt="n",
+ type="l", xlab="maturity", ylab="yield", col=colvors)
> # Add x-axis
> axis(1, seq_along(rownames(ycurves)), rownames(ycurves))
> # Add legend
> legend("topleft", legend=colnames(ycurves), y.intersp=0.1,
+ bty="n", col=colvors, lty=1, lwd=6, inset=0.05, cex=1.0)
```

Treasury Yield Curve Over Time

The *yield curve* has changed shape dramatically depending on the economic conditions: in recessions rates drop and the curve flattens, while in expansions rates rise and the curve steepens.

```
> # Load constant maturity Treasury rates
> load(file="/Users/jerzy/Develop/lecture_slides/data/rates_data.RData")
> # Get end-of-year dates since 2006
> datev <- xts::endpoints(ratesenv$DGS1["2006/"], on="years")
> datev <- zoo::index(ratesenv$DGS1["2006/"][[datev]])
> # Create time series of end-of-year rates
> ycurves <- eapply(ratesenv, function(ratev) ratev[datev])
> ycurves <- rutils::do_call(cbind, ycurves)
> # Rename columns and rows, sort columns, and transpose into matrix
> colnames(ycurves) <- substr(colnames(ycurves), start=4, stop=11)
> ycurves <- ycurves[, order(as.numeric(colnames(ycurves)))]
> colnames(ycurves) <- paste0(colnames(ycurves), "yr")
> ycurves <- t(ycurves)
> colnames(ycurves) <- substr(colnames(ycurves), start=1, stop=4)
> # Plot matrix using plot.zoo()
> colorv <- colorRampPalette(c("red", "blue"))(NCOL(ycurves))
> plot.zoo(ycurves, main="Yield Curve Since 2006", lwd=3, xaxt="n"
+   plot.type="single", xlab="maturity", ylab="yield", col=colorv)
> # Add x-axis
> axis(1, seq_along(rownames(ycurves)), rownames(ycurves))
> # Add legend
> legend("topleft", legend=colnames(ycurves), y.intersp=0.1,
+   bty="n", col=colorv, lty=1, lwd=4, inset=0.05, cex=0.8)
```

Yield curve since 2006



```
> # Alternative plot using matplot()
> matplot(ycurves, main="Yield curve since 2006", xaxt="n", lwd=3, 1
+   type="l", xlab="maturity", ylab="yield", col=colorv)
> # Add x-axis
> axis(1, seq_along(rownames(ycurves)), rownames(ycurves))
> # Add legend
> legend("topleft", legend=colnames(ycurves), y.intersp=0.1,
+   bty="n", col=colorv, lty=1, lwd=4, inset=0.05, cex=0.8)
```

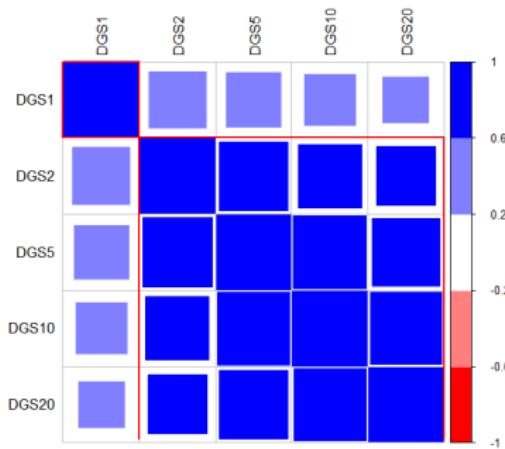
Covariance Matrix of Interest Rates

The covariance matrix \mathbb{C} , of the interest rate matrix \mathbf{r} is given by:

$$\mathbb{C} = \frac{(\mathbf{r} - \bar{\mathbf{r}})^T (\mathbf{r} - \bar{\mathbf{r}})}{n - 1}$$

```
> # Extract rates from ratesenv
> symbolv <- c("DGS1", "DGS2", "DGS5", "DGS10", "DGS20")
> ratem <- mget(symbolv, envir=ratesenv)
> ratem <- rutils::do_call(cbind, ratem)
> ratem <- zoo::na.locf(ratem, na.rm=FALSE)
> ratem <- zoo::na.locf(ratem, fromLast=TRUE)
# Calculate daily percentage rates changes
> retp <- rutils::diffit(log(ratem))
> # Center (de-mean) the returns
> retp <- lapply(retp, function(x) {x - mean(x)})
> retp <- rutils::do_call(cbind, retp)
> sapply(retp, mean)
# Covariance and Correlation matrices of Treasury rates
> covmat <- cov(retp)
> cormat <- cor(retp)
# Reorder correlation matrix based on clusters
> library(corrplot)
> ordern <- corrMatOrder(cormat, order="hclust",
+   hclust.method="complete")
> cormat <- cormat[ordern, ordern]
```

Correlation of Treasury Rates



```
> # Plot the correlation matrix
> x11(width=6, height=6)
> colorv <- colorRampPalette(c("red", "white", "blue"))
> corrplot(cormat, title=NA, tl.col="black",
+   method="square", col=colorv(NCOL(cormat)), tl.cex=0.8,
+   cl.offset=0.75, cl.cex=0.7, cl.align.text="l", cl.ratio=0.25)
> title("Correlation of Treasury Rates", line=1)
# Draw rectangles on the correlation matrix plot
> corrRect.hclust(cormat, k=NROW(cormat) %% 2,
+   method="complete", col="red")
```

Principal Component Vectors

Principal components are linear combinations of the k return vectors r_i :

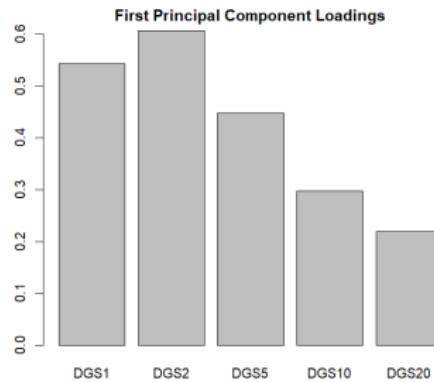
$$\mathbf{pc}_j = \sum_{i=1}^k w_{ij} \mathbf{r}_i$$

Where \mathbf{w}_j is a vector of weights (loadings) of the principal component j , with $\mathbf{w}_i^T \mathbf{w}_j = 1$.

The weights w_j are chosen to maximize the variance of the *principal components*, under the condition that they are orthogonal:

$$\mathbf{w}_j = \arg \max \left\{ \mathbf{p} \mathbf{c}_j^T \mathbf{p} \mathbf{c}_j \right\}$$

$$\mathbf{p}\mathbf{c}_i^T \mathbf{p}\mathbf{c}_j = 0 \quad (i \neq j)$$



```

> # Find weights with maximum variance
> optim1 <- optim(par=weight1,
+   fn=objfun,
+   retp=retp,
+   method="L-BFGS-B",
+   upper=rep(5.0, nweights),
+   lower=rep(-5.0, nweights))
> # Optimal weights and maximum variance
> weights1 <- optim1$par
> objfun(weights1, retp)
> # Plot first principal component loadings
> x11(width=6, height=5)
> par(mar=c(3, 3, 2, 1), oma=c(0, 0, 0, 0), mgp=c(2, 1, 0))
> barplot(weights1, names.arg=names(weights1),
+   xlab="", ylab="", main="First Principal Component Loadings")

```

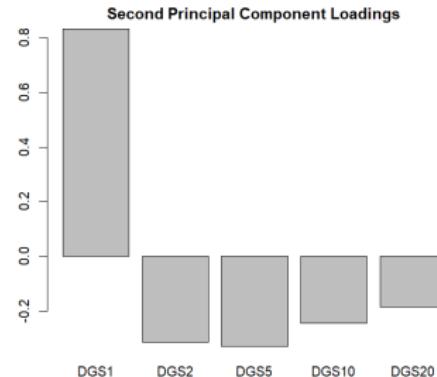
Higher Order Principal Components

The *second principal component* can be calculated by maximizing its variance, under the constraint that it must be orthogonal to the *first principal component*.

Similarly, higher order *principal components* can be calculated by maximizing their variances, under the constraint that they must be orthogonal to all the previous *principal components*.

The number of principal components is equal to the dimension of the covariance matrix.

```
> # pc1 weights and returns
> pc1 <- drop(retp %*% weights1)
> # Redefine objective function
> objfun <- function(weightv, retp) {
+   retp <- retp %*% weightv
+   -1e7*var(retp) + 1e7*(1 - sum(weightv^2))^2 +
+   1e7*sum(weights1*weightv)^2
+ } # end objfun
> # Find second principal component weights
> optiml <- optim(par=weightv,
+                   fn=objfun,
+                   retp=retp,
+                   method="L-BFGS-B",
+                   upper=rep(5.0, nweights),
+                   lower=rep(-5.0, nweights))
```



```
> # pc2 weights and returns
> weights2 <- optiml$par
> pc2 <- drop(retp %*% weights2)
> sum(pc1*pc2)
> # Plot second principal component loadings
> barplot(weights2, names.arg=names(weights2),
+           xlab="", ylab="", main="Second Principal Component Loadings")
```

Eigenvalues of the Covariance Matrix

The portfolio variance: $\mathbf{w}^T \mathbb{C} \mathbf{w}$ can be maximized under the *quadratic* weights constraint $\mathbf{w}^T \mathbf{w} = 1$, by maximizing the *Lagrangian* \mathcal{L} :

$$\mathcal{L} = \mathbf{w}^T \mathbb{C} \mathbf{w} - \lambda (\mathbf{w}^T \mathbf{w} - 1)$$

Where λ is a *Lagrange multiplier*.

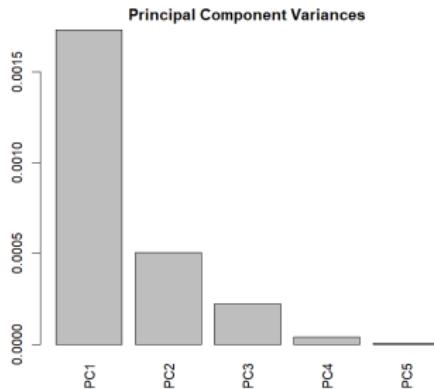
The maximum variance portfolio weights can be found by differentiating \mathcal{L} with respect to \mathbf{w} and setting it to zero:

$$\mathbb{C} \mathbf{w} = \lambda \mathbf{w}$$

The above is the *eigenvalue equation* of the covariance matrix \mathbb{C} , with the optimal weights \mathbf{w} forming an *eigenvector*, and λ is the *eigenvalue* corresponding to the *eigenvector* \mathbf{w} .

The *eigenvalues* are the variances of the *eigenvectors*, and their sum is equal to the sum of the return variances:

$$\sum_{i=1}^k \lambda_i = \frac{1}{1-k} \sum_{i=1}^k \mathbf{r}_i^T \mathbf{r}_i$$



```
> eigend <- eigen(covmat)
> eigend$vectors
> # Compare with optimization
> all.equal(sum(diag(covmat)), sum(eigend$values))
> all.equal(abs(eigend$vectors[, 1]), abs(weights1), check.attributes=FALSE)
> all.equal(abs(eigend$vectors[, 2]), abs(weights2), check.attributes=FALSE)
> all.equal(eigend$values[1], var(pc1), check.attributes=FALSE)
> all.equal(eigend$values[2], var(pc2), check.attributes=FALSE)
> # Eigenvalue equations are satisfied approximately
> (covmat %*% weights1) / weights1 / var(pc1)
> (covmat %*% weights2) / weights2 / var(pc2)
> # Plot eigenvalues
> barplot(eigend$values, names.arg=paste0("PC", 1:nweights),
+   las=3, xlab="", ylab="", main="Principal Component Variances")
```

Principal Component Analysis Versus Eigen Decomposition

Principal Component Analysis (PCA) is equivalent to the eigen decomposition of either the correlation or the covariance matrix.

If the input time series are scaled, then PCA is equivalent to the eigen decomposition of the *correlation matrix*.

If the input time series are *not* scaled, then PCA is equivalent to the eigen decomposition of the *covariance matrix*.

Scaling the input time series improves the accuracy of the *PCA dimension reduction*, allowing a smaller number of *principal components* to more accurately capture the data contained in the input time series.

The function `prcomp()` performs *Principal Component Analysis* on a matrix of data (with the time series as columns), and returns the results as a list of class `prcomp`.

The `prcomp()` argument `scale=TRUE` specifies that the input time series should be scaled by their standard deviations.

```
> # Eigen decomposition of correlation matrix
> eigend <- eigen(cormat)
> # Perform PCA with scaling
> pcad <- prcomp(retp, scale=TRUE)
> # Compare outputs
> all.equal(eigend$values, pcad$sdev^2)
> all.equal(abs(eigend$vectors), abs(pcad$rotation),
+   check.attributes=FALSE)
> # Eigen decomposition of covariance matrix
> eigend <- eigen(covmat)
> # Perform PCA without scaling
> pcad <- prcomp(retp, scale=FALSE)
> # Compare outputs
> all.equal(eigend$values, pcad$sdev^2)
> all.equal(abs(eigend$vectors), abs(pcad$rotation),
+   check.attributes=FALSE)
```

Principal Component Analysis of the Yield Curve

Principal Component Analysis (PCA) is a *dimension reduction* technique, that explains the returns of a large number of correlated time series as linear combinations of a smaller number of principal component time series.

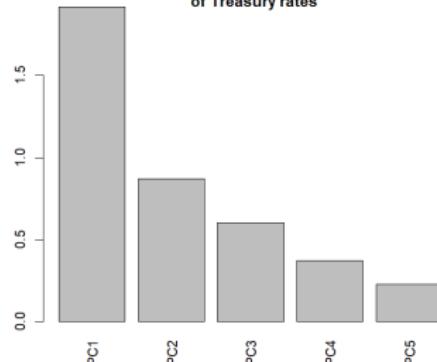
The input time series are often scaled by their standard deviations, to improve the accuracy of *PCA dimension reduction*, so that more information is retained by the first few *principal component* time series.

If the input time series are not scaled, then *PCA* analysis is equivalent to the *eigen decomposition* of the covariance matrix, and if they are scaled, then *PCA* analysis is equivalent to the *eigen decomposition* of the correlation matrix.

The function `prcomp()` performs *Principal Component Analysis* on a matrix of data (with the time series as columns), and returns the results as a list of class `prcomp`.

The `prcomp()` argument `scale=TRUE` specifies that the input time series should be scaled by their standard deviations.

Scree Plot: Volatilities of Principal Components of Treasury rates



A *scree plot* is a bar plot of the volatilities of the principal components.

```
> # Perform principal component analysis PCA
> pcad <- prcomp(retp, scale=TRUE)
> # Plot standard deviations
> barplot(pcad$sdev, names.arg=colnames(pcad$rotation),
+   las=3, xlab="", ylab="",
+   main="Scree Plot: Volatilities of Principal Components
+   of Treasury rates")
```

Yield Curve Principal Component Loadings (Weights)

Principal component loadings are the weights of portfolios which have mutually orthogonal returns.

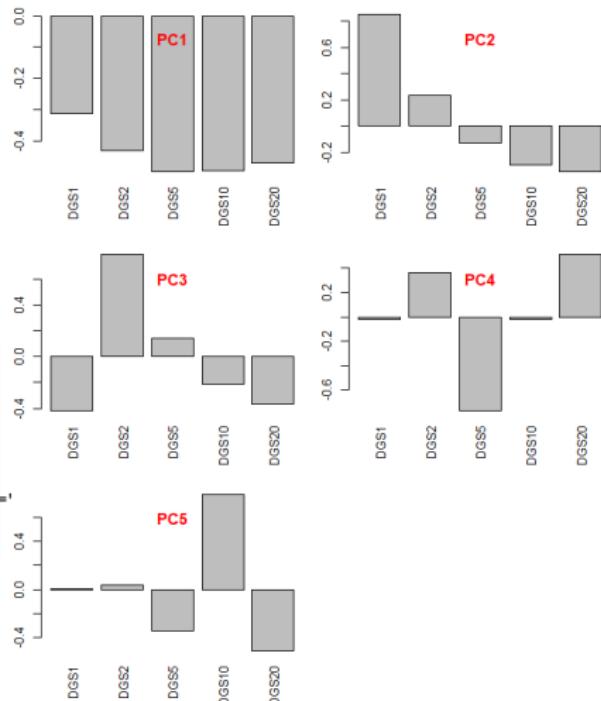
The *principal component* portfolios represent the different orthogonal modes of the data variance.

The first *principal component* of the yield curve is the correlated movement of all rates up and down.

The second *principal component* is yield curve steepening and flattening.

The third *principal component* is the yield curve butterfly movement.

```
> # Calculate principal component loadings (weights)
> pcad$rotation
> # Plot loading barplots in multiple panels
> par(mfrow=c(3,2))
> par(mar=c(3.5, 2, 2, 1), oma=c(0, 0, 0, 0))
> for (ordern in 1:NCOL(pcad$rotation)) {
+   barplot(pcad$rotation[, ordern], las=3, xlab="", ylab="", main=
+   title(paste0("PC", ordern), line=-2.0, col.main="red")
+ } # end for
```



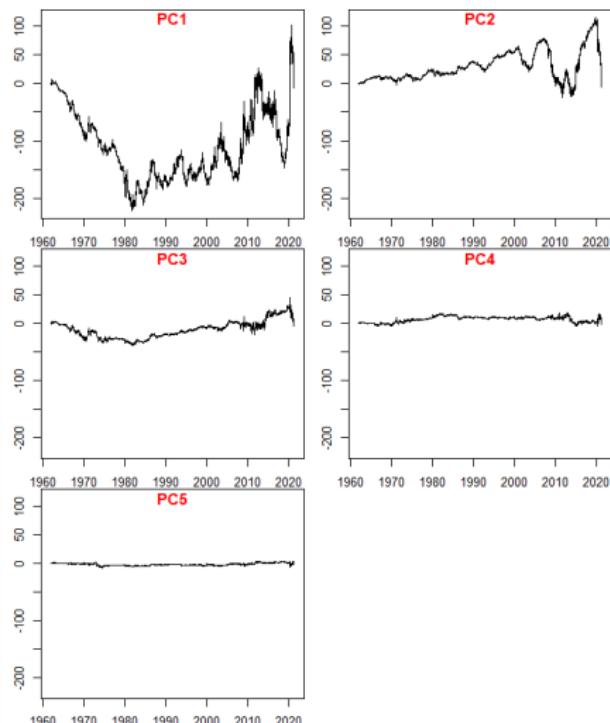
Yield Curve Principal Component Time Series

The time series of the *principal components* can be calculated by multiplying the loadings (weights) times the original data.

The *principal component* time series have mutually orthogonal returns.

Higher order *principal components* are gradually less volatile.

```
> # Standardize (center and scale) the returns
> retp <- lapply(retp, function(x) {(x - mean(x))/sd(x)})
> retp <- rutils::do_call(cbind, retp)
> sapply(retp, mean)
> sapply(retp, sd)
> # Calculate principal component time series
> retpcac <- retp %*% pcad$rotation
> all.equal(pcad$x, retpcac, check.attributes=FALSE)
> # Calculate products of principal component time series
> round(t(retpcac) %*% retpcac, 2)
> # Coerce to xts time series
> retpcac <- xts(retpcac, order.by=zoo::index(retp))
> retpcac <- cumsum(retpcac)
> # Plot principal component time series in multiple panels
> par(mfrow=c(3,2))
> par(mar=c(2, 0, 1), oma=c(0, 0, 0, 0))
> rangev <- range(retpcac)
> for (ordern in 1:NCOL(retpcac)) {
+   plot.zoo(retpcac[, ordern], ylim=rangev, xlab="", ylab="")
+   title(paste0("PC", ordern), line=-1, col.main="red")
+ } # end for
```



Inverting Principal Component Analysis

The original time series can be calculated *exactly* from the time series of all the *principal components*, by inverting the loadings matrix.

The function `solve()` solves systems of linear equations, and also inverts square matrices.

```
> # Invert all the principal component time series  
> retPCA <- retP %*% pcad$rotation  
> solved <- retPCA %*% solve(pcad$rotation)  
> all.equal(coredata(retP), solved)
```

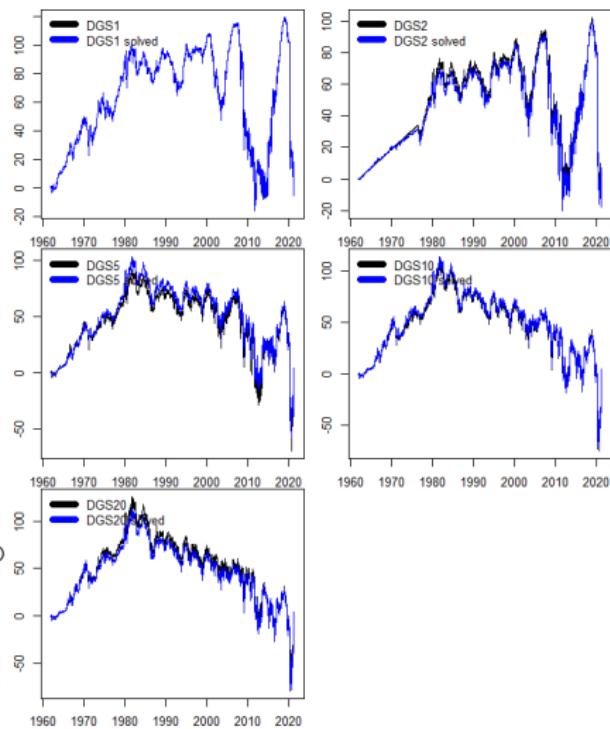
Dimension Reduction Using Principal Component Analysis

The original time series can be calculated approximately from just the first few *principal components*, which demonstrates that PCA is a form of dimension reduction.

A popular rule of thumb is to use the *principal components* with the largest variances, which sum up to 80% of the total variance of returns.

The *Kaiser-Guttman* rule uses only *principal components* with variance greater than 1.

```
> # Invert first 3 principal component time series
> solved <- retpca[, 1:3] %*% solve(pcad$rotation)[1:3, ]
> solved <- xts::xts(solved, zoo::index(retp))
> solved <- cumsum(solved)
> retc <- cumsum(retp)
> # Plot the solved returns
> par(mfrow=c(3,2))
> par(mar=c(2, 2, 0, 1), oma=c(0, 0, 0, 0))
> for (symbol in symbolv) {
+   plot.zoo(cbind(retc[, symbol], solved[, symbol]),
+             plot.type="single", col=c("black", "blue"), xlab="", ylab="")
+   legend(x="topleft", bty="n", y.intersp=0.1,
+   legend=paste0(symboln, c("", " solved")),
+   title=NULL, inset=0.0, cex=1.0, lwd=6,
+   lty=1, col=c("black", "blue"))
+ } # end for
```



Calibrating Yield Curve Using Package *RQuantLib*

The package *RQuantLib* is an interface to the *QuantLib* open source C/C++ library for quantitative finance, mostly designed for pricing fixed-income instruments and options.

The function *DiscountCurve()* calibrates a *zero coupon yield curve* from *money market rates*, *Eurodollar futures*, and *swap rates*.

The function *DiscountCurve()* interpolates the *zero coupon* rates into a vector of dates specified by the *times* argument.

```
> library(RQuantLib) # Load RQuantLib
> # Specify curve parameters
> curvep <- list(tradeDate=as.Date("2018-01-17"),
+   settleDate=as.Date("2018-01-19"),
+   dt=0.25,
+   interpWhat="discount",
+   interpHow="loglinear")
> # Specify market data: prices of FI instruments
> pricev <- list(d3m=0.0363,
+   fut1=96.2875,
+   fut2=96.7875,
+   fut3=96.9875,
+   fut4=96.6875,
+   s5y=0.0443,
+   s10y=0.05165,
+   s15y=0.055175)
> # Specify dates for calculating the zero rates
> datev <- seq(0, 10, 0.25)
> # Specify the evaluation (as of) date
> setEvaluationDate(as.Date("2018-01-17"))
> # Calculate the zero rates
> ratev <- DiscountCurve(params=curvep, tsQuotes=pricev, times=datev)
> # Plot the zero rates
> x11()
> plot(x=ratev$zerorates, t="l", main="zerorates")
```

Financial and Commodity Futures Contracts

The underlying assets delivered in *commodity futures* contracts are commodities, such as grains (corn, wheat), or raw materials and metals (oil, aluminum).

The underlying assets delivered in *financial futures* contracts are financial assets, such as stocks, bonds, and currencies.

Many futures contracts use cash settlement instead of physical delivery of the asset.

Futures contracts on different underlying assets can have quarterly, monthly, or even weekly expiration dates.

The front month futures contract is the contract with the closest expiration date to the current date.

Symbols of futures contracts are obtained by combining the contract code with the month code and the year.

For example, *ESM9* is the symbol for the *S&P500* index E-mini futures expiring in June 2019.

Futures contract	Code	Month	Code
S&P500 index	ES	January	F
10yr Treasury	ZN	February	G
VIX index	VX	September	H
Gold	GC	April	J
Oil	CL	May	K
Euro FX	EC	June	M
Swiss franc	SF	July	N
Japanese Yen	JY	August	Q
		September	U
		October	V
		November	X
		December	Z

Interactive Brokers provides more information about futures contracts:

[IB Contract and Symbol Database](#)

[IB Traded Products](#)

[List of Popular Futures Contracts.](#)

E-mini Futures Contracts

E-mini futures are contracts with smaller notionals and tick values, which are more suitable for retail investors.

For example, the *QM E-mini oil future* notional is 500 barrels, while the standard *CL oil future* notional is 1,000 barrels.

The tick value is the change in the dollar value of the futures contract due to a one tick change in the underlying price.

For example, the tick value of the *ES E-mini S&P500* future is \$12.50, and one tick is 0.25.

So if the *S&P500* index changes by one tick (0.25), then the value of a single *ES E-mini* contract changes by \$12.50, while the standard *SP* contract value changes by \$62.5.

The *ES E-mini S&P500 futures* trade almost continuously 24 hours per day, from 6:00 PM Eastern Time (ET) on Sunday night to 5:00 PM Friday night (with a trading halt between 4:15 and 4:30 PM ET each day).

Futures contract	Standard	E-mini
S&P500 index	SP	ES
10yr Treasury	ZN	ZN
VIX index	VX	delisted
Gold	GC	YG
Oil	CL	QM
Euro FX	EC	E7
Swiss franc	SF	MSF
Japanese Yen	JY	J7

Plotting S&P500 Futures Data

The function `data.table::fread()` reads .csv files over five times faster than the function `read.csv()`!

The function `as.POSIXct.numeric()` coerces a numeric value representing the *moment of time* into a `POSIXct` *date-time*, equal to the *clock time* in the local *time zone*.

```
> # Load data for S&P Emini futures June 2019 contract
> dirn <- "/Users/jerzy/Develop/data/ib_data"
> filen <- file.path(dirn, "ESohlc.csv")
> # Read a data table from CSV file
> pricev <- data.table::fread(filen)
> class(pricev)
> # Coerce first column from string to date-time
> unlist(sapply(pricev, class))
> tail(pricev)
> prices$Index <- as.POSIXct(prices$Index,
+   tz="America/New_York", origin="1970-01-01")
> # Coerce prices into xts series
> pricev <- data.table::as.xts.data.table(pricev)
> class(pricev)
> tail(pricev)
> colnames(pricev)[1:5] <- c("Open", "High", "Low", "Close", "Volu
> tail(pricev)
```



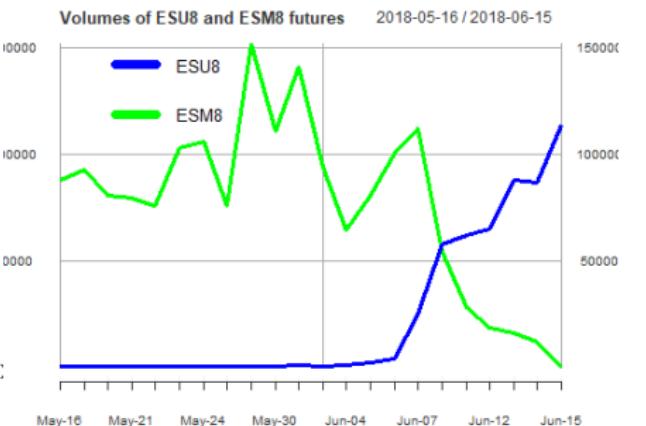
```
> # Plot OHLC data in x11 window
> x11(width=5, height=4) # Open x11 for plotting
> par(mar=c(5, 5, 2, 1), oma=c(0, 0, 0, 0))
> chart_Series(x=pricev, TA="add_Vo()", 
+   name="S&P500 futures")
> # Plot dygraph
> dygraphs::dygraph(pricev[, 1:4], main="OHLC prices") %>%
+   dyCandlestick()
```

Consecutive Contract Futures Volumes

The trading volumes of a futures contract drop significantly shortly before its expiration, and the successive contract volumes increase.

The contract with the highest trading volume is usually considered the most liquid contract.

```
> # Load ESU8 data
> dirn <- "/Users/jerzy/Develop/data/ib_data"
> filen <- file.path(dirn, "ESU8.csv")
> ESU8 <- data.table::fread(filen)
> # Coerce ESU8 into xts series
> ESU8$V1 <- as.Date(as.POSIXct.numeric(ESU8$V1,
+ tz="America/New_York", origin="1970-01-01"))
> ESU8 <- data.table::as.xts.data.table(ESU8)
> colnames(ESU8)[1:5] <- c("Open", "High", "Low", "Close", "Volume")
> # Load ESM8 data
> filen <- file.path(dirn, "ESM8.csv")
> ESM8 <- data.table::fread(filen)
> # Coerce ESM8 into xts series
> ESM8$V1 <- as.Date(as.POSIXct.numeric(ESM8$V1,
+ tz="America/New_York", origin="1970-01-01"))
> ESM8 <- data.table::as.xts.data.table(ESM8)
> colnames(ESM8)[1:5] <- c("Open", "High", "Low", "Close", "Volume")
```



```
> # Plot last month of ESU8 and ESM8 volume data
> endd <- end(ESM8)
> startd <- (endd - 30)
> volumm <- cbind(Vo(ESU8), Vo(ESM8))[paste0(startd, "/", endd)]
> colnames(volumm) <- c("ESU8", "ESM8")
> colrv <- c("blue", "green")
> plot(volumm, col=colrv, lwd=3, major.ticks="days",
+       format.labels="%b-%d", observation.based=TRUE,
+       main="Volumes of ESU8 and ESM8 futures")
> legend("topleft", legend=colnames(volumm), col=colrv, y.intersp=0.5,
+ title=NULL, bty="n", lty=1, lwd=6, inset=0.1, cex=0.7)
```

Chaining Together Futures Prices

Chaining futures means splicing together prices from several consecutive futures contracts.

A continuous futures contract is a time series of prices obtained by chaining together prices from consecutive futures contracts.

The price of the continuous contract is equal to the most liquid contract times a scaling factor.

When the next contract becomes more liquid, then the continuous contract price is rolled over to that contract.

Futures contracts with different maturities (expiration datev) trade at different prices because of the futures curve, which causes price jumps between consecutive futures contracts.

The old contract price is multiplied by a scaling factor after that contract is rolled, to remove price jumps.

So the continuous contract prices are not equal to the past futures prices.

Interactive Brokers provides information about Continuous Contract Futures market data:

[Continuous Contract Futures Data](#)



```
> # Find date when ESU8 volume exceeds ESM8
> exceeds <- (volumm[, "ESU8"] > volumm[, "ESM8"])
> indeks <- match(TRUE, exceeds)
> # indeks <- min(which(exceeds))
> # Scale the ESM8 prices
> indeks <- zoo::index(exceeds[indeks])
> ratio <- as.numeric(Cl(ESU8[indeks])/Cl(ESM8[indeks]))
> ESM8[, 1:4] <- ratio*ESM8[, 1:4]
> # Calculate continuous contract prices
> chaind <- rbind(ESM8[zoo::index(ESM8) < indeks],
+                   ESU8[zoo::index(ESU8) >= indeks])
> # Or
> # chaind <- rbind(ESM8[paste0("/", indeks-1)],
> #                   ESU8[paste0(indeks, "/")])
> # Plot continuous contract prices
> chart_Series(y=chaind["2018"], TA="add.Vo()")
```

VIX Volatility Index

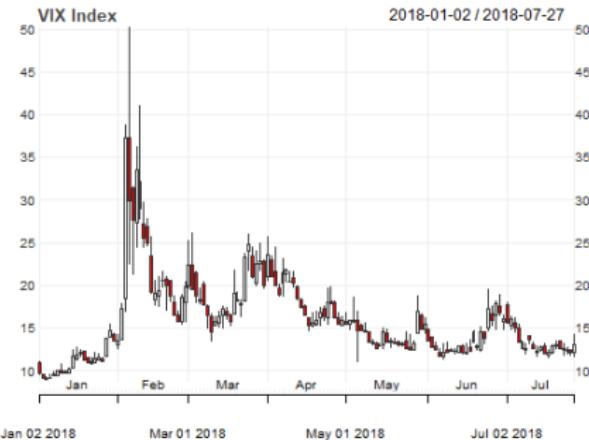
The VIX Volatility Index is an average of the implied volatilities of options on the *S&P500* Index (SPX).

The VIX index is an estimate of the *future* stock market volatility that is expected (anticipated) by investors.

The VIX index is not a directly tradable asset, but it can be traded using VIX futures.

The CBOE provides daily historical data for the VIX index.

```
> # Download VIX index data from CBOE
> vix_index <- data.table::fread("http://www.cboe.com/publish/schedu
> class(vix_index)
> dim(vix_index)
> tail(vix_index)
> sapply(vix_index, class)
> vix_index <- xts(vix_index[, -1],
+   order.by=as.Date(vix_index$date, format="%m/%d/%Y"))
> colnames(vix_index) <- c("Open", "High", "Low", "Close")
> # Save the VIX data to binary file
> load(file="/Users/jerzy/Develop/data/ib_data/vix_cboe.RData")
> ls(vixenv)
> vixenv$vix_index <- vix_index
> save(vixenv, file="/Users/jerzy/Develop/data/ib_data/vix_cboe.RData")
```



```
> # Plot VIX OHLC data in x11 window
> chart_Series(x=vix_index["2018"], name="VIX Index")
> # Plot dygraph
> dygraphs::dygraph(vix_index, main="VIX Index") %>%
+   dyCandlestick()
```

VIX Futures Contracts

VIX futures are cash-settled futures contracts on the VIX Index.

The most liquid VIX futures are with monthly expiration dates ([CBOE Expiration Calendar](#)), but weekly VIX futures are also traded.

These are the [VIX Futures Monthly Expiration Dates](#) from 2004 to 2019.

VIX futures are traded on the *CFE* (CBOE Futures Exchange):

<http://cfe.cboe.com/>
<http://www.cboe.com/vix>

VIX Contract Specifications:

[VIX Contract Specifications](#)
[VIX Expiration Calendar](#)

Standard and Poor's explains the methodology of the [VIX Futures Indices](#)

```
> # Read CBOE monthly futures expiration dates
> datev <- read.csv(file="/Users/jerzy/Develop/data/vix_data/vix_dat"
> datev <- as.Date(datev[, 1])
> yearv <- format(datev, format="%Y")
> yearv <- substring(yearv, 4)
> # Monthly futures contract codes
> codes <-
+   c("F", "G", "H", "J", "K", "M",
+     "N", "Q", "U", "V", "X", "Z")
> symbolv <- paste0("VX", codes, yearv)
> datev <- as.data.frame(datev)
> colnames(datev) <- "exp_dates"
> rownames(datev) <- symbolv
> # Write dates to CSV file, with row names
> write.csv(datev, row.names=TRUE,
+   file="/Users/jerzy/Develop/data/vix_data/vix_futures.csv")
> # Read back CBOE futures expiration dates
> datev <- read.csv(file="/Users/jerzy/Develop/data/vix_data/vix_fut
+   row.names=1)
> datev[, 1] <- as.Date(datev[, 1])
```

VIX Futures Curve

Futures contracts with different expiration dates trade at different prices, known as the *futures curve* (or *term structure*).

The VIX futures curve is similar to the interest rate *yield curve*, which displays yields at different bond maturities.

The VIX futures curve is not the same as the VIX index term structure.

More information about the VIX Index and the VIX futures curve:

[VIX Futures](#)

[VIX Futures Data](#)

[VIX Futures Curve](#)

[VIX Index Term Structure](#)

```
> # Load VIX futures data from binary file
> load(file="/Users/jerzy/Develop/data/vix_data/vix_cboe.RData")
> # Get all VIX futures for 2018 except January
> symbolv <- ls(vixenv)
> symbolv <- symbolv[grep(glob2rx("*8"), symbolv)]
> symbolv <- symbolv[2:9]
> # Specify dates for curves
> startd <- as.Date("2018-01-11")
> endd <- as.Date("2018-02-05")
> # Extract all VIX futures prices on the dates
> futcurves <- lapply(symbolv, function(symboln) {
+   xtsv <- get(x=symboln, envir=vixenv)
+   Cl(xtsv[c(startd, endd)])
+ }) # end lapply
> futcurves <- rutils::do_call(cbind, futcurves)
> colnames(futcurves) <- symbolv
> futcurves <- t(coredata(futcurves))
> colnames(futcurves) <- c("Contango 01/11/2018",
+                           "Backwardation 02/05/2018")
```

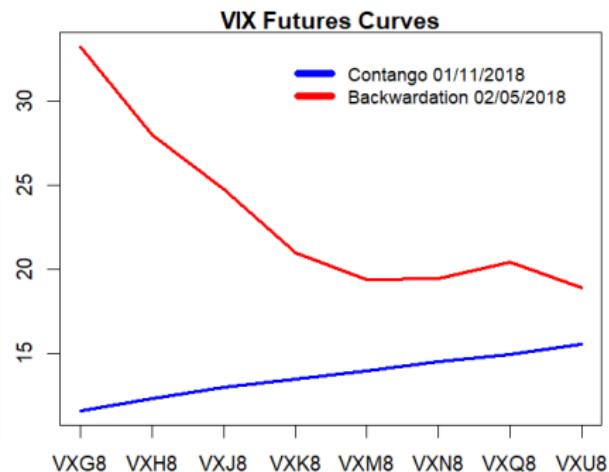
Contango and Backwardation of VIX Futures Curve

When prices are *low* then the futures curve is usually *upward sloping*, known as *contango*.

Futures prices are in *contango* most of the time.

When prices are *high* then the curve is usually *downward sloping*, known as *backwardation*.

```
> x11(width=7, height=5)
> par(mar=c(3, 2, 1, 1), oma=c(0, 0, 0, 0))
> plot(futcurves[, 1], type="l", lty=1, col="blue", lwd=3,
+       xaxt="n", xlab="", ylab="", ylim=range(futcurves),
+       main="VIX Futures Curves")
> axis(1, at=(1:NROW(futcurves)), labels=rownames(futcurves))
> lines(futcurves[, 2], lty=1, lwd=3, col="red")
> legend(x="topright", legend=colnames(futcurves),
+         inset=0.05, cex=1.0, bty="n", y.intersp=0.1,
+         col=c("blue", "red"), lwd=6, lty=1)
```



Futures Prices at Constant Maturity

A constant maturity futures price is the price of a hypothetical futures contract with an expiration date at a fixed number of days in the future.

Futures prices at a constant maturity can be calculated by interpolating the prices of contracts with neighboring expiration dates.

```
> # Load VIX futures data from binary file
> load(file="/Users/jerzy/Develop/data/vix_data/vix_cboe.RData")
> # Read CBOE futures expiration dates
> datev <- read.csv(file="/Users/jerzy/Develop/data/vix_data/vix_fut"
+   row.names=1)
> symbolv <- rownames(datev)
> datev <- as.Date(datev[, 1])
> tday <- as.Date("2018-05-07")
> maturd <- (tday + 30)
> # Find neighboring futures contracts
> indeks <- match(TRUE, datev > maturd)
> frontd <- datev[indeks-1]
> backd <- datev[indeks]
> symbolf <- symbolv[indeks-1]
> symbolb <- symbolv[indeks]
> pricef <- get(x=symbolf, envir=vixenv)
> pricef <- as.numeric(Cl(pricef[tday]))
> priceb <- get(x=symbolb, envir=vixenv)
> priceb <- as.numeric(Cl(priceb[tday]))
> # Calculate the constant maturity 30-day futures price
> ratiop <- as.numeric(maturd - frontd)/as.numeric(backd - frontd)
> pricec <- (ratiop*priceb + (1-ratiop)*pricef)
```

VIX Futures Investing

The volatility index moves in the opposite direction to the underlying asset price.

An increase in the VIX index coincides with a drop in stock prices, and vice versa.

Taking a *long* position in VIX futures is similar to a *short* position in stocks, and vice versa.

There are several exchange-traded funds (*ETFs*) and exchange traded notes (*ETNs*) which are linked to VIX futures.

The [VXX ETN](#) provides the total return on the long VIX futures index.

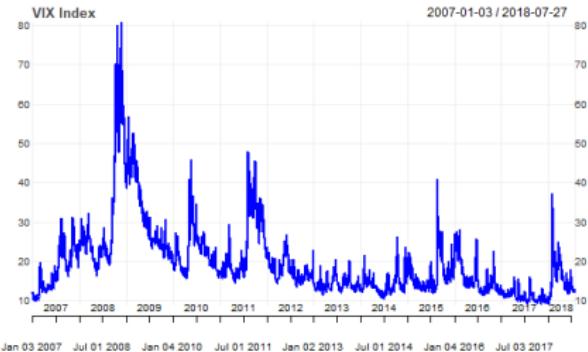
VXX is short market risk because it's long VIX futures, and the VIX rises when stock prices drop.

The [SVXY ETF](#) provides the total return of short VIX futures contracts.

SVXY is long market risk because it's short VIX futures, and the VIX drops when stock prices rise.

Standard and Poor's explains the calculation of the Total Return on VIX Futures Indices.

```
> # Plot VIX and SVXY data in x11 window
> plot_theme <- chart_theme()
> plot_theme$col$line.col <- "blue"
> chart_Series(x=Cl(vixenv$vix_index["2007/"]),
+   theme=plot_theme, name="VIX Index")
> chart_Series(x=Cl(rutils::etfenv$VTI["2007/"]),
+   theme=plot_theme, name="VTI ETF")
```



VIX Crash on February 5th 2018

The SVXY and XIV ETFs rallied strongly after the financial crisis of 2008, so they became very popular with individual investors, and became very "crowded trades".

The SVXY and XIV ETFs had \$3.6 billion of assets at the beginning of 2018.

On February 5th 2018 the U.S. stock markets experienced a mini-crash, which was exacerbated by VIX futures short sellers.

As a result, the XIV ETF hit its termination event and its value dropped to zero:

Volatility Caused Stock Market Crash XIV ETF Termination Event

```
> chart_Series(x=Cl(vixenv$vix_index["2017/2018"]),
+               theme=plot_theme, name="VIX Index")
> chart_Series(x=Cl(rtutils::etfenv$SVXY["2017/2018"]),
+               theme=plot_theme, name="SVXY ETF")
```



draft: Types of Market Data

Fundamental company data summarizes the financial, economic, and regulatory state of a company.

Fundamental company data can be divided into several different types:

- Balance Sheet (assets and liabilities),
- Income Statement (profits and losses),
- Cash Flow Statement (current operating cash flows),
- Financial Ratios (performance and risk measures),

Financial ratios summarize the performance and risk measures of a company, and can be used for investment decisions, like value investing.

```
> # Read table of fundamental data into data frame
> dframe <- read.csv(file="/Users/jerzy/Develop/lecture_slides/data/...
```

Balance.Sheet	Income.Statement	Cash.Flow.Statement	Financial.Ratios
Cash & Equivalents	Total Revenue	Cash from Operations	Earnings per Share
Investments	Cost of Goods Sold	Cash from Investments	Price/Earnings Ratio
Receivables	Sales, G and A	Cash from Financing	EBIT
Property & Equipment	Research & Development	FX Adjustment	EBITDA
Goodwill & Intangibles	Depreciation & Amortization	Capital Expenditure	Dividend Yield
Total Assets	Operating Expenses	Starting Cash	Gross Margin
Accounts Payable	Operating Income	Ending Cash	Profit Margin
Long-Term Debt	Investment Income		Free Cash Flow
Total Liabilities	Non-Operating Income		Asset Turnover
Common Stock	Pre-Tax Income		Inventory Turnover
			Receivable Turnover

Types of Fundamental Company Data

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Common Stock	Pre-Tax Income		Inventory Turnover
			Receivable Turnover

Sources of Fundamental Company Data

Fundamental company data is obtained from financial statements provided to government agencies and from earnings statements provided to investors.

U.S. companies are required to provide quarterly *10Q* reports and annual *10K* reports to the *Securities and Exchange Commission (SEC)*.

The *10Q* and *10K* reports are publicly available on the *SEC EDGAR* website.

The data provided by *EDGAR* only goes back to the year 2009, because the *SEC* did not mandate electronic filing before then.

The data from the *10Q* and *10K* reports is compiled by vendors such as *Compustat* and *FactSet*, into premium databases.

There are also free databases of fundamental company data, from providers such as *SimFin*, *usfundamentals*, and *Quandl*.

WRDS redistributes fundamental company data from *Compustat*, *S&P Capital IQ*, *Thomson Reuters*, *FactSet*, *Markit*, etc.

There are occasional gaps in the quarterly data, because companies are not required to file quarterly reports on dates when they're also filing annual reports.

The report harmonization procedure fails when companies change their accounting treatment from year to year.

Quandl has written a review of both premium and free sources of fundamental company data.

Identifiers of Company Data

Identifiers are strings that correspond to *corporate entities* and *securities*.

Headers are current identifiers, while *historical identifiers* have date ranges when they were valid.

Some *universal identifiers* are company namev, tickers, CUSIP, SEDOL, ISIN, and CIK.

Most *universal identifiers*, such as company namev, tickers, CUSIPs, etc. change over time due to corporate events such as mergers, bankruptices, etc.

Tickers are short and recognizable strings, but are not unique, and can change over time and can be reused by a different company.

CUSIPs change infrequently and are never reused, and identify securities in the U.S. and Canada.

SEDOL identify securities in the UK.

ISIN identify international securities in the UK.

CIK identify corporations and individuals who have filed disclosures with the SEC.

Data vendors such as *Compustat*, *Capital IQ*, *IBES*, *Markit*, and *FactSet* have introduced *proprietary identifiers* that are *permanent*.

CRSP *PERMCO* and *PERMNO* are identifiers of companies and securities.

Compustat *GVKEYs* and *IIDs* are identifiers of companies and securities.

The *PERMCO* and *PERMNO* are *permanent identifiers* which never change, even if other identifiers such as tickers do change.

So analysts use *permanent identifiers*, such as *PERMCO*, *PERMNO*, and *GVKEY*.

Capital IQ Company IDs are identifiers of companies.

IBES tickers are identifiers of securities.

Markit RED codes are identifiers of companies.

Factset Entity IDs and *Perm Sec IDs* are identifiers of companies and securities.

Wharton Research Data Services WRDS

Wharton Research Data Services ([WRDS](#)) is a distributor of premium third party data for the academic and research communities.

WRDS provides time series of security prices and fundamental company data, and other financial, econometric, and social datasets.

WRDS provides stock prices, options and implied volatilities, stock fundamentals, financial ratios, zoo::indexes, earnings estimates, analyst ratings, etc.

WRDS redistributes fundamental company data from *Compustat*, *S&P Capital IQ*, *Thomson Reuters*, *FactSet*, *Hedge Fund Research*, *Markit*, etc.

NYU students can obtain user accounts for **WRDS** data.

The screenshot shows the WRDS homepage with a navigation bar at the top featuring links for CONTACT, JERZY'S ACCOUNT, and LOGOUT. Below the navigation is a search bar labeled "Search WRDS". The main content area is divided into several sections:

- Subscriptions:** A grid of links to various data sources including Bank Regulatory, Beta Suite by WRDS, Blockholders, CBOE Indexes, Compustat - Capital IQ, Contributed Data, CRSP, CSMAR, DMEF Academic Data, Dow Jones, Financial Ratios Suite by WRDS, IBES, IHS Global Insight, Infogroup, Institutional Shareholder Services (ISS), Intraday Indicators by WRDS, IRI, Linking Suite by WRDS, OTC Markets, Perm World Tables, Peters and Taylor Total Q, PHLX, Public, Research Quotient, SEC Order Execution, TAG, Thomson Reuters, and TRACE.
- Analytics by WRDS:** Three cards showcasing different analytical tools:
 - SEC Analytics Suite:** Researchers will gain an overview of WRDS' powerful SEC research platform. Key features include access to 15 million filings from a single index, full-text searching over 3.5 million filings, and sentiment analysis.
 - U.S. Daily Event Study:** Investigate abnormal stock returns/betas around event dates by uploading your own "events" file or analyzing reaction to firm-specific events from Capital IQ's Key Development database.
 - Intraday Indicators:** Stock specific daily and intraday (5 min, 10 min and 30 min) indicators created from the TAG intraday dataset. Features include daily and intraday (5 min, 10 min and 30 min) indicators, and requires subscription to TAG dataset.
- Classroom by WRDS:** A section for classroom resources.

WRDS Help and Documentation

WRDS provides extensive *Learning Resources and Documentation*.

WRDS provides online help and a guide to its datasets:

Getting Started

WRDS Data

Finding Data

Understanding Identifiers

Company Identifiers

Futures Contracts

Using SAS Studio

The screenshot shows the WRDS Classroom Tools homepage. At the top, there's a search bar and navigation links for 'Get Data', 'Analytics', 'Classroom', 'Research', and 'Support'. Below the header, there's a banner for 'Classroom Tools by wrds' featuring a classroom setting. To the right, there's a section titled 'FEATURED TOOLS:' with two examples: 'Treasury Yield Curve' (showing a field of crops) and 'Fiscal Policy: Multiplier Effect' (showing a stack of coins). A navigation bar below the banner includes 'Grid View' and 'List View' buttons, followed by categories: All Topics, Accounting, Fixed Income, Introduction to WRDS, Investments, Macroeconomics, SEC, and Test Analytics. The main content area is divided into four sections: 'Getting Started' (with a pencil icon), 'What Data is in WRDS?' (with a blue starburst icon), 'Finding the Data You Want' (with a person on a surfboard icon), and 'Understanding Identifiers' (with a globe icon). Each section has a brief description and a 'More >' button.

WRDS Vendor and Database Manuals

WRDS provides many *Vendor and Database Manuals*.

The screenshot shows the 'Manuals and Overviews' section of the WRDS website. At the top, there's a navigation bar with links for Home, Support, and Manuals and Overviews. The main title 'Manuals and Overviews' is centered above a grid of vendor names. Each name is preceded by a small grey triangle icon and a link. The vendors are arranged in three columns:

Column 1	Column 2	Column 3
> AHA	> Global Insight	> Research Quotient
> Audit Analytics	> HFR	> Sustainalytics
> Bank Regulatory	> IBB/EIS	> TAQ
> Blockholders	> IMS	> TRACE
> BoardEx	> IRI	> Thomson Reuters
> Bureau van Dijk	> ISS (Formerly RiskMetrics)	> Total_6
> CBOE Indexes	> ISSM	> Toyo Keizai
> CENTRIS	> Infogroup	> TwoIQ
> CRSP	> KLD	> WRDS Bag of Words
> CSIMAR	> KMINE	> WRDS Factors (Backtester)
> CUSIP	> LSPD	> WRDS Beta Suite
> Clarivate	> Levin	> WRDS Bond Return
> Compustat	> MPLINKS	> WRDS Efficient Frontier
> Comscore	> MSCI	> WRDS Event Study Suite
> DMEF	> MSRB	> WRDS Financial Ratios

Downloading Data From WRDS

The two main databases on WRDS are the *Compustat* database of fundamental company data and security prices, and the *CRSP* database of security prices.

The WRDS data can be accessed through vendor pages, which are conveniently organized by *concept*.

The easiest way to download data from WRDS into R, is by first downloading it into a .csv file, and then reading it into R.

Browse Data by Concept

[Concepts](#) [Not Subscribed](#) [Your Queries](#) [Tools](#)

Concept Finder

Search

Advanced Search

Company Financials

Financial Statements

- S&P Compustat
- Thomson Reuters Worldscope
- Factset Fundamentals
- B&D Analysis
- B&D Crisis
- PRACAP Pacific Basin
- CSMAR Financials - China Stock Market & Accounting Research
- S&P Capital IQ Capital Structure
- Calcbench As-Reported Filings & Footnotes

Audit & Regulatory Filings

- WRDS SEC Analytics Suite
- Audit Analytics
- S&P Filings Database

Banks

- S&P Compustat Bank
- SNL
- B&D Orbis Bank Focus
- Bank Regulatory Call Reports - Federal Reserve Bank of Chicago
- FRB H15 Interest Rates

Segments / Industry Data

- S&P Compustat Segments
- Thomson Reuters Worldscope Segments
- S&P Compustat Industry-Specific
- Thomson Reuters Ibis KPI
- Factset Revenue
- B&D Iris Insurance Companies

Compensation

- S&P Compustat Executive
- S&P Capital IQ People Intelligence
- ISS Incentive Lab
- BoardEx
- MSCI GM Ratings

Intellectual Property

- IBBNIE

Top of Section

Financial Markets, Prices, Returns

Stock Prices

- CRSP
- Compustat
- Factset

The Compustat Database on WRDS

Compustat is a provider of fundamental company data, and also security prices, and other data such as credit ratings.

Daily North American security prices can be downloaded from the *Compustat Daily Prices* database, which can be reached by navigating from the *WRDS* home page to *North America - Daily* and then to *Security Daily*.

Compustat is part of *S&P Capital IQ*.

Compustat uses the *GVKEY* and *IID* identifiers of companies and securities.

Compustat provides only recent time series of data starting in 1983.

Compustat - Capital IQ from Standard & Poor's

Learn more about S&P Global Market Intelligence data through WRDS [»](#)

For more about this dataset, see the [Dataset List](#), [Manuals and Overviews](#) or [FAQs](#).

Compustat

Databases in this section are updated every day, unless otherwise noted. Update schedules should not be confused with end-of-day or end-of-month data such as stock prices.

- [North America - Daily](#)
- [Global - Daily](#)
- [Bank - Daily](#)
- [Historical Segments - Only](#)
- [Execucomp - Monthly Updates](#)

Capital IQ

Capital IQ is a suite of databases from S&P. They connect to the Compustat family of databases through GVKEY.

- [Capital Structure](#)
- [Identifiers](#)
- [Key Developments](#)
- [People Intelligence](#)
- [Transactions](#)
- [Transcripts](#)

Other Compustat

- | | |
|--|------|
| North America - Annual Updates | (15) |
| Margin Tax Rates | (1) |
| S&P Filing Dates | (1) |
| Preliminary History | (1) |
| Unrestated Quarterly | (2) |
| Point in Time | (2) |
| North America - Daily Updates (Non-Historical) | (15) |

North America - Daily

For more about this dataset, see the [Dataset List](#), [Manuals and Overviews](#) or [FAQs](#).

Compustat North America is a database of U.S. and Canadian fundamental and market information on active and inactive publicly held companies. It provides more than 300 annual and 100 quarterly Income Statement, Balance Sheet, Statement of Cash Flows, and supplemental data items. For most companies, annual history is available back to 1950 and quarterly history back to 1962, with monthly market history back to 1962.

Compustat North America files also contain information on aggregates, industry segments, banks, market prices, dividends, and earnings.

Fundamentals Annual	Industry Specific Quarterly	Segments (Non-Historical)
Fundamentals Quarterly	Pension Annual	Segments (Non-Historical) - Customer
Index Constituents	Pension Quarterly	Simplified Financial Statement Extract
Index Fundamentals	Ratings	Supplemental Short Interest File
Index Prices	Security Daily	Financial Ratios Industry Level
Industry Specific Annual	Security Monthly	Financial Ratios Firm Level

Package *rwrds* for Downloading Data From WRDS

The package *rwrds* contains functions for downloading data from WRDS.

```
> # Install package "rwrds"
> devtools::install_github("davidsovich/rwrds")
> # Load package "rwrds"
> library(rwrds)
> # Get documentation for package "rwrds"
> packageDescription("rwrds")
> # Load help page
> help(package="rwrds")
> # List all datasets in "rwrds"
> data(package="rwrds")
> # List all objects in "rwrds"
> ls("package:rwrds")
> # Remove rwrds from search path
> detach("package:rwrds")
```

Downloading Names Table From Compustat

The *Compustat* names table is a database containing various company *identifiers* (company name, tickers, CUSIPs, GVKEYs).

The names table can be used to cross-reference the *identifiers*, for example to find the *GVKEYs* from the company *tickers*.

The function `rwrds::compustat_names()` downloads the names table from *Compustat*.

```
> library(rwrds)
> library(dplyr)
> # Establish connection to WRDS
> connv <- rwrds::connvnect(username="jp3900", password="RipvanWink")
> # Download Compustat names table as dplyr object
> namet <- rwrds::compustat_names(wrds=connv, subset=FALSE, dl=TRUE)
> dim(namet)
> # Save names table as csv file
> write.csv(namet, file="/Users/jerzy/Develop/lecture_slides/data/com/
> # rm(namet)
> # Read names table from csv file
> namet <- read.csv(file="/Users/jerzy/Develop/lecture_slides/data/com/
> # symboln <- "VTI"
> # match(symboln, namet$tic)
> # Create ETF symbols (tickers)
> symbolv <- c("VTI", "VEU", "EEM")
> # Get cusips of symbolv
> indeks <- match(symbolv, namet$tic)
> names(indeks) <- symbolv
> etf_cusips <- namet$cusip[indeks]
> names(etf_cusips) <- symbolv
> # Save cusips into text file
> cat(etf_cusips, file="/Users/jerzy/Develop/lecture_slides/data/eti/
> # Save gvkeys into text file
> etf_gvkeys <- namet$gvkey[indeks]
> names(etf_gvkeys) <- symbolv
> cat(etf_gvkeys, file="/Users/jerzy/Develop/lecture_slides/data/eti/
```

draft: Downloading Index Constituents From Compustat

The names and tickers of the constituents of a given index can be downloaded from the [WRDS Compustat web page](#).

The constituents can be downloaded for a specific date, or for a range of dates, to obtain the names and tickers of all the companies which belonged to the index during that time.

The *S&P500* Index ticker is equal to *i0003*, and its *GVKEY* is equal to 3.

WRDS provides [help about how to download index constituents](#). The table with the index constituents can be read into R as a .csv from the file downloaded from the [WRDS Compustat web page](#).

The table of constituents is a data frame containing various company *identifiers* (company name, tickers, CUSIPs, GVKEYs).

Some GVKEYs are duplicates because some companies entered the index more than once.

The GVKEYs and CUSIPs can be saved into text files for use in WRDS data queries.

```
> # Read .csv file with S&P500 constituents
> sp500table <- read.csv(file="/Users/jerzy/Develop/lecture_slides/
> class(sp500table)
> dim(sp500table)
> head(sp500table)
> # Select unique sp500 tickers and save them into text file
> ticksp500 <- unique(sp500table$co_tic)
```

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Index Prices

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Industry Specific Quarterly

Person Annual

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Security Daily

Security Monthly

Segments (Non-Historical)

Segments (Non-Historical) - Customer

Simplified Financial Statement Extract

Supplemental Short Interest File

Financial Ratios Short Interest File

Financial Ratios Firm Level

Financial Ratios Firm Level

Query Form Variable Descriptions Manuals and Overviews FAQs Dataset List

Compustat Daily Updates - Index Constituents

You have 0 saved queries for this dataset.

Step 1: Choose your date range.

Date Variable: DateRange

Date range: 2010-01 to 2020-07

Step 2: Apply your company codes.

I0C003 G0VKEYX

Select an option for entering company codes

Code List Name Please enter Company codes separated by a space. Example: I0C003 00005 00008 | Code Lookup |

Code File No file selected Upload a plain-text file (.txt), having one code per line.

Selected Saved Codes Choose from your saved codes.

Search the entire database This method allows you to search the entire database of records. Please be aware that this method can take a very long time to run because it's dependent upon the size of the database.

Step 3: Query Variables.

How does this work?

Q. Search All **Index Information** **Company Information**

Select **All** Selected **Clear All** (0)

Search All

- COINN – Index Name
- INDICATR – Index Category Code
- INDTYPE – Index Code Type
- SPM – S&P Industry Index Identifier
- SPB – S&P Major Index Identifier
- I0C – Ticker
- COINM – Company Name
- i0C003 – Constituent Ticker
- COINL – Constituent ID

Downloading the S&P500 Index Constituents

As of July 2020, the *S&P500* stock index constituents data was removed from *Compustat*, so it's no longer available on *WRDS*.

As an alternative, users can download the *SPY ETF* constituents from *State Street*.

The file *sp500_constituents.csv* contains the symbols (tickers) for almost 800 stocks belonging to the *S&P500* stock index, either now or in the past.

```
> # Read .csv file with S&P500 constituents
> sp500table <- read.csv(file="/Users/jerzy/Develop/lecture_slides/
> class(sp500table)
> dim(sp500table)
> head(sp500table)
```

Downloading Fundamental Company Data

Fundamental company data can be downloaded from the *Compustat Fundamentals* database.

The user can download data for either a single identifier, or for many identifiers supplied in a text file.

Step 1: Choose your date range.

Date Variable: Date Date
Date range: 2010-12 To 2020-07

Step 2: Apply your company codes.

- MSFT
Please enter Company codes separated by a space.
Example: IBM MSFT DELL / [Code Lookup](#)
- No file selected
Upload a plain text file (.txt), having one code per line.
- Select Saved Codes
Choose from your saved codes.
- Search the entire database
This method allows you to search the entire database of records. Please be aware that this method can take a very long time to run because it is dependent upon the size of the dataset.

Screening Variables

Several screening variables are pre-selected to produce one record per GVKEY-DATADATE pair, while keeping the vast majority of records. Examples of excluded rows include those with missing data, different views of the same data (pro forma, pro-FASB). Click on each variable for a more detailed explanation.

Consolidation Level	On	Off	Sum	Avg	Min	Max	Count	Output
Industry Format	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Data Format	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Population Source	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Quarter Type	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>				
Currency	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>				
Company Status	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>				

Step 3: Choose variable types.

Select Variable Types

Select the items you would like to include in your search.

Select All (2) Selected (1) Clear All (1)

Downloading Daily Prices From *Compustat*

Daily security prices can be downloaded from the [Compustat Daily Prices](#) database.

The user can download data for either a single identifier, or for many identifiers in a text file.

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Fundamentals Annual

Fundamentals Quarterly

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Industry Specific Annual

Industry Specific Quarterly

Person Annual

Pension Quarterly

Ratings

Security Daily

Security Monthly

Segments (Non-Historical)

Segments (Non-Historical) - Customer

Simplified Financial Statement Extract

Supplemental Short Interest File

Query Form Variable Descriptions Manuals and Overviews FAQs Dataset List

Compustat Daily Updates - Security Daily

You have 1 saved queries for this dataset.

Step 1: Choose your date range.

Date Variables: DateRange
DateRange
2010-01-01 2010-07-01

Step 2: Apply your company codes.

MSFT ○ GIVEX ○ CUBIT ○ BIE ○ NAMOS ○ OK ○ GIC Sub-Industry

Select an option for entering company codes

MSFT I
Please enter Company code separated by a space.
Example: WMT MSFT GOOG / Code Lookup]

Browse... No file selected
Upload a plain text file (.txt), having one code per line.

Selected Based On Codes
Choose from your saved codes.

Search the entire database
This method allows you to search the entire database of records. Please be aware that this method can take a very long time to run because it is dependent upon the size of the database.

The query for *OHLC* prices should also include the *split adjustment factor* and the *total return factor*.

Step 3: Query Variables

Step 2: Query

Q Search All	Identifying Information	Identifying Information, cont.	Data Items
<div style="display: flex; justify-content: space-between;"> <div style="flex: 1;"> <p>Select <input checked="" type="checkbox"/> All</p> <ul style="list-style-type: none"> <input type="radio"/> DIVSPAYDATE -- Special Cash Dividends - Daily Payment Date <input type="radio"/> DIVI -- Indicated Annual Dividend - Current <input type="radio"/> DIVRATED -- Indicated Annual Dividend Rate - Daily <input type="radio"/> EPS -- Current EPS <input type="radio"/> EPSSMO -- Current EPS Month <input type="radio"/> IID -- Issue ID - Dividends <input type="radio"/> PAYDATE -- Dividend Payment Date <input type="radio"/> PAYDATEIND -- Dividend Payment Date Indicator <input type="radio"/> PRICSTD -- Price Status Code - Daily <input type="radio"/> RECORDDATE -- Dividend Record Date </div> <div style="flex: 1; text-align: right;"> <p>(24)</p> </div> </div>	<p>Selected <input type="checkbox"/> Clear All</p> <ul style="list-style-type: none"> <input checked="" type="checkbox"/> Company Name <input checked="" type="checkbox"/> Ticker Symbol <input checked="" type="checkbox"/> CUSIP <input checked="" type="checkbox"/> PRCOD -- Price - Open - Daily <input checked="" type="checkbox"/> PRCHD -- Price - High - Daily <input checked="" type="checkbox"/> PRCLD -- Price - Low - Daily <input checked="" type="checkbox"/> PRCCD -- Price - Close - Daily <input checked="" type="checkbox"/> CSHTRD -- Trading Volume - Daily <input checked="" type="checkbox"/> AJEXDI -- Adjustment Factor (Issue)-Cumulative by Ex-Date <input checked="" type="checkbox"/> TRFD -- Daily Total Return Factor 	<p>(10)</p>	

Reading Daily Prices Into R

The time series data downloaded into a .csv file can then be read into R.

But the data downloaded from the *Compustat Daily Prices* database may contain data for several related securities, so it must be properly selected (pruned).

The OHLC prices can be adjusted by dividing them by the *split adjustment factor* and multiplying them by the *total return factor*.

The OHLC prices are also divided by the final *total return factor* so that the most recent adjusted prices are equal to the most recent market prices.

```
> # Read .csv file with TAP OHLC prices
> ohlc <- read.csv(file="/Users/jerzy/Develop/lecture_slides/data/TAP.csv")
> # ohlc contains cusips not in cusipsp500
> cusips <- unique(ohlc$cusip)
> cusips %in% cusipsp500
> # Select data only for cusipsp500
> ohlc <- ohlc[ohlc$cusip %in% cusipsp500, ]
> # ohlc contains tickers not in ticksp500
> tickers <- unique(ohlc$tic)
> tickers %in% ticksp500
> # Select data only for ticksp500
> ohlc <- ohlc[ohlc$tic %in% ticksp500, ]
> # Select ticker from sp500table
> symboln <- sp500table$co_tic[match(ohlc$gvkey[1], sp500table$gvkey)]
> # Adjustment factor and total return factor
> factadj <- drop(ohlc[, "ajexdi"])
> factr <- drop(ohlc[, "trfd"])
> # Extract index of dates
> datev <- drop(ohlc[, "datadate"])
> datev <- lubridate::ymd(datev)
> # Select only OHLCV data columns
> ohlc <- ohlc[, c("prcod", "prchd", "prcld", "prcd", "cshtrd")]
> colnames(ohlc) <- paste(symboln, c("Open", "High", "Low", "Close"))
> # Coerce to xts series
> ohlc <- xts::xts(ohlc, datev)
> # Fill the missing (NA) Open prices
> isna <- is.na(ohlc[, 1])
> ohlc[isna, 1] <- (ohlc[isna, 2] + ohlc[isna, 3])/2
> sum(is.na(ohlc))
> # Adjust all the prices
> ohlc[, 1:4] <- factr*ohlc[, 1:4]/factadj/factr[NROW(factr)]
> ohlc <- na.omit(ohlc)
> plot(quantmod::Cl(ohlc), main="TAP Stock")
```

Function for Reading Daily Prices Into R

The function `format_ohlc()` formats raw data downloaded from *Compustat* into a time series of *OHLC* prices.

```
> # Define formatting function for OHLC prices
> format_ohlc <- function(ohlc, pricenv) {
+   # Select ticker from sp500table
+   symboln <- sp500table$co_tic[match(ohlc$gvkey[1], sp500table$gvkey[1])][1]
+   # Split adjustment and total return factors
+   factadj <- drop(ohlc[, c("ajexdi")])
+   factr <- drop(ohlc[, "trfd"])
+   factr <- ifelse(is.na(factr), 1, factr)
+   # Extract dates index
+   datev <- drop(ohlc[, "datadate"])
+   datev <- lubridate::ymd(datev)
+   # Select only OHLCV data
+   ohlc <- ohlc[, c("prcod", "prchd", "prcld", "prccd", "cshtrd")]
+   colnames(ohlc) <- paste(symboln, c("Open", "High", "Low", "Close"))
+   # Coerce to xts series
+   ohlc <- xts::xts(ohlc, datev)
+   # Fill NA prices
+   isna <- is.na(ohlc[, 1])
+   ohlc[isna, 1] <- (ohlc[isna, 2] + ohlc[isna, 3])/2
+   # Adjust the prices
+   ohlc[, 1:4] <- factr*ohlc[, 1:4]/factadj/factr[NROW(factr)]
+   # Copy the OHLCV data to pricenv
+   ohlc <- na.omit(ohlc)
+   assign(x=symboln, value=ohlc, envir=pricenv)
+   symbol
+ } # end format_ohlc
```

Reading Index Constituent Prices Into R

The prices for all the index constituents are first downloaded from *Compustat* into a single .csv file, and then they are read into R and formatted into a time series of *OHLC* prices.

But the prices downloaded from the *Compustat Daily Prices* database often contain prices for several related securities from the same company, so they must be properly selected (pruned) to match the index constituents.

```
> # Load OHLC prices from .csv file downloaded from WRDS by cusip
> pricesp500 <- read.csv(file="/Users/jerzy/Develop/lecture_slides/cusipsp500.csv")
> # sp500_prices contains cusips not in cusipsp500
> cusips <- unique(sp500_prices$cusip)
> NROW(cusipsp500); NROW(cusips)
> # Select data only for cusipsp500
> pricesp500 <- pricesp500[sp500_prices$cusip %in% cusipsp500, ]
> # sp500_prices contains tickers not in ticksp500
> tickers <- unique(sp500_prices$tic)
> NROW(ticksp500); NROW(tickers)
> # Select data only for ticksp500
> pricesp500 <- pricesp500[sp500_prices$tic %in% ticksp500, ]
> # Create new data environment
> sp500env <- new.env()
> # Perform OHLC aggregations by cusip column
> pricesp500 <- split(pricesp500, sp500_prices$cusip)
> process_ed <- lapply(pricesp500, format_ohlc, pricenv=sp500env)
```

Managing Exceptions in Index Constituent Prices

Some securities of past index constituents may no longer be trading because of corporate events (mergers, bankruptcies, etc.), so they should be removed from the data.

Tickers which contain a dot in their name (like "BRK.B") are not valid symbols in R, so they must be renamed.

The column names for symbol "LOW" (Lowe's company) must be renamed for the extractor function `quantmod::Lo()` to work properly.

```
> # Get end dates of series in sp500env
> endd <- eapply(sp500env, end)
> endd <- unlist(endd)
> endd <- as.Date(endd)
> # Remove elements with short end dates
> ishort <- (endd < max(endd))
> rm(list=names(sp500env)[ishort], envir=sp500env)
> # Rename element "BRK.B" to "BRKB"
> sp500env$BRKB <- sp500env$BRK.B
> rm(BRK.B, envir=sp500env)
> names(sp500env$BRKB) <- paste("BRKB",
+   c("Open", "High", "Low", "Close", "Volume"), sep=".")
> # Rename element "LOW" to "LOWES"
> sp500env$LOWES <- sp500env$LOW
> rm(LOW, envir=sp500env)
> names(sp500env$LOWES) <- paste("LOWES",
+   c("Open", "High", "Low", "Close", "Volume"), sep=".")
> # Rename element "BF.B" to "BFB"
> sp500env$BFB <- sp500env$BF.B
> rm(BF.B, envir=sp500env)
> names(sp500env$BFB) <- paste("BFB",
+   c("Open", "High", "Low", "Close", "Volume"), sep="."))
> # Save OHLC prices to .RData file
> save(sp500env, file="/Users/jerzy/Develop/lecture_slides/data/sp500env.RData")
> plot(quantmod::Cl(sp500env$MSFT))
```

Saving WRDS Queries

WRDS queries can be saved and reused again.

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Industry Specifics Annual

Industry Specifics Quarterly

Pension Annual

Pension Quarterly

Ratings

Security Daily

Security Monthly

Segments (Non-Historical)

Segments (Non-Historical) - Customer

Simplified Financial Statement Extract

Supplemental Short Interest File

Financial Ratios Industry Level

Financial Ratios Firm Level

?on.cfm?nav...

Step 1: Choose your date range

Date Variable: Dateset

Date range: 2010-01-01 to 2020-07-05

Step 2: Apply your company codes

TIC GMEY CUSP SIC NCBS OKC SIC SubIndustry

Select an option for entering company codes

Company Codes

Please enter Company codes separated by a space.
Example: IBM MSFT DELL COMGLOBE

Code Last Name

Save code file in Saved Codes

Browse No file selected
Select a plain text file (.txt), having one code per line.

Select Saved Codes
Choose from your saved codes.

Search the entire database
This method allows you to search the entire database of records. Please be aware that this method can take a very long time to run because it is dependent upon the size of the database.

Step 3: Query Variables.

How does this work?

Q. Search All 693 Identifying Information 95 Identifying Information, cont. 895 Data Items 955

draft: Downloading Fundamental Company Data From Quandl

SEC is a free database of stock fundamentals extracted from SEC and (but not harmonized),

<https://www.quandl.com/data/SEC>

RAYMOND is a free database of harmonized stock fundamentals, based on the *SEC* database,

<https://www.quandl.com/data/RAYMOND>

<https://www.quandl.com/data/RAYMOND?keyword=aapl>

Wharton Research Data Services (*WRDS*) is a distributor of third party data for the academic and research communities.

WRDS provides time series of stock prices and fundamental company data, and other financial, econometric, and social datasets.

WRDS redistributes fundamental company data from *Compustat*, *S&P Capital IQ*, *Thomson Reuters*, *FactSet*, *Hedge Fund Research*, *Markit*, etc.

The Center for Research in Security Prices (*CRSP*) is a provider of historical security prices for the academic and research communities.

Much of the *WRDS* data is free, while premium data can be obtained under a temporary license.

WRDS provides online help and a guide to its datasets:

<https://wrds-www.wharton.upenn.edu>

WRDS provides stock prices, stock fundamentals, financial ratios, zoo::indexes, options and volatility,

```
> library(Quandl) # Load package Quandl
> # Register Quandl API key
> Quandl.api_key("pVJi9Nv3V8CD3Js5s7Qx")
>
> # Quandl stock market data
> # https://blog.quandl.com/stock-market-data-ultimate-guide-part-1
> # https://blog.quandl.com/stock-market-data-the-ultimate-guide-part-2
>
> # Download RAYMOND metadata
> # https://www.quandl.com/data/RAYMOND-Raymond/documentation/metadata
>
> # Download S&P500 Index constituents
> # https://s3.amazonaws.com/static.quandl.com/tickers/SP500.csv
>
> # Download AAPL gross profits from RAYMOND
> profitAAPL <- Quandl("RAYMOND/AAPL_GROSS_PROFIT_Q", type="xts")
> chart_Series(profitAAPL, name="AAPL gross profits")
>
> # Download multiple time series
> priceEV <- Quandl(code=c("NSE/OIL", "WIKI/AAPL"),
+ startd="2013-01-01", type="xts")
>
> # Download datasets for AAPL
> # https://www.quandl.com/api/v3/datasets/WIKI/AAPL.json
>
> # Download metadata for AAPL
> priceEV <- Quandl(code=c("NSE/OIL", "WIKI/AAPL"),
+ startd="2013-01-01", type="xts")
> # https://www.quandl.com/api/v3/datasets/WIKI/AAPL/metadata.json
>
> # scrape fundamental data from Google using quantmod - doesn't work
> funda_mamentals <- getFinancials("HPQ", src="google", auto.assign=FALSE)
> # view quarterly fundamentals
> viewFinancials(funda_mamentals, period="Q")
> viewFinancials(funda_mamentals)
>
> # scrape fundamental data from Yahoo using quantmod
> # table of Yahoo data fields
```

The CRSP Database on WRDS

The Center for Research in Security Prices (*CRSP*) is a provider of historical security prices, and is an affiliate of the University of Chicago Booth School of Business.

CRSP data provides daily prices, but it's updated only monthly, quarterly, and annually.

CRSP provides very long time series of data starting in 1926.

CRSP data is indexed using the *PERMCO* company identifier and the *PERMNO* security identifier.

Since a single company can have many securities, therefore a single *PERMCO* may be linked to multiple *PERMNOs*.

WRDS provides a tool to translate tickers to *PERMCO/PERMNO*:

https://wrds-web.wharton.upenn.edu/wrds/ds/crsp/tools_a/dse/translate/index.cfm

The screenshot shows the top navigation bar of the Wharton WRDS website. It includes links for "WRDS", "WRDS RESEARCH DATA SERVICES", "Get Data", "Analytics", "Classroom", "Research", and "Support". Below the navigation is a search bar labeled "Search WRDS". The main content area is titled "The Center for Research in Security Prices (CRSP)".

The Center for Research in Security Prices (CRSP)

For more about this dataset, see the [Dataset List](#), [Manuals and Overviews](#) or [FAQs](#).

Annual Update

Databases in this section are updated once each year, in early February. Update schedules should not be confused with end-of-day, end-of-month, or end-of-quarter data such as stock prices.

Stock / Security Files		Index / Treasury and Inflation		Tools	
Stock / Events		Index / CRSP Selected Series		Stock-1952 / Security Files	
Stock / Portfolio Assignments		CRSP/Computational Merged		Stock-1952 / Events	
Index / Stock File Indexes		Treasuries		Zrim REIT	
Index / Cap-Based Portfolios		Treasury / Daily (Legacy)		10 Year U.S. Stock	
Index / S&P 500 Indexes		Treasury / Monthly (Legacy)			

Quarterly Update

Databases in this section are updated in February, May, August, and November. Update schedules should not be confused with end-of-day, end-of-month, or end-of-quarter data such as stock prices.

Mutual Funds		Stock-1952 / Events		Index History - Intrady	
Tools		Index / Stock File Indexes		CRSP/Computational Merged	
Stock / Security Files		Index / Cap-Based Portfolios		Treasuries	
Stock / Events		Index / S&P 500 Indexes		Treasury / Daily (Legacy)	
Stock / Portfolio Assignments		Index / Treasury and Inflation		Treasury / Monthly (Legacy)	
Stock-1952 / Security Files		Index / CRSP Selected Series		Zrim REIT	

Monthly Update

Databases in this section are updated around the 12th business day of each month. Update schedules should not be confused with end-of-day, end-of-month, or end-of-quarter data such as stock prices.

Stock / Security Files		Index / Stock File Indexes		CRSP/Computational Merged	
Stock / Events		Index / Cap-Based Portfolios		Treasuries	
Stock / Portfolio Assignments		Index / S&P 500 Indexes		Treasury / Daily (Legacy)	
Stock-1952 / Security Files		Index / Treasury and Inflation		Treasury / Monthly (Legacy)	
Stock-1952 / Events		Index / CRSP Selected Series		Zrim REIT	

Downloading Daily Prices From CRSP

Daily North American security prices can be downloaded from the *CRSP daily* database.

The time series data can be downloaded into a .csv file, and then read into R.

```
> # Specify class for column "TICKER" so that "F" doesn't become FAI
> col_class <- "character"
> names(col_class) <- "TICKER"
> # Read .csv file with Ford OHLC prices
> ohlc <- read.csv(file="/Users/jerzy/Develop/lecture_slides/data/F."
+   colClasses=col_class)
> symboln <- ohlc[, "TICKER"]
> # Adjustment factor
> factadj <- drop(ohlc[, "CFACPR"])
> # Extract dates index
> datev <- drop(ohlc[, "date"])
> datev <- lubridate::ymd(datev)
> # Select only OHLCV data
> ohlc <- ohlc[, c("OPENPRC", "ASKHI", "BIDLO", "PRC", "VOL")]
> colnames(ohlc) <- paste(symboln, c("Open", "High", "Low", "Close"))
> # Coerce to xts series
> ohlc <- xts::xts(ohlc, datev)
> # Fill missing Open NA prices
> isna <- is.na(ohlc[, 1])
> ohlc[isna, 1] <- (ohlc[isna, 2] + ohlc[isna, 3])/2
> # Adjust all the prices
> ohlc[, 1:4] <- ohlc[, 1:4]/factadj/factr[NROW(factr)]
> plot(quantmod::Cl(ohlc), main="Ford Stock")
```

The screenshot shows the Wharton WRDS Intraday Research Data Services interface. At the top, there's a navigation bar with links like 'Home', 'Get Data', 'Analytics', 'Classroom', 'Research', and 'Support'. Below the navigation is a search bar labeled 'Search WRDS'.

The main area is titled 'CRSP Daily Stock'. It displays a message: 'You have 4 saved queries for this dataset.' Below this, there are three steps:

- Step 1: Choose your date range.** A date range selector shows '1929-01-01' to '2019-12-31'.
- Step 2: Apply your company codes.** This section includes a radio button for 'F' (selected) and other options like 'OPEMNO', 'OPRICO', etc. It also has a 'Create List Name' field and a note about saving codes to a list.
- Step 3: Query Variables.** This section shows a dropdown menu with various variables selected, such as 'AdjClose', 'PERMNO', 'PERMCO', 'Market Value', 'NAISI Index', 'Value-Weighted Return (includes distributions)', 'Value-Weighted Return (excluding dividends)', and 'Equal-Weighted Return (includes distributions)'.

draft: The Merged CRSP/Compustat Database

Links:

<http://kaichen.work/?p=138>

<http://www.crsp.org/products/documentation/crsp-link>

<https://mingze-gao.com/posts/merge-compustat-and-crsp/>

<http://www.crsp.org/products/documentation/crspcompmerged-database-guide>

The Center for Research in Security Prices (*CRSP*) is a provider of historical security prices.

CRSP data is indexed using the *PERMCO* company identifier and the *PERMNO* security identifier.

Therefore a given *PERMCO* may be linked to multiple *PERMNOs*.

Compustat provides financial statement data of a company. The micro unit on Compustat is each and every company. However, it is less known that Compustat also provides security data. In addition, because the coverage of Compustat is more extensive than that of *CRSP*, Compustat contains additional security data that are unavailable on *CRSP*.

Compustat uses *IID* and *GVKEY* to identify all securities. A marker item, *PRIMISS*, indicates whether a security is primary or secondary.

Similar to *PERMCO* on *CRSP*, one *GVKEY* may have multiple *IIDs* assigned to it.

Database	Identifier	Description
CRSP	PERMCO	Permanent company identifier.
CRSP	PERMNO	Permanent security identifier. One PERMNO belongs to only one PERMCO. One PERMCO may have one or more PERMNOs.
Compustat	GVKEY	Permanent company identifier.
Compustat	IID	Permanent security identifier. One GVKEY may have multiple IIDs. Both are needed to identify a Compustat security.
Compustat	PRIMISS	Indicator for primary (P) or secondary (J) securities.

draft: Downloading Daily Prices From Merged CRSP/Compustat Database

Daily North American security prices can be downloaded from the *CRSP/Compustat daily* database.

The time series data can be downloaded into a .csv file, and then read into R.

```
> # Read .csv file with TAP OHLC prices
> ohlc <- read.csv(file="/Users/jerzy/Develop/lecture_slides/data/TI")
> symboln <- ohlc[, "tic"]
> # Adjustment factor and total return factor
> factadj <- drop(ohlc[, "ajexdi"])
> factr <- drop(ohlc[, "trfd"])
> # Extract dates index
> datev <- drop(ohlc[, "datadate"])
> datev <- lubridate::ymd(datev)
> # Select only OHLCV data
> ohlc <- ohlc[, c("prcod", "prchd", "prclid", "prccd", "cshtrd")]
> colnames(ohlc) <- paste(symboln, c("Open", "High", "Low", "Close"))
> # Coerce to xts series
> ohlc <- xts::xts(ohlc, datev)
> # Fill missing Open NA prices
> isna <- is.na(ohlc[, 1])
> ohlc[isna, 1] <- (ohlc[isna, 2] + ohlc[isna, 3])/2
> sum(is.na(ohlc))
> # Adjust all the prices
> ohlc[, 1:4] <- factr*ohlc[, 1:4]/factadj/factr[NROW(factr)]
> plot(quantmod::Cl(ohlc), main="TAP Stock")
```

Computstat Daily Updates - Security Daily

You have 3 saved queries for this dataset.

Step 1: Choose your date range.

Date Variable: **datecode**

Date range: to

Step 2: Apply your company codes.

INC GIVNY CUSIP SIC NAMES OGI GIC Sub-Industry

Select an option for entering company codes

MFC1

Please enter Company code separated by a space.
Example: IBM MSFT DELL [Code Listings]

MFC2

No code selected
Upload a plain text file (.txt), having one code per line.

MFC3

Select Saved Codes
Choose from your saved codes.

Search the entire database

This method allows you to search the entire database of records. Please be aware that this method can take a very long time to run because it is dependent upon the size of the database.

Step 3: Query Variables.

How does this work?

	Search All	Name	Identifying Information	Identifying Information, cont.	Data Items
Select	<input checked="" type="checkbox"/> All	(24)	<input type="checkbox"/> Selected	<input type="checkbox"/> Clear All	(10)
UNIVATD – Unadjusted Annual Dividend Rate - Daily	<input type="radio"/>		<input checked="" type="checkbox"/> Company Name		
Paymnt Date Indicator	<input type="radio"/>		<input checked="" type="checkbox"/> Date Range		
UNVSD – Special Cash Dividends - Daily	<input type="radio"/>		<input checked="" type="checkbox"/> CUSIP		
UNVOD – Unadjusted Special Cash Dividends - Daily Payment Date	<input type="radio"/>		<input checked="" type="checkbox"/> AJEXDI – Adjustment Factor (Index)- Cumulative by Ex-Dates		
UNVOD – Unadjusted Special Cash Dividends - Daily	<input type="radio"/>		<input checked="" type="checkbox"/> GIVNY		
UNVATD – Unadjusted Annual Dividend Rate - Daily	<input type="radio"/>		<input checked="" type="checkbox"/> PRCD2 – Price - Close - Daily		
MPB – Current MPB	<input type="radio"/>		<input checked="" type="checkbox"/> PRCD2 – Price High - Daily		
MPBM2 – Current MPB Month	<input type="radio"/>		<input checked="" type="checkbox"/> PRCD2 – Price Low - Daily		
IDI – Index ID - Universe	<input type="radio"/>		<input checked="" type="checkbox"/> PRCD2 – Price - Open - Daily		
			<input checked="" type="checkbox"/> PRCD2 – Daily Total Return Factor		

Downloading Fama-French Factors from Quandl

The Fama/French factors are constructed using six value-weight portfolios formed on size and book-to-market,

<https://www.quandl.com/data/KFRENCH/FACTORS.D>

Mkt-RF is the excess return on the market (value-weighted NYSE, AMEX, and NASDAQ stocks minus the one-month Treasury bill rate).

SMB (Small Minus Big) is the return on the three small-cap portfolios minus the three big-cap portfolios.

HML (High Minus Low) is the return on the two value portfolios minus the two growth portfolios.

```
> # Download Fama-French factors from KFRENCH database
> factors <- Quandl(code="KFRENCH/FACTORS_D",
+   startd="2001-01-01", type="xts")
> dim(factors)
> head(factors)
> tail(factors)
> chart_Series(cumsum(factors["2001/", 1]/100),
+   name="Fama-French factors")
```

Trade and Quote (TAQ) Data

High frequency data is typically formatted as either Trade and Quote (TAQ) data, or Open-High-Low-Close (OHLC) data.

Trade and Quote (TAQ) data contains intraday *trades* and *quotes* on exchange-traded stocks and futures.

TAQ data is often called *tick data*, with a *tick* being a row of data containing new *trades* or *quotes*.

The TAQ data is spaced irregularly in time, with data recorded each time a new trade or quote arrives.

Each row of TAQ data may contain the quote and trade prices, and the corresponding quote size or trade volume: *Bid.Price*, *Bid.Size*, *Ask.Price*, *Ask.Size*, *Trade.Price*, *Volume*.

TAQ data is often split into *trade data* and *quote data*.

```
> # Load package HighFreq  
> library(HighFreq)  
> # Or load the high frequency data file directly:  
> # symbolv <- load("~/Users/jerzy/Develop/R/HighFreq/data/hf_data.RData")  
> head(HighFreq::SPY_TAQ)  
> head(HighFreq::SPY)  
> tail(HighFreq::SPY)
```

Downloading TAQ Data From WRDS

TAQ data can be downloaded from the *WRDS TAQ* web page.

The *TAQ* data are at millisecond frequency, and are *consolidated* (combined) from the New York Stock Exchange *NYSE* and other exchanges.

The *WRDS TAQ* web page provides separately *trades* data and separately *quotes* data.

The screenshot shows the Wharton Research Data Services (WRDS) website interface for the TAQ Millisecond Trade and Quote dataset. The top navigation bar includes links for Home, Get Data, Analytics, Classroom, Research, Support, and Search. Below the navigation, there are tabs for TAQ, Millisecond Trade and Quote, Consolidated Quotes, and Consolidated Trades. The main content area is titled "TAQ - Millisecond Consolidated Trades". A note for users states: "Note to TAQ users: Missing trades in the April 5, 2012 Consolidated Trades dataset. There are roughly 65,000 missing trade records for tickers with initial letters M through R from 08:42 through 10:02:50 on April 5, 2012. NYSE has reported to WRDS that NASDAQ was not disseminating trade reports during that time period. The actual number of trade records (for 'M' through 'R') during that time from NASDAQ (exchange code 'Q') was 2,232, but the average during the rest of the week was 68,274. The missing trades amount to about 12% of total trades in those equities." A message below the note says: "WRDS will provide an update as soon as the files are available." On the left, a sidebar indicates "You have 1 saved query for this dataset." The main form contains three steps: Step 1: Choose your date range (set to Mar 16 2020), Step 2: What Time Range (set to Beginning 00, 30, 00, Ending 15, 00, 00), and Step 3: Apply your company codes (radio button selected for "SYMBOL (use pipe)"). A note under Step 3 says: "Please enter Company codes separated by a space. Example: IBM|MSFT|DELL | CME|LOOK|etc". There is also an option to "Browse" or "No file selected" for company codes, and a checkbox for "Code List Name" which is unchecked. At the bottom right, there are several small icons for navigating between pages.

Reading TAQ Data From .csv Files

Trade and Quote (TAQ) data stored in .csv files can be very large, so it's better to read it using the function `data.table::fread()` which is much faster than the function `read.csv()`.

Each *trade* or *quote* contributes a *tick* (row) of data, and the number of ticks can be very large (hundred of thousands per day, or more).

The function `strptime()` coerces character strings representing the date and time into POSIXlt *date-time* objects.

The argument `format="%H:%M:%OS"` allows the parsing of fractional seconds, for example

"15:59:59.989847074".

The function `as.POSIXct()` coerces objects into `POSIXct` *date-time* objects, with a numeric value representing the *moment of time* in seconds.

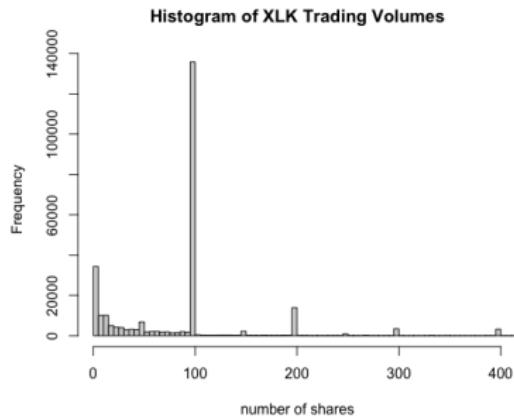
```
> library(HighFreq)
> # Read TAQ trade data from csv file
> taq <- data.table::fread(file="/Users/jerzy/Develop/lecture_slides/taq_1min.csv")
> # Inspect the TAQ data in data.table format
> taq
> class(taq)
> colnames(taq)
> sapply(taq, class)
> symboln <- taq$SYM_ROOT[1]
> # Create date-time index
> datev <- paste(taq$DATE, taq$TIME_M)
> # Coerce date-time index to POSIXlt
> datev <- strptime(datev, "%Y%m%d %H:%M:%OS")
> class(datev)
> # Display more significant digits
> # options("digits")
> options(digits=20, digits.secs=10)
> last(datev)
> unclass(last(datev))
> as.numeric(last(datev))
> # Coerce date-time index to POSIXct
> datev <- as.POSIXct(datev)
> class(datev)
> last(datev)
> unclass(last(datev))
> as.numeric(last(datev))
> # Calculate the number of seconds
> as.numeric(last(datev)) - as.numeric(first(datev))
> # Calculate the number of ticks per second
> NROW(taq)/(6.5*3600)
> # Select TAQ data columns
> taq <- taq[, .(price=PRICE, volume=SIZE)]
```

Trading Volumes in High Frequency Data

The trading volumes represent the number of shares traded at a given price.

The histogram of the trading volumes shows that the highest frequencies of trades are for *round lots* - trades that are multiples of 100 shares.

There are also significant frequencies for *odd lots*, with small volumes of less than 100 shares.



```
> # Coerce trade ticks to xts series  
> xlk <- xts::xts(taq[, .(price, volume)], datev)  
> colnames(xlk) <- c("price", "volume")  
> save(xlk, file="/Users/jerzy/Develop/data/xlk_tick_trades_20200310.RData")  
> # Plot histogram of the trading volumes  
> hist(xlk$volume, main="Histogram of XLK Trading Volumes",  
+       breaks=1e5, xlim=c(1, 400), xlab="number of shares")
```

Microstructure Noise in High Frequency Data

High frequency data contains *microstructure noise* in the form of *price spikes* and the *bid-ask bounce*.

Price spikes are single ticks with prices far away from the average.

Price spikes are often caused by data collection errors, but sometimes they represent actual trades with very large lot (trade) sizes.

The *bid-ask bounce* is the bouncing of traded prices between the bid and ask prices.

The *bid-ask bounce* creates an illusion of rapidly changing prices, while in reality the mid price is unchanged.



```
> # Plot dygraph
> dygraphs::dygraph(xlk$price, main="XLK Intraday Prices for 2020-03-16")
+   dyOptions(colors="blue", strokeWidth=1)
> # Plot in x11 window
> x11(width=6, height=5)
> quantmod::chart_Series(x=xlk$price, name="XLK Intraday Prices for 2020-03-16")
```

The Bid-ask Bounce of High Frequency Prices

The *bid-ask bounce* is the bouncing of traded prices between the bid and ask prices.

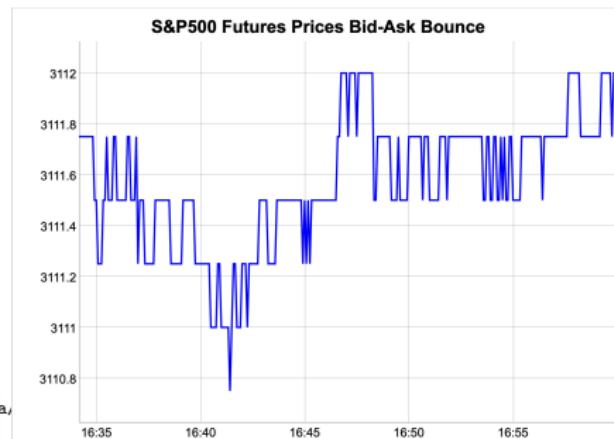
The *bid-ask bounce* is prominent at very high frequency time scales or in periods of low volatility.

The *bid-ask bounce* creates an illusion of rapidly changing prices, while in fact the mid price is constant.

The *bid-ask bounce* inflates the estimates of realized volatility, above the actual volatility.

The *bid-ask bounce* creates the appearance of mean reversion (negative autocorrelation), that isn't tradeable for most traders.

```
> pricev <- read.zoo(file="/Users/jerzy/Develop/lecture_slides/data/  
+   header=TRUE, sep=",")  
> pricev <- as.xts(pricev)  
> dygraphs::dygraph(pricev$Close,  
+   main="S&P500 Futures Prices Bid-Ask Bounce") %>%  
+   dyOptions(colors="blue", strokeWidth=2)
```



Price Spikes And Trading Volumes in High Frequency Data

The number of the *price spikes* depends on the level of trading volumes, with the number decreasing with higher trading volumes.

The number of price spikes is lower for trade prices with larger trading volumes.



```
> # Plot dygraph of trade prices of at least 100 shares
> dygraphs::dygraph(xlk$price[xlk$volume >= 100, ],
+   main="XLK Prices for Trades of At Least 100 Shares") %>%
+   dyOptions(colors="blue", strokeWidth=1)
```

Removing Odd Lot Trades From TAQ Data

The trading volumes represent the number of shares traded at a given price.

The histogram of the trading volumes shows that the highest frequencies of trades are for *round lots* - trades that are multiples of 100 shares.

There are also significant frequencies for *odd lots*, with small volumes of less than 100 shares.

The *odd lot* ticks are often removed to reduce the size of the TAQ data.

Selecting only the large lot trades reduces microstructure noise (price spikes, bid-ask bounce) in high frequency data.

```
> # Select the large trade lots of at least 100 shares
> dim(taq)
> tickb <- taq[taq$volume >= 100]
> dim(tickb)
> # Number of large lot ticks per second
> NROW(tickb)/(6.5*3600)
> # Plot histogram of the trading volumes
> hist(tickb$volume, main="Histogram of XLK Trading Volumes",
+       breaks=100000, xlim=c(1, 400), xlab="number of shares")
> # Save trade ticks with large lots
> data.table::fwrite(tickb, file="/Users/jerzy/Develop/data/xlk_ticks_trades_20200316_diglots.csv")
> # Coerce trade prices to xts
> xlkb <- xts::xts(tickb[, .(price, volume)], tickb$index)
> colnames(xlkb) <- c("price", "volume")
```



```
> # Plot dygraph of the large lots
> dygraphs::dygraph(xlkb$price,
+   main="XLK Prices for Trades of At Least 100 Shares") %>%
+   dyOptions(colors="blue", strokeWidth=1)
> # Plot the large lots
> x11(width=6, height=5)
> quantmod::chart_Series(x=xlkb$price,
+   name="XLK Trade Ticks for 2020-03-16 (large lots only)")
```

draft: Identifying Isolated Price Spikes In Intraday Data

Isolated price spikes in high frequency data can be identified using a *three-point filter* (tri-filter). histogram of returns

The tri-filter compares two price ratios of three neighboring prices:

p_0, p_1, p_2 is a median filter that replaces the central value with the median of the three values. Create three-point classifier for bad prices. Identify bad prices in-sample using

z-scores are equal to the prices minus the median of the prices, divided by the median absolute deviation (*MAD*) of prices:

$$z_i = \frac{p_i - \text{median}(p)}{\text{MAD}}$$

If the absolute value of the *z-score* exceeds the *threshold value* then it's classified as *bad data*, and it can be removed or replaced.

```
> # Calculate the centered Hampel filter to remove bad prices
> lookb <- 71 # Look-back interval
> halfb <- lookb %/% 2 # Half-back interval
> pricev <- xlk$price
> # Calculate the trailing median and MAD
> medianv <- HighFreq::roll_mean(pricev, lookb=lookb, method="nonparam",
+ colnames(medianv) <- c("median")
> madv <- HighFreq::roll_var(pricev, lookb=lookb, method="nonparam",
> # madv <- TTR::runMAD(pricev, n=lookb)
> # Center the median and the MAD
> medianv <- rutils::lagit(medianv, lagg=(-halfb), pad_zeros=FALSE,
> madv <- rutils::lagit(madv, lagg=(-halfb), pad_zeros=FALSE)
> # Calculate the Z-scores
```



```
> # Define discrimination threshold value
> threshv <- 6*madz
> # Identify good prices with small z-scores
> isgood <- (abs(zscores) < threshv)
> # Calculate the number of bad prices
> sum(!isgood)
> # Scrub bad prices by replacing them with previous good prices
> priceg <- pricev
> priceg[!isgood] <- NA
> priceg <- zoo::na.locf(priceg)
> # Plot dygraph of the scrubbed prices
> dygraphs::dygraph(priceg, main="Scrubbed XLK Intraday Prices") %>
+ dyOptions(colors="blue", strokeWidth=1)
> # Plot using chart_Series()
> x11(width=6, height=5)
> quantmod::chart_Series(x=priceg,
+ name="Clean XLK Intraday Prices for 2020-03-16")
```

The Hampel Filter For Filtering Price Spikes

Price spikes in high frequency data can be identified using a *Hampel filter*.

The z-scores are equal to the prices minus the median of the prices, divided by the median absolute deviation (MAD) of prices:

$$z_i = \frac{p_i - \text{median}(p)}{\text{MAD}}$$

If the absolute value of the z-score exceeds the threshold value then it's classified as *bad data*, and it can be removed or replaced.

```
> # Calculate the centered Hampel filter to remove bad prices
> lookb <- 71 # Look-back interval
> halfb <- lookb %/% 2 # Half-back interval
> pricev <- xlk$price
> # Calculate the trailing median and MAD
> medianv <- HighFreq::roll_mean(pricev, lookb=lookb, method="nonparametric")
> colnames(medianv) <- c("median")
> madv <- HighFreq::roll_var(pricev, lookb=lookb, method="nonparametric")
> # madv <- TTR::runMAD(pricev, n=lookb)
> # Center the median and the MAD
> medianv <- rutils::lagit(medianv, lagg=(-halfb), pad_zeros=FALSE)
> madv <- rutils::lagit(madv, lagg=(-halfb), pad_zeros=FALSE)
> # Calculate the Z-scores
> zscores <- ifelse(madv > 0, (pricev - medianv)/madv, 0)
> # Z-scores have very fat tails
> range(zscores); mad(zscores)
> madz <- mad(zscores[abs(zscores) > 0])
> hist(zscores, breaks=50000, xlim=c(-2*madz, 2*madz))
```



```
> # Define discrimination threshold value
> threshv <- 6*madz
> # Identify good prices with small z-scores
> isgood <- (abs(zscores) < threshv)
> # Calculate the number of bad prices
> sum(!isgood)
> # Overwrite bad prices and calculate time series of scrubbed prices
> priceg <- pricev
> priceg[!isgood] <- NA
> priceg <- zoo::na.locf(priceg)
> # Plot dygraph of the scrubbed prices
> dygraphs::dygraph(priceg, main="Scrubbed XLK Intraday Prices") %>
+   dyOptions(colors="blue", strokeWidth=1)
> # Plot using chart_Series()
> x11(width=6, height=5)
> quantmod::chart_Series(x=priceg,
+   name="Clean XLK Intraday Prices for 2020-03-16")
```

Classifying Data Outliers Using the Hampel Filter

The Hampel filter is a *classifier* which classifies the prices as either good or bad data points.

In order to measure the performance of the Hampel filter, we add price spikes to the clean prices, to see how accurately they're classified.

Let the *null hypothesis* be that the given price is a good data point.

A positive result corresponds to rejecting the *null hypothesis*, while a negative result corresponds to accepting the *null hypothesis*.

The classifications are subject to two different types of errors: *type I* and *type II* errors.

A *type I error* is the incorrect rejection of a TRUE *null hypothesis* (i.e. a "false positive"), when good data is classified as bad.

A *type II error* is the incorrect acceptance of a FALSE *null hypothesis* (i.e. a "false negative"), when bad data is classified as good.

```
> # Add 200 random price spikes to the clean prices
> set.seed(1121, "Mersenne-Twister", sample.kind="Rejection")
> nspikes <- 200
> nrows <- NROW(priceg)
> ispike <- logical(nrows)
> ispike[sample(x=nrows, size=nspikes)] <- TRUE
> priceb <- priceg
> priceb[ispike] <- priceb[ispike]*
+   sample(c(0.999, 1.001), size=nspikes, replace=TRUE)
> # Plot the bad prices and their medians
> medianv <- HighFreq::roll_mean(priceb, lookb=lookb, method="nonparametric")
> pricem <- cbind(priceb, medianv)
> colnames(pricem) <- c("prices with spikes", "median")
> dygraphs::dygraph(pricem, main="XLK Prices With Spikes") %>%
+   dyOptions(colors=c("red", "blue"))
> # Calculate the z-scores
> madv <- HighFreq::roll_var(priceb, lookb=lookb, method="nonparametric")
> zscores <- ifelse(madv > 0, (priceb - medianv)/madv, 0)
> # Z-scores have very fat tails
> range(zscores); mad(zscores)
> madz <- mad(zscores[abs(zscores) > 0])
> hist(zscores, breaks=10000, xlim=c(-4*madz, 4*madz))
> # Identify good prices with small z-scores
> thresh <- 3*madz
> isgood <- (abs(zscores) < thresh)
> # Calculate the number of bad prices
> sum(!isgood)
```

Confusion Matrix of a Binary Classification Model

A *binary classification model* categorizes cases based on its forecasts whether the *null hypothesis* is TRUE or FALSE.

The confusion matrix summarizes the performance of a classification model on a set of test data for which the actual values of the *null hypothesis* are known.

		Forecast	
		Null is FALSE	Null is TRUE
Actual	Null is FALSE	True Positive (sensitivity)	False Negative (type II error)
	Null is TRUE	False Positive (type I error)	True Negative (specificity)

```
> # Calculate the confusion matrix
> table(actual=!ispoke, forecast=isgood)
> sum(!isgood)
> # FALSE positive (type I error)
> sum(!ispoke & !isgood)
> # FALSE negative (type II error)
> sum(ispoke & isgood)
```

Let the *null hypothesis* be that the given price is a good data point.

The *true positive rate* (known as the *sensitivity*) is the fraction of FALSE *null hypothesis* cases that are correctly classified as FALSE.

The *false negative rate* is the fraction of FALSE *null hypothesis* cases that are incorrectly classified as TRUE (type II error).

The sum of the *true positive* plus the *false negative* rate is equal to 1.

The *true negative rate* (known as the *specificity*) is the fraction of TRUE *null hypothesis* cases that are correctly classified as TRUE.

The *false positive rate* is the fraction of TRUE *null hypothesis* cases that are incorrectly classified as FALSE (type I error).

The sum of the *true negative* plus the *false positive* rate is equal to 1.

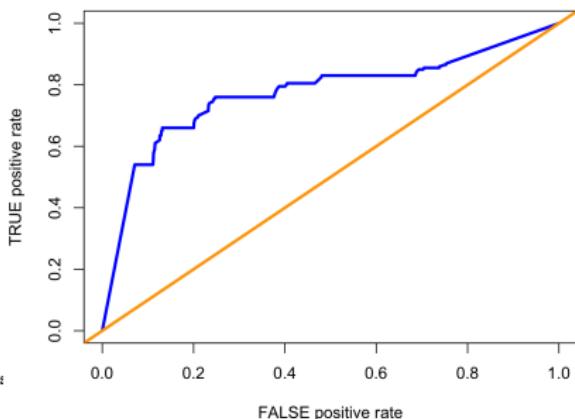
Receiver Operating Characteristic (ROC) Curve

The *ROC curve* is the plot of the *true positive rate*, as a function of the *false positive rate*, and illustrates the performance of a binary classifier.

The area under the *ROC curve* (AUC) measures the classification ability of a binary classifier.

```
> # Confusion matrix as function of threshold
> confun <- function(actualv, zscores, threshv) {
+   confmat <- table(actualv, (abs(zscores) < threshv))
+   confmat <- confmat / rowSums(confmat)
+   ctypeI=confmat[2, 1], typeII=confmat[1, 2])
+ } # end confun
> confun(!ispike, zscores, threshv=threshv)
> # Define vector of discrimination thresholds
> threshv <- madz*seq(from=0.1, to=3.0, by=0.05)/2
> # Calculate the error rates
> errorr <- sapply(threshv, confun, actualv=!ispike, zscores=zscores)
> errorr <- t(errorr)
> rownames(errorr) <- threshv
> errorr <- rbind(c(1, 0), errorr)
> errorr <- rbind(errorr, c(0, 1))
> # Calculate the area under the ROC curve (AUC)
> truepos <- (1 - errorr[, "typeII"])
> truepos <- (truepos + rutils::lagit(truepos))/2
> falsepos <- rutils::diffit(errorr[, "typeI"])
> abs(sum(truepos*falsepos))
```

ROC Curve for Hampel Classifier



```
> # Plot ROC curve for Hampel classifier
> plot(x=errorr[, "typeI"], y=1-errorr[, "typeII"],
+       xlab="FALSE positive rate", ylab="TRUE positive rate",
+       xlim=c(0, 1), ylim=c(0, 1),
+       main="ROC Curve for Hampel Classifier",
+       type="l", lwd=3, col="blue")
> abline(a=0.0, b=1.0, lwd=3, col="orange")
```

Filtering Bad Data From Daily Stock Prices

Daily stock prices can also contain bad data points consisting of mostly single, isolated spikes in prices.

The number of false positives may be too high, so the Hampel filter parameters (the look-back interval and the threshold) need adjustment.

For example, the VXX has only one bad price (on 2010-11-08), but the Hampel filter identifies many more than that (which are false positives).

```

> # Load log VXX prices
> load("/Users/jerzy/Develop/lecture_slides/data/pricevxx.RData")
> nrow <- NROW(pricev)
> # Calculate the centered Hampel filter for VXX
> lookb <- 7 # Look-back interval
> halfb <- lookb %% 2 # Half-back interval
> medianv <- HighFreq::roll_mean(pricev, lookb=lookb, method="nonparametric")
> medianv <- rutils::lagit(medianv, lagg=(-halfb), pad_zeros=FALSE)
> madv <- HighFreq::roll_var(pricev, lookb=lookb, method="nonparametric")
> madv <- rutils::lagit(madv, lagg=(-halfb), pad_zeros=FALSE)
> zscores <- ifelse(madv > 0, (pricev - medianv)/madv, 0)
> range(zscores); mad(zscores)
> madz <- mad(zscores[abs(zscores) > 0])
> hist(zscores, breaks=100, xlim=c(-3*madz, 3*madz))
> # Define discrimination threshold value
> threshv <- 9*madz
> # Calculate the good prices
> isgood <- (abs(zscores) < threshv)
> sum(!isgood)
> # Dates of the bad prices
> zscore$index[!isgood]

```



```

> # Calculate the false positives
> falsep <- !isgood
> falsep[which(zoo:::index(pricev) == as.Date("2010-11-08"))] <- FALSE
> # Plot dygraph of the prices with bad prices
> datam <- cbind(pricev, zscores)
> colnames(datam)[2] <- "ZScores"
> colv <- colnames(datam)
> dygraphs::dygraph(datam, main="VXX Prices With Z-Scores and False
+ dyAxis("y", label=colv[1], independentTicks=TRUE) %>%
+ dyAxis("y2", label=colv[2], independentTicks=TRUE) %>%
+ dySeries(name=colv[1], axis="y", strokeWidth=1, col="blue") %>%
+ dySeries(name=colv[2], axis="y2", strokeWidth=1, col="red") %>%
+ dyEvent(zoo:::index(pricev[falsep]), label=rep("false"), sum(falsep))
+ dyEvent(zoo:::index(pricev["2010-11-08"]), label="true", strokeP

```

draft: Filtering Combined Spikes From Stock Prices

The narrow Hampel filter isn't very good anyway

The narrow Hampel filter using the median of 3 prices can only identify single isolated spikes.

But sometimes several bad prices occur in a row, one after another.

The narrow Hampel filter cannot identify multiple bad prices in a row, and will therefore produce false negatives (bad prices identified as good).

```
> # Add single isolated spike to the prices
> priceb <- pricev
> priceb["2017-11-20"] <- 1.2*priceb["2017-11-20"]
> # Calculate the Z-scores
> medianv <- HighFreq::roll_mean(priceb, lookb=lookb, method="nonparametric")
> medianv <- rutils::lagit(medianv, lagg=(-halfb), pad_zeros=FALSE)
> madv <- HighFreq::roll_var(priceb, lookb=lookb, method="nonparametric")
> madv <- rutils::lagit(madv, lagg=(-halfb), pad_zeros=FALSE)
> zscores <- ifelse(madv > 0, (priceb - medianv)/madv, 0)
> madz <- mad(zscores[abs(zscores) > 0])
> # Calculate the number of bad prices
> threshv <- 9*madz
> isgood <- (abs(zscores) < threshv)
> sum(!isgood)
> zoo::index(priceb[!isgood])
> # Add two neighboring spikes to the prices
> priceb <- pricev
> priceb["2017-11-20"] <- 1.2*priceb["2017-11-21"]
> priceb["2017-11-21"] <- 1.2*priceb["2017-11-21"]
> # Calculate the Z-scores
> medianv <- HighFreq::roll_mean(priceb, lookb=lookb, method="nonparametric")
> medianv <- rutils::lagit(medianv, lagg=(-halfb), pad_zeros=FALSE)
> madv <- HighFreq::roll_var(priceb, lookb=lookb, method="nonparametric")
> madv <- rutils::lagit(madv, lagg=(-halfb), pad_zeros=FALSE)
> zscores <- ifelse(madv > 0, (priceb - medianv)/madv, 0)
> madz <- mad(zscores[abs(zscores) > 0])
> # Calculate the number of bad prices
> isgood <- (abs(zscores) < threshv)
> sum(!isgood)
> zoo::index(priceb[!isgood])
```

Scrubbing Bad Stock Prices

Bad stock prices can be scrubbed (replaced) with the previous good price.

But it's incorrect to replace bad prices with the average of the previous good price and the next good price, since that would cause data snooping.

```
> # Replace bad stock prices with the previous good prices
> priceg <- pricev
> priceg[!isgood] <- NA
> priceg <- zoo::na.locf(priceg)
> # Calculate the Z-scores
> medianv <- HighFreq::roll_mean(priceg, lookb=lookb, method="nonparametric")
> medianv <- rutils::lagit(medianv, lagg=(-halfb), pad_zeros=FALSE)
> madv <- HighFreq::roll_var(priceg, lookb=lookb, method="nonparametric")
> madv <- rutils::lagit(madv, lagg=(-halfb), pad_zeros=FALSE)
> zscores <- ifelse(madv > 0, (priceg - medianv)/madv, 0)
> madz <- mad(zscores[abs(zscores) > 0])
> # Calculate the number of bad prices
> threshv <- 9*madz
> isgood <- (abs(zscores) < threshv)
> sum(!isgood)
> zoo::index(priceg[!isgood])
```

Scrubbed VXX Prices With False Positives



```
> # Calculate the false positives
> falsep <- !isgood
> falsep[which(zoo::index(priceg) == as.Date("2010-11-08"))] <- FALSE
> # Plot dygraph of the prices with bad prices
> dygraphs::dygraph(priceg, main="Scrubbed VXX Prices With False Positives")
+ dyEvent(zoo::index(priceg[falsep]), label=rep("false", sum(falsep)))
+ dyOptions(colors="blue", strokeWidth=1)
```

ROC Curve for Daily Hampel Classifier

In order to measure the performance of the Hampel filter, we add price spikes to the clean prices, to see how accurately they're classified.

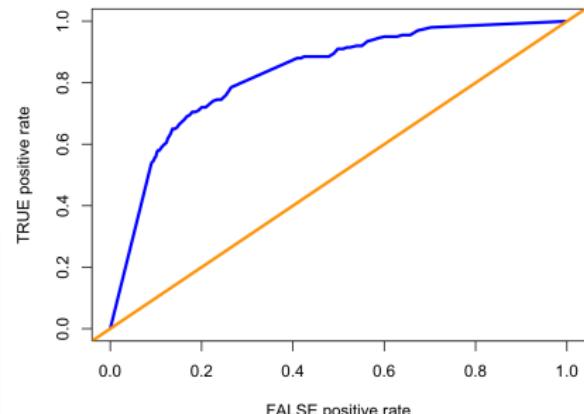
The performance of the Hampel noise classification model depends on the length of the look-back time interval.

The optimal *look-back interval* and *threshold value* can be determined using *cross-validation*.

```
> # Add 200 random price spikes to the clean prices
> set.seed(1121, "Mersenne-Twister", sample.kind="Rejection")
> nspikes <- 200
> ispike <- logical(nrows)
> ispike[sample(x=nrows, size=nspikes)] <- TRUE
> priceb <- priceg
> priceb[ispike] <- priceb[ispike]*
+   sample(c(0.99, 1.01), size=nspikes, replace=TRUE)
> # Calculate the Z-scores
> medianv <- HighFreq::roll_mean(priceb, lookb=lookb, method="nonparametric")
> medianv <- rutils::lagit(medianv, lagg=(-halfb), pad_zeros=FALSE)
> madv <- HighFreq::roll_var(priceb, lookb=lookb, method="nonparametric")
> madv <- rutils::lagit(madv, lagg=(-halfb), pad_zeros=FALSE)
> zscores <- ifelse(madv > 0, (priceb - medianv)/madv, 0)
> madz <- mad(zscores[abs(zscores) > 0])
> # Define vector of discrimination thresholds
> threshv <- madz*seq(from=0.1, to=3.0, by=0.05)/2
> # Calculate the error rates
> errorr <- sapply(threshv, confun, actualv=!ispike, zscores=zscore)
> errorr <- t(errorr)
> rownames(errorr) <- threshv
> errorr <- rbind(c(1, 0), errorr)
> errorr <- rbind(errorr, c(0, 1))

> # Calculate the area under the ROC curve (AUC)
> truepos <- (1 - errorr[, "typeII"])
> truepos <- (truepos + rutils::lagit(truepos))/2
> falsepos <- rutils::diffit(errorr[, "typeI"])
> abs(sum(truepos*falsepos))
> # Plot ROC curve for Hampel classifier
> plot(x=errorr[, "typeI"], y=1-errorr[, "typeII"],
+       xlab="FALSE positive rate", ylab="TRUE positive rate",
+       xlim=c(0, 1), ylim=c(0, 1),
+       main="ROC Curve for Daily Hampel Classifier",
+       type="l", lwd=3, col="blue")
> abline(a=0.0, b=1.0, lwd=3, col="orange")
```

ROC Curve for Daily Hampel Classifier



Aggregating TAQ Data to OHLC

The *data table* columns can be aggregated over categories (factors) defined by one or more columns passed to the "by" argument.

Multiple *data table* columns can be referenced by passing a list of names specified by the dot .() operator.

The function `round.POSIXt()` rounds date-time objects to seconds, minutes, hours, days, months or years.

The function `as.POSIXct()` coerces objects to class `POSIXct`.

```
> # Round time index to seconds
> tickg[, zoo::index := as.POSIXct(round.POSIXt(index, "secs"))]
> # Aggregate to OHLC by seconds
> ohlc <- tickg[, .(open=first(price), high=max(price), low=min(price))]
> # Round time index to minutes
> tickg[, zoo::index := as.POSIXct(round.POSIXt(index, "mins"))]
> # Aggregate to OHLC by minutes
> ohlc <- tickg[, .(open=first(price), high=max(price), low=min(price))]
```



```
> # Coerce OHLC prices to xts
> ohlc <- xts::xts(ohlc[, -"index"], ohlc$index)
> # Plot dygraph of the OHLC prices
> dygraphs::dygraph(ohlc[, -5], main="XLK Trade Ticks for 2020-03-16")
+   dyCandlestick()
> # Plot the OHLC prices
> x11(width=6, height=5)
> quantmod::chart_Series(x=ohlc, TA="add_Vo()", 
+   name="XLK Trade Ticks for 2020-03-16 (OHLC)")
```

draft: Trade and Quote (TAQ) Data

Trade and Quote (TAQ) Data

The NYSE TAQ set is 'consolidated' meaning that the trades and quotes come from many exchanges, including the NASDAQ system. TAQ has all trades and quotes from the Consolidated Tape / Consolidated Quote, which includes data from the regional exchanges. (See

<https://www.tradeearca.com/marketdata/intermarket.aspx> for a brief discussion of CTA/CQ and OTC/UTP.)

[https://wrds-](https://wrds-www.wharton.upenn.edu/pages/support/research-wrds/research-guides/wrds-taq-faqs/)

[www.wharton.upenn.edu/pages/support/research-wrds/research-guides/wrds-taq-faqs/](https://wrds-www.wharton.upenn.edu/pages/support/research-wrds/research-guides/wrds-taq-faqs/)

High frequency data is typically formatted as either Trade and Quote (TAQ) data, or *Open-High-Low-Close (OHLC)* data.

Trade and Quote (TAQ) data contains intraday trades and quotes on exchange-traded stocks and futures.

The TAQ data is spaced irregularly in time, with data recorded each time a new trade or quote arrives.

Each row of TAQ data contains both the quote and trade prices, and the corresponding quote size or trade volume.

Each row of TAQ data contains both the quote and trade prices, and the corresponding quote size or trade volume: *Bid.Price*, *Bid.Size*, *Ask.Price*, *Ask.Size*, *Trade.Price*, *Volume*.

	Bid.Price	Bid.Size	Ask.Price	Ask.Size	Trade.Price	SPY.Open	SPY.High	SPY.Low	SPY.Close	SPY.Volume
2014-05-02 00:00:01	188	1	189	15	189	147	147	147	147	591203
2014-05-02 08:00:01	188	1	189	5	189	147	147	147	147	385457
2014-05-02 08:00:02	189	1	189	5	189	147	147	147	147	343700
2014-05-02 08:01:13	188	1	189	5	189	147	147	147	147	863418
2014-05-02 08:01:29	188	1	189	5	189	147	147	147	147	457500
2014-05-02 08:01:52	189	2	189	5	189	147	147	147	147	416708
> head(HighFreq::SPY)										
	SPY.Open	SPY.High	SPY.Low	SPY.Close	SPY.Volume					
2008-01-02 09:31:00	147	147	147	147	591203					
2008-01-02 09:32:00	147	147	147	147	385457					
2008-01-02 09:33:00	147	147	147	147	343700					
2008-01-02 09:34:00	147	147	147	147	863418					
2008-01-02 09:35:00	147	147	147	147	457500					
2008-01-02 09:36:00	147	147	147	147	416708					
> tail(HighFreq::SPY)										
	SPY.Open	SPY.High	SPY.Low	SPY.Close	SPY.Volume					
2014-05-19 15:56:00	189	189	189	189	321321					
2014-05-19 15:57:00	189	189	189	189	299474					
2014-05-19 15:58:00	189	189	189	189	261357					
2014-05-19 15:59:00	189	189	189	189	435886					
2014-05-19 16:00:00	189	189	189	189	1824185					
2014-05-19 16:01:00	189	189	189	189	63920					

Open-High-Low-Close (*OHLC*) Data

*Open-High-Low-Close (*OHLC*)* data contains intraday trade prices and trade volumes.

OHLC data is evenly spaced in time, with each row containing the *Open*, *High*, *Low*, *Close* prices, and the trade *Volume*, recorded over the past time interval (called a *bar* of data).

The *Open* and *Close* prices are the first and last trade prices recorded in the time bar.

The *High* and *Low* prices are the highest and lowest trade prices recorded in the time bar.

The *Volume* is the total trading volume recorded in the time bar.

The *OHLC* data format provides a way of efficiently compressing *TAQ* data, while preserving information about price levels, volatility (range), and trading volumes.

In addition, evenly spaced *OHLC* data allows for easier analysis of multiple time series, since the prices for different assets are given at the same moments in time.

```
> # Load package HighFreq  
> library(HighFreq)  
> head(HighFreq::SPY)
```

	SPY.Open	SPY.High	SPY.Low	SPY.Close	SPY.Volume
2008-01-02 09:31:00	147	147	147	147	591203
2008-01-02 09:32:00	147	147	147	147	385457
2008-01-02 09:33:00	147	147	147	147	343700
2008-01-02 09:34:00	147	147	147	147	863418
2008-01-02 09:35:00	147	147	147	147	457500
2008-01-02 09:36:00	147	147	147	147	416708

Plotting High Frequency OHLC Data

Aggregating high frequency *TAQ* data into *OHLC* format with lower periodicity allows for data compression while maintaining some information about volatility.

```
> # Load package HighFreq
> library(HighFreq)
> # Define symbol
> symboln <- "SPY"
> # Load OHLC data
> dirout <- "/Users/jerzy/Develop/data/hfreq/scrub/"
> symboln <- load(file.path(dirout, paste0(symboln, ".RData")))
> interval <-"2013-11-11 09:30:00/2013-11-11 10:30:00"
> chart_Series(SPY[interval], name=symboln)
```

The package *HighFreq* contains both *TAQ* data and *Open-High-Low-Close (OHLC)* data.

If you are not able to install package *HighFreq* then download the file *hf_data.RData* from the NYU share drive and load it.



Package *HighFreq* for Managing High Frequency Data

The package *HighFreq* contains functions for managing high frequency time series data, such as:

- converting *TAQ* data to *OHLC* format,
- chaining and joining time series,
- scrubbing bad data,
- managing time zones and aligning time indices,
- aggregating data to lower frequency (periodicity),
- calculating rolling aggregations (VWAP, Hurst exponent, etc.),
- calculating seasonality aggregations,
- estimating volatility, skewness, and higher moments,

```
> # Install package HighFreq from github
> devtools::install_github(repo="algoquant/HighFreq")
> # Load package HighFreq
> library(HighFreq)
> # Get documentation for package HighFreq
> # Get short description
> packageDescription(HighFreq)
> # Load help page
> help(package=HighFreq)
> # List all datasets in HighFreq
> data(package=HighFreq)
> # List all objects in HighFreq
> ls("package:HighFreq")
> # Remove HighFreq from search path
> detach("package:HighFreq")
```

draft: Package HighFreq for Managing High Frequency Data

Package HighFreq contains functions for managing high frequency *TAQ* and *OHLC* market data:

- reading and writing data from files,
- managing time zones and aligning indices,
- chaining and joining time series,
- scrubbing bad data points,
- converting *TAQ* data to *OHLC* format,
- aggregating data to lower frequency,

HighFreq is inspired by the package `highfrequency`, and follows many of its conventions.

HighFreq depends on packages `xts`, `quantmod`, `lubridate`, and `caTools`.

The function `scrub_agg()` scrubs a single day of *TAQ* data, aggregates it, and converts it to *OHLC* format.

The function `save_scrub_agg()` loads, scrubs, aggregates, and binds multiple days of *TAQ* data for a single symbol, and saves the *OHLC* time series to a single `*.RData` file.

```
> # Install package HighFreq from github
> install.packages("devtools")
> library(devtools)
> install_github(repo="algoquant/HighFreq")
> # Load package HighFreq
> library(HighFreq)
> # Set data directories
> dirin <- "/Users/jerzy/Develop/data/hfreq/src/"
> dirout <- "/Users/jerzy/Develop/data/hfreq/scrub/"
> # Define symbol
> symboln <- "SPY"
> # Load a single day of TAQ data
> symboln <- load(file.path(dirin, paste0(symboln, "/2014.05.02.")))
> # Scrub, aggregate single day of TAQ data to OHLC
> ohlc_data <- scrub_agg(taq_data=get(symboln))
> # Aggregate TAQ data for the symbol, and save to file
> HighFreq::save_scrub_agg(symboln,
+                           dirin=dirin,
+                           dirout=dirout,
+                           period="minutes")
```

Datasets in Package *HighFreq*

The package *HighFreq* contains several high frequency time series, in *xts* format, stored in a file called `hf_data.RData`:

- a time series called `SPY_TAQ`, containing a single day of *TAQ* data for the *SPY* ETF.
- three time series called `SPY`, `TLT`, and `VXX`, containing intraday 1-minute *OHLC* price bars for the *SPY*, *TLT*, and *VXX* ETFs.

Even after the *HighFreq* package is loaded, its datasets aren't loaded into the workspace, so they aren't listed in the workspace.

That's because the datasets in package *HighFreq* are set up for *lazy loading*, which means they can be called as if they were loaded, even though they're not loaded into the workspace.

The datasets in package *HighFreq* can be loaded into the workspace using the function `data()`.

The data is set up for *lazy loading*, so it doesn't require calling `data(hf_data)` to load it into the workspace before calling it.

```
> # Load package HighFreq
> library(HighFreq)
> # You can see SPY when listing objects in HighFreq
> ls("package:HighFreq")
> # You can see SPY when listing datasets in HighFreq
> data(package=HighFreq)
> # But the SPY dataset isn't listed in the workspace
> ls()
> # HighFreq datasets are lazy loaded and available when needed
> head(HighFreq::SPY)
> # Load all the datasets in package HighFreq
> data(hf_data)
> # HighFreq datasets are now loaded and in the workspace
> head(HighFreq::SPY)
```

Distribution of High Frequency Returns

High frequency returns exhibit *large negative skewness* and *very large kurtosis* (leptokurtosis), or fat tails.

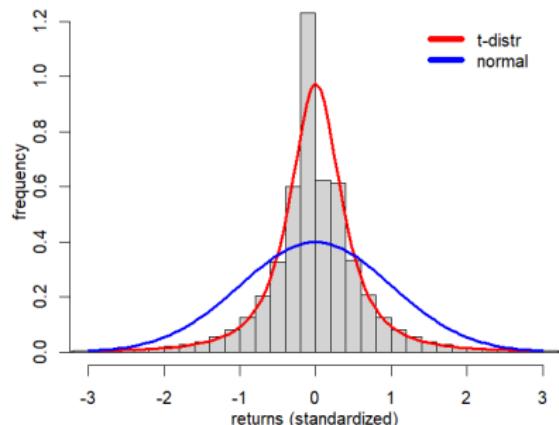
Student's *t-distribution* has fat tails, so it fits high frequency returns much better than the normal distribution.

The function `fitdistr()` from package *MASS* fits a univariate distribution into a sample of data, by performing *maximum likelihood* optimization.

The function `hist()` calculates and plots a histogram, and returns its data *invisibly*.

```
> # Calculate SPY percentage returns
> ohlc <- HighFreq::SPY
> nrows <- NROW(ohlc)
> closep <- log(quantmod::Cl(ohlc))
> retp <- rutils::diffit(closep)
> colnames(retp) <- "SPY"
> # Standardize raw returns to make later comparisons
> retp <- (retp - mean(retp))/sd(retp)
> # Calculate moments and perform normality test
> sapply(c(var=2, skew=3, kurt=4), function(x) sum(retp^x)/nrows)
> tseries::jarque.bera.test(retp)
> # Fit SPY returns using MASS::fitdistr()
> optiml <- MASS::fitdistr(retp, densfun="t", df=2)
> loc <- optiml$estimate[1]
> scalev <- optiml$estimate[2]
```

Distribution of High Frequency SPY Returns



```
> # Plot histogram of SPY returns
> histp <- hist(retp, col="lightgrey", mgpc=c(2, 1, 0),
+   xlab="returns (standardized)", ylab="frequency", xlim=c(-3, 3),
+   breaks=1e3, freq=FALSE, main="Distribution of High Frequency SPY
> # lines(density(retp, bw=0.2), lwd=3, col="blue")
> # Plot t-distribution function
> curve(expr=dt((x-loc)/scalev, df=2)/scalev,
+   type="l", lwd=3, col="red", add=TRUE)
> # Plot the Normal probability distribution
> curve(expr=dnorm(x, mean=mean(retp),
+   sd=sd(retp)), add=TRUE, lwd=3, col="blue")
> # Add legend
> legend("topright", inset=0.05, bty="n",
+   leg=c("t-distr", "normal"), y.intersp=0.1,
+   lwd=6, lty=1, col=c("red", "blue"))
```

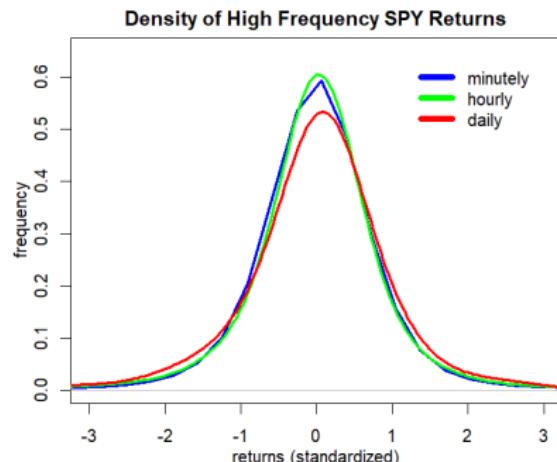
Distribution of Aggregated High Frequency Returns

The distribution of returns depends on the sampling frequency.

High frequency returns aggregated to a lower periodicity become less negatively skewed and less fat tailed, and closer to the normal distribution.

The function `xts::to.period()` converts a time series to a lower periodicity (for example from hourly to daily periodicity).

```
> # Hourly SPY percentage returns
> closep <- log(Cl(xts::to.period(x=ohlc, period="hours")))
> retsh <- rutils::diffit(closep)
> retsh <- (retsh - mean(retsh))/sd(retsh)
> # Daily SPY percentage returns
> closep <- log(Cl(xts::to.period(x=ohlc, period="days")))
> retd <- rutils::diffit(closep)
> retd <- (retd - mean(retd))/sd(retd)
> # Calculate moments
> sapply(list(minutely=retp, hourly=retsh, daily=retd),
+         function(rets) {sapply(c(var=2, skew=3, kurt=4),
+                               function(x) mean(rets^x))})
+ }) # end supply
```



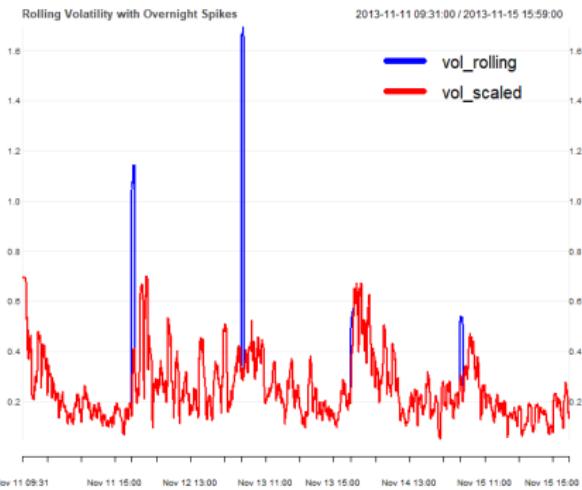
```
> # Plot densities of SPY returns
> plot(density(retp, bw=0.4), xlim=c(-3, 3),
+       lwd=3, mgp=c(2, 1, 0), col="blue",
+       xlab="returns (standardized)", ylab="frequency",
+       main="Density of High Frequency SPY Returns")
> lines(density(retsh, bw=0.4), lwd=3, col="green")
> lines(density(retd, bw=0.4), lwd=3, col="red")
> # Add legend
> legend("topright", inset=0.05, bty="n",
+        leg=c("minutely", "hourly", "daily"), y.intersp=0.1,
+        lwd=6, lty=1, col=c("blue", "green", "red"))
```

Estimating Rolling Volatility of High Frequency Returns

The volatility of high frequency returns can be inflated by large overnight returns.

The large overnight returns can be scaled down by dividing them by the overnight time interval.

```
> # Calculate rolling volatility of SPY returns
> ret2013 <- rtp["2013-11-11/2013-11-15"]
> # Calculate rolling volatility
> lookb <- 11 # Look-back interval
> endd <- seq_along(ret2013)
> startp <- c(rep_len(1, lookb),
+   endd[1:(NROW(endd)-lookb)])
> endd[endd < lookb] <- lookb
> vol_rolling <- sapply(seq_along(endd),
+   function(it) sd(ret2013[startp[it]:endd[it]]))
> vol_rolling <- xts::xts(vol_rolling, zoo::index(ret2013))
> # Extract time intervals of SPY returns
> indeks <- c(60, diff(xts::index(ret2013)))
> head(indeks)
> table(indeks)
> # Scale SPY returns by time intervals
> ret2013 <- 60*ret2013/indeks
> # Calculate scaled rolling volatility
> vol_scaled <- sapply(seq_along(endd),
+   function(it) sd(ret2013[startp[it]:endd[it]]))
> vol_rolling <- cbind(vol_rolling, vol_scaled)
> vol_rolling <- na.omit(vol_rolling)
> sum(is.na(vol_rolling))
> sapply(vol_rolling, range)
```



```
> # Plot rolling volatility
> x11(width=6, height=5)
> plot_theme <- chart_theme()
> plot_theme$col$line.col <- c("blue", "red")
> chart_Series(vol_rolling, theme=plot_theme,
+   name="Rolling Volatility with Overnight Spikes")
> legend("topright", legend=colnames(vol_rolling),
+   inset=0.1, bg="white", lty=1, lwd=6, y.intersp=0.1,
+   col=plot_theme$col$line.col, bty="n")
```

Daily Volume and Volatility of High Frequency Returns

Trading volumes typically rise together with market price volatility.

The function `apply.daily()` from package `xts` applies functions to time series over daily periods.

The function `calc.var.ohlc()` from package `HighFreq` calculates the variance of an *OHLC* time series using range estimators.

```
> # Volatility of SPY
> sqrt(HighFreq::calcvar.ohlc(ohlc))
> # Daily SPY volatility and volume
> volatd <- sqrt(xts::apply.daily(ohlc, FUN=calcvar.ohlc))
> colnames(volatd) <- ("SPY_volatility")
> volumv <- quantmod::Vo(ohlc)
> volumd <- xts::apply.daily(volumv, FUN=sum)
> colnames(volumd) <- ("SPY_volume")
> # Plot SPY volatility and volume
> datav <- cbind(volatd, volumd)[2008/2009]
> colv <- colnames(datav)
> dygraphs::dygraph(datav,
+   main="SPY Daily Volatility and Trading Volume") %>%
+   dyAxis("y", label=colv[1], independentTicks=TRUE) %>%
+   dyAxis("y2", label=colv[2], independentTicks=TRUE) %>%
+   dySeries(name=colv[1], axis="y", col="red", strokeWidth=3) %>%
+   dySeries(name=colv[2], axis="y2", col="blue", strokeWidth=3)
```



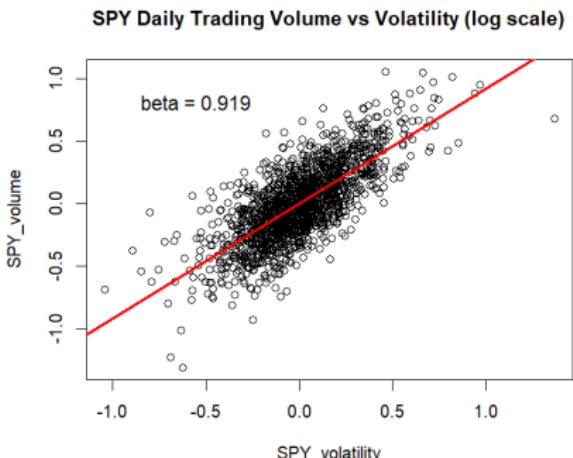
Beta of Volume vs Volatility of High Frequency Returns

As a general empirical rule, the *trading volume* v in a given time period is roughly proportional to the *volatility* of the returns σ : $v \propto \sigma$.

The regression of the *log trading volume* versus the *log volatility* fails the *Durbin-Watson test* for the autocorrelation of residuals.

But the regression of the *differences* passes the *Durbin-Watson test*.

```
> # Regress log of daily volume vs volatility
> datav <- log(cbind(volumd, volatd))
> colv <- colnames(datav)
> dframe <- as.data.frame(datav)
> formulav <- as.formula(paste(colv, collapse=""))
> regmod <- lm(formulav, data=dframe)
> regmod <- lm(formulav, data=dframe)
> # Durbin-Watson test for autocorrelation of residuals
> lmtest::dwtest(regmod)
> # Regress diff log of daily volume vs volatility
> dframe <- as.data.frame(rutils::diffit(datav))
> regmod <- lm(formulav, data=dframe)
> lmtest::dwtest(regmod)
> summary(regmod)
> plot(formulav, data=dframe, main="SPY Daily Trading Volume vs Volatility (log scale)")
> abline(regmod, lwd=3, col="red")
> mtext(paste("beta =", round(coef(regmod)[2], 3)), cex=1.2, lwd=3, side=2, las=2, adj=(-0.5), padj=(-7))
```

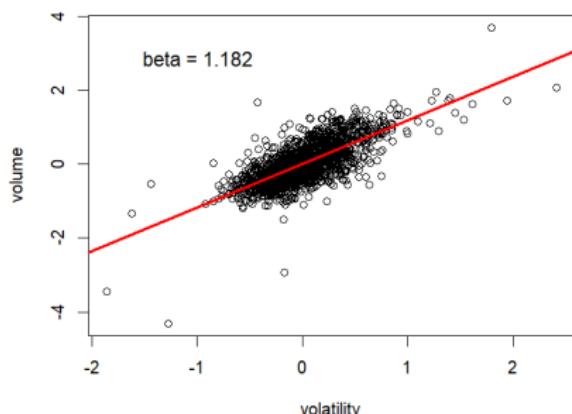


Beta of Hourly Trading Volume vs Volatility

Hourly aggregations of high frequency data also support the rule that the *trading volume* is roughly proportional to the *volatility* of the returns: $v \propto \sigma$.

```
> # 60 minutes of data in lookb interval
> lookb <- 60 # Look-back interval
> vol2013 <- volum["2013"]
> ret2013 <- rtp["2013"]
> # Define end points with beginning stub
> nrows <- NROW(ret2013)
> nagg <- nrows %/% lookb
> endd <- nrows-lookb*nagg + (0:nagg)*lookb
> startp <- c(1, endd[1:(NROW(endd)-1)])
> # Calculate SPY volatility and volume
> datav <- sapply(seq.along(endd), function(it) {
+   endp <- startp[it]:endd[it]
+   c(volume=sum(vol2013[endp]),
+     volatility=sd(ret2013[endp]))
+ }) # end sapply
> datav <- t(datav)
> datav <- rutils::diffit(log(datav))
> dframe <- as.data.frame(datav)
```

SPY Hourly Trading Volume vs Volatility (log scale)



```
> formulav <- as.formula(paste(colnames(datav), collapse="~"))
> regmod <- lm(formulav, data=dframe)
> lmtest::dwtest(regmod)
> summary(regmod)
> plot(formulav, data=dframe,
+       main="SPY Hourly Trading Volume vs Volatility (log scale)")
> abline(regmod, lwd=3, col="red")
> mtext(paste("beta =", round(coef(regmod)[2], 3)), cex=1.2, lwd=3,
```

High Frequency Returns in Trading Time

The *trading time* (volume clock) is the time measured by the level of *trading volume*, with the *volume clock* running faster in periods of higher *trading volume*.

The time-dependent volatility of high frequency returns (*heteroskedasticity*) produces their *leptokurtosis* (large kurtosis, or fat tails).

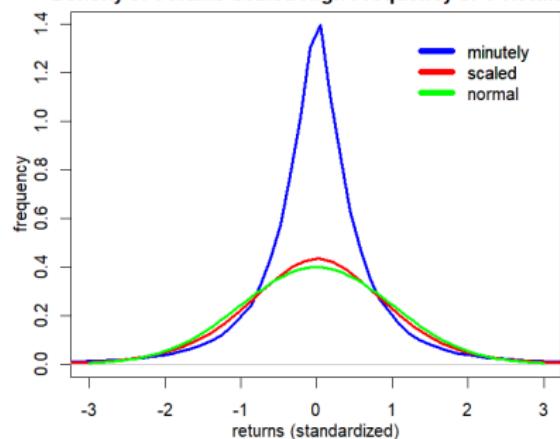
The returns can be divided by the *square root of the trading volumes* to obtain scaled returns over equal trading volumes.

But the returns should not be divided by very small volumes below a certain threshold.

The scaled returns have a smaller *skewness* and *kurtosis*, and they also have even higher autocorrelations than unscaled returns.

```
> # Scale returns using volume (volume clock)
> retsc <- ifelse(volumv > 1e4, retp/sqrt(volumv), 0)
> retsc <- retsc/sd(retsc)
> # Calculate moments of scaled returns
> nrows <- NROW(retp)
> supply(list(retp=retp, retsc=retsc),
+   function(rets) {sapply(c(skew=3, kurt=4),
+     function(x) sum((rets/sd(rets))^x)/nrows)
+ }) # end supply
```

Density of Volume-scaled High Frequency SPY Returns



```
> x11(width=6, height=5)
> par(mar=c(3, 3, 2, 1), oma=c(1, 1, 1, 1))
> # Plot densities of SPY returns
> plot(density(retp), xlim=c(-3, 3),
+       lwd=3, mgp=c(2, 1, 0), col="blue",
+       xlab="returns (standardized)", ylab="frequency",
+       main="Density of Volume-scaled High Frequency SPY Returns")
> lines(density(retsc, bw=0.4), lwd=3, col="red")
> curve(expr=dnorm, add=TRUE, lwd=3, col="green")
> # Add legend
> legend("topright", inset=0.05, bty="n", y.intersp=0.1,
+   leg=c("minutely", "scaled", "normal"),
+   lwd=6, lty=1, col=c("blue", "red", "green"))
```

Autocorrelations of High Frequency Returns

The *Ljung-Box* test, tests if the autocorrelations of a time series are *statistically significant*.

The *null hypothesis* of the *Ljung-Box* test is that the autocorrelations are equal to zero.

The *Ljung-Box* statistic is small for time series that have *statistically insignificant* autocorrelations.

The function `Box.test()` calculates the *Ljung-Box* test and returns the test statistic and its p-value.

For *minutely SPY* returns, the *Ljung-Box* statistic is large and its *p*-value is very small, so we can conclude that *minutely SPY* returns have statistically significant autocorrelations.

For *scaled minutely SPY* returns, the *Ljung-Box* statistic is even larger, so its autocorrelations are even more statistically significant.

SPY returns aggregated to longer time intervals are less autocorrelated.

```
> # Ljung-Box test for minutely SPY returns
> Box.test(retp, lag=10, type="Ljung")
> # Ljung-Box test for daily SPY returns
> Box.test(retd, lag=10, type="Ljung")
> # Ljung-Box test statistics for scaled SPY returns
> sapply(list(retp=retp, retsc=retsc),
+         function(rets) {
+           Box.test(rets, lag=10, type="Ljung")$statistic
+ }) # end sapply
> # Ljung-Box test statistics for aggregated SPY returns
> sapply(list(minutely=retp, hourly=retsh, daily=retd),
+         function(rets) {
+           Box.test(rets, lag=10, type="Ljung")$statistic
+ }) # end sapply
```

The level of the autocorrelations depends on the sampling frequency, with higher frequency returns having more significant negative autocorrelations.

As the returns are aggregated to a lower periodicity, they become less autocorrelated, with daily returns having almost insignificant autocorrelations.

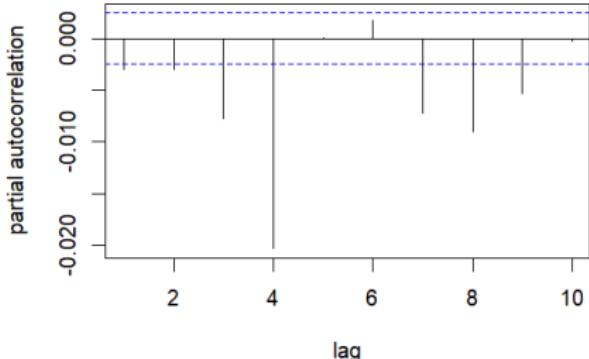
Partial Autocorrelations of High Frequency Returns

High frequency minutely SPY returns have statistically significant negative autocorrelations.

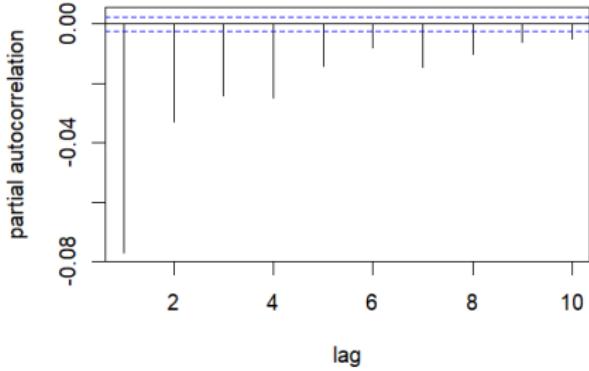
SPY returns *scaled* by the trading volumes have even more significant negative autocorrelations.

```
> # Set plot parameters
> x11(width=6, height=8)
> par(mar=c(4, 4, 2, 1), oma=c(0, 0, 0, 0))
> layout(matrix(c(1, 2), ncol=1), widths=c(6, 6), heights=c(4, 4))
> # Plot the partial autocorrelations of minutely SPY returns
> pacfl <- pacf(as.numeric(retp), lag=10,
+                 xlab="lag", ylab="partial autocorrelation", main="")
> title("Partial Autocorrelations of Minutely SPY Returns", line=1)
> # Plot the partial autocorrelations of scaled SPY returns
> pacfs <- pacf(as.numeric(retsc), lag=10,
+                 xlab="lag", ylab="partial autocorrelation", main="")
> title("Partial Autocorrelations of Scaled SPY Returns", line=1)
> # Calculate the sums of partial autocorrelations
> sum(pacfl$acf)
> sum(pacfs$acf)
```

Partial Autocorrelations of Minutely SPY Returns



Partial Autocorrelations of Scaled SPY Returns



Market Liquidity, Trading Volume and Volatility

Market illiquidity is defined as the market price impact resulting from supply-demand imbalance.

Market liquidity \mathcal{L} is proportional to the square root of the *trading volume* v divided by the price volatility σ :

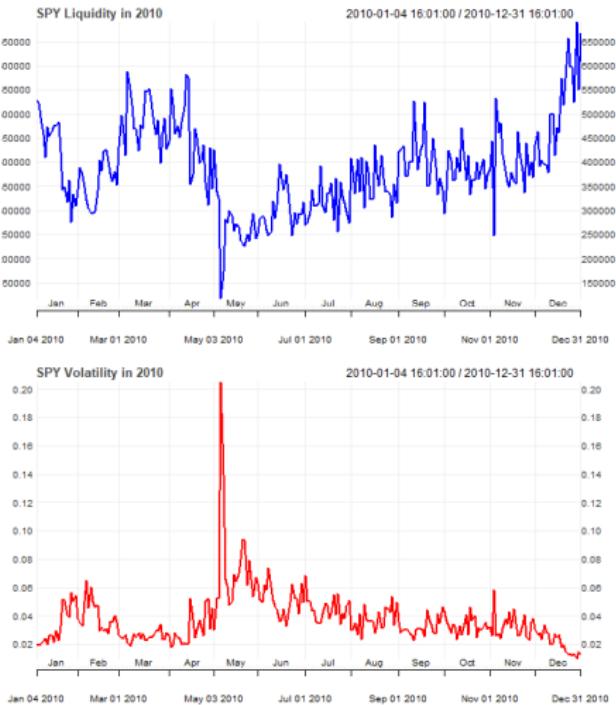
$$\mathcal{L} \sim \frac{\sqrt{v}}{\sigma}$$

Market illiquidity spiked during the May 6, 2010 *flash crash*.

Research suggests that market crashes are caused by declining market liquidity:

Donier et al., Why Do Markets Crash?

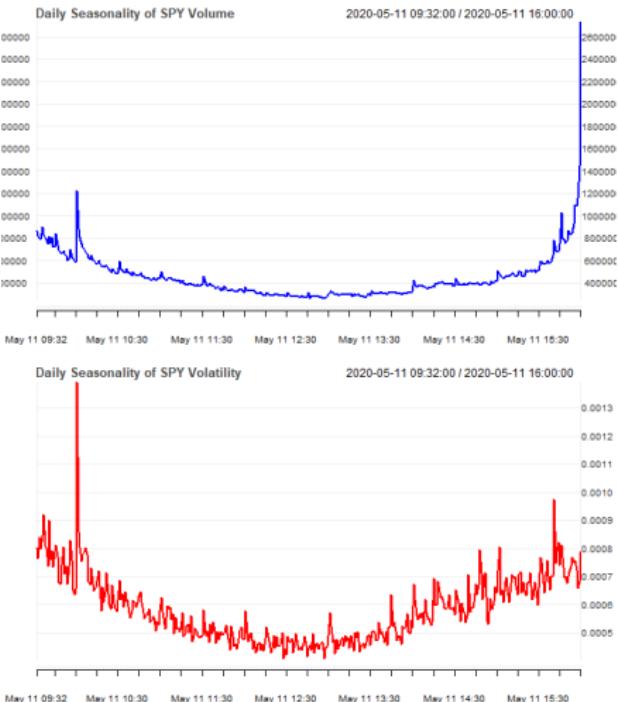
```
> # Calculate market illiquidity
> liquidv <- sqrt(volumd)/volatd
> # Plot market illiquidity
> x11(width=6, height=7) ; par(mfrow=c(2, 1))
> plot_theme <- chart_theme()
> plot_theme$col$line.col <- c("blue")
> chart_Series(liquidv["2010"], theme=plot_theme,
+   name="SPY Liquidity in 2010", plot=FALSE)
> plot_theme$col$line.col <- c("red")
> chart_Series(volatd["2010"]),
+   theme=plot_theme, name="SPY Volatility in 2010")
```



Intraday Seasonality of Volume and Volatility

The volatility and trading volumes are typically higher at the beginning and end of the trading sessions.

```
> # Calculate intraday time index with hours and minutes
> datev <- format(zoo::index(retp), "%H:%M")
> # Aggregate the mean volume
> volumagg <- tapply(X=volumv, INDEX=datev, FUN=mean)
> volumagg <- drop(volumagg)
> # Aggregate the mean volatility
> volagg <- tapply(X=retp^2, INDEX=datev, FUN=mean)
> volagg <- sqrt(drop(volagg))
> # Coerce to xts
> datev <- as.POSIXct(paste(Sys.Date(), names(volumagg)))
> volumagg <- xts::xts(volumagg, datev)
> volagg <- xts::xts(volagg, datev)
> # Plot seasonality of volume and volatility
> x11(width=6, height=7) ; par(mfrow=c(2, 1))
> plot_theme <- chart_theme()
> plot_theme$col$line.col <- c("blue")
> chart_Series(volumagg[c(-1, -NROW(volumagg))], theme=plot_theme,
+   name="Intraday Seasonality of SPY Volume", plot=FALSE)
> plot_theme$col$line.col <- c("red")
> chart_Series(volagg[c(-1, -NROW(volagg))], theme=plot_theme,
+   name="Intraday Seasonality of SPY Volatility")
```

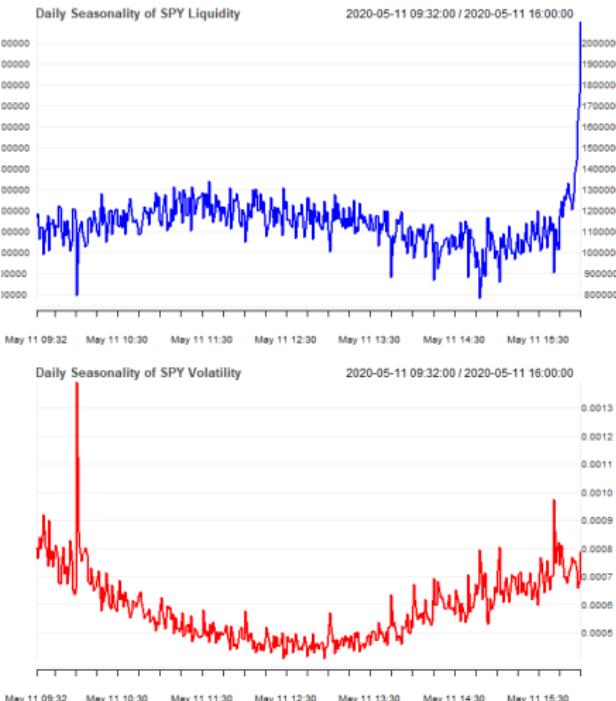


Intraday Seasonality of Liquidity and Volatility

Market liquidity is typically the highest at the end of the trading session, and the lowest at the beginning.

The end of day spike in trading volumes and liquidity is driven by computer-driven investors liquidating their positions.

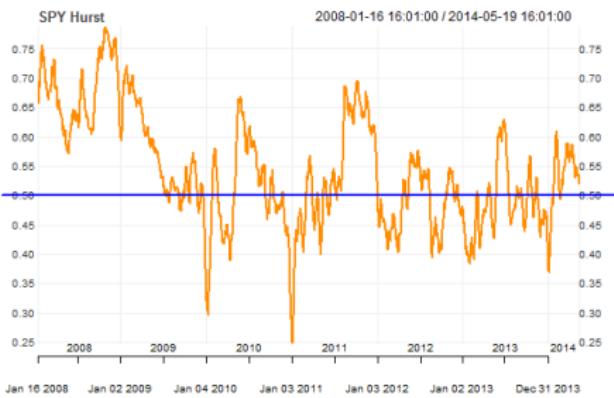
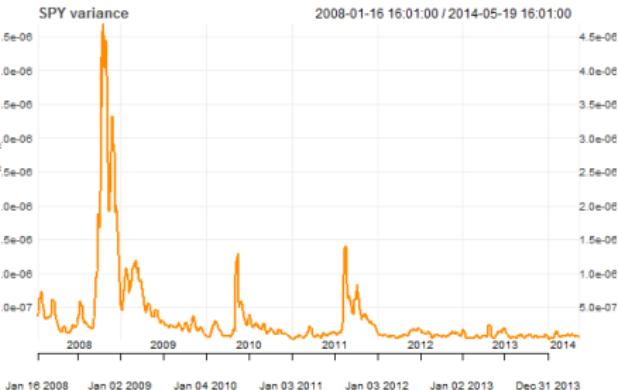
```
> # Calculate market liquidity
> liquidv <- sqrt(volumagg)/volagg
> # Plot intraday seasonality of market liquidity
> x11(width=6, height=7) ; par(mfrow=c(2, 1))
> plot_theme <- chart_theme()
> plot_theme$col$line.col <- c("blue")
> chart_Series(liquidv[c(-1, -NROW(liquidv))], theme=plot_theme,
+   name="Intraday Seasonality of SPY Liquidity", plot=FALSE)
> plot_theme$col$line.col <- c("red")
> chart_Series(volagg[c(-1, -NROW(volagg))], theme=plot_theme,
+   name="Intraday Seasonality of SPY Volatility")
```



draft: Daily Volatility and Hurst Exponent

The Hurst exponent typically moves higher with higher market price volatility, and is above 0.5 with high volatility.

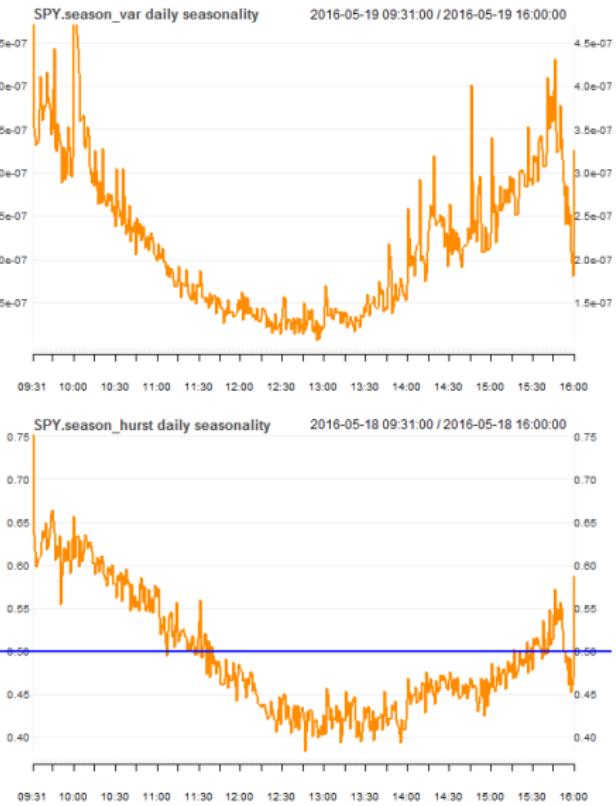
```
> chart_Series(roll_sum(volatd, 10)[-1:10])/10, name=paste(symboln  
> chart_Series(roll_sum(hurstd, 10)[-1:10])/10, name=paste(symboln  
> abline(h=0.5, col="blue", lwd=2)
```



draft: Intraday Seasonality of Hurst Exponent and Volatility

The Hurst exponent typically moves higher with higher market price volatility, and is above 0.5 with high volatility.

```
> # Intraday seasonality of Hurst exponent
> interval <- "2013"
> season_hurst <- season_ality(hurst_ohlc(ohlc=SPY[interval, 1:4]))
> season_hurst <- season_hurst[-(nrow(season_hurst))]
> colnames(season_hurst) <- paste0(colname(get(symboln)), ".season_")
> plot_theme <- chart_theme()
> plot_theme$format.labels <- "%H:%M"
> chobj <- chart_Series(x=season_hurst,
+   name=paste(colnames(season_hurst),
+   "intraday seasonality"), theme=plot_theme,
+   plot=FALSE)
> ylim <- chobj$get_ylim()
> ylim[[2]] <- structure(c(ylim[[2]][1],
+   ylim[[2]][2]), fixed=TRUE)
> chobj$set_ylim(ylim)
> plot(chobj)
> abline(h=0.5, col="blue", lwd=2)
> # Intraday seasonality of volatility
> season_var <- season_ality(vol_ohlc(ohlc=SPY))
```



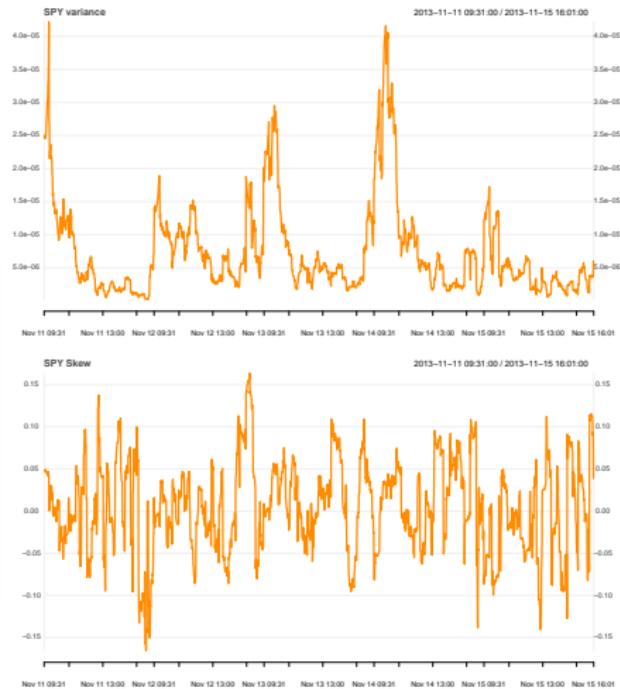
draft: Estimating Skew From OHLC Data

The function `skew_ohlc()` from package `HighFreq` calculates a skew-like indicator:

$$s^3 = \frac{1}{n} \sum_{i=1}^n ((H_i - O_i)(H_i - C_i)(H_i - 0.5(O_i + C_i)) + (L_i - O_i)(L_i - C_i)(L_i - 0.5(O_i + C_i)))$$

The function `roll_agg_ohlc()` aggregates rolling, volume weighted moment estimators.

```
> library(rutils) # Load package rutils
> # Rolling variance
> varv <- roll_agg_ohlc(ohlc=SPY, agg_fun="vol_ohlc")
> # Rolling skew
> skewn <- roll_agg_ohlc(ohlc=SPY, agg_fun="skew_ohlc")
> skewn <- skewn/(varv)^{1.5}
> skewn[1, ] <- 0
> skewn <- zoo::na.locf(skewn)
> interval <- "2013-11-11/2013-11-15"
> chart_Series(varv[interval],
+               name=paste(symboln, "variance"))
> chart_Series(skewn[interval],
+               name=paste(symboln, "Skew"),
+               ylim=c(-1, 1))
```



draft: Daily Volatility and Skew From OHLC Data

The function `agg_ohlc()` calculates a statistical estimator over an *OHLC* time series.

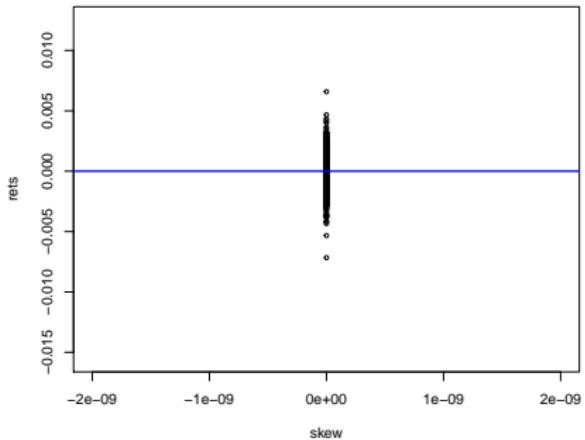
```
> # Daily variance and skew
> volatd <- xts::apply.daily(x=HighFreq::SPY, FUN=agg_ohlc,
+   agg_fun="vol_ohlc")
> colnames(volatd) <- paste0(symboln, ".var")
> daily_skew <- xts::apply.daily(x=HighFreq::SPY, FUN=agg_ohlc,
+   agg_fun="skew_ohlc")
> daily_skew <- daily_skew/(volatd)^{(1.5)}
> colnames(daily_skew) <- paste0(symboln, ".skew")
> interval <- "2013-06-01/"
> chart_Series(volatd[interval],
+   name=paste(symboln, "variance"))
> chart_Series(daily_skew[interval],
+   name=paste(symboln, "skew"))
```



draft: Regression of Skews Versus Returns

A regression of lagged skews versus returns appears to be statistically significant, especially in periods of high volatility during the financial crisis of 2008–09.

```
> rtp <- calc_rets(xts_data=SPY)
> skewn <- skew_ohlc(log_ohlc=log(SPY[, -5]))
> colnames(skewn) <- paste0(symboln, ".skew")
> skewl <- rutils::lag_it(skewn)
> skewl[1, ] <- 0
> datav <- cbind(rtp[, 1], sign(skewl))
> formulav <- as.formula(paste(colnames(datav)[1],
+     paste(paste(colnames(datav)[-1],
+       collapse=" + "), "- 1"), sep=""))
> formulaav
> regmod <- lm(formulav, data=datav)
> summary(regmod)$coef
> summary(lm(formulav, data=datav["/2011-01-01"]))$coef
> summary(lm(formulav, data=datav["2011-01-01"]))$coef
```



```
> interval <- "2013-12-01/"
> plot(formulav, data=datav[interval],
+       xlim=c(-2e-09, 2e-09),
+       cex=0.6, xlab="skew", ylab="rets")
> abline(regmod, col="blue", lwd=2)
```

draft: Contrarian Strategy Using Skew Oscillator

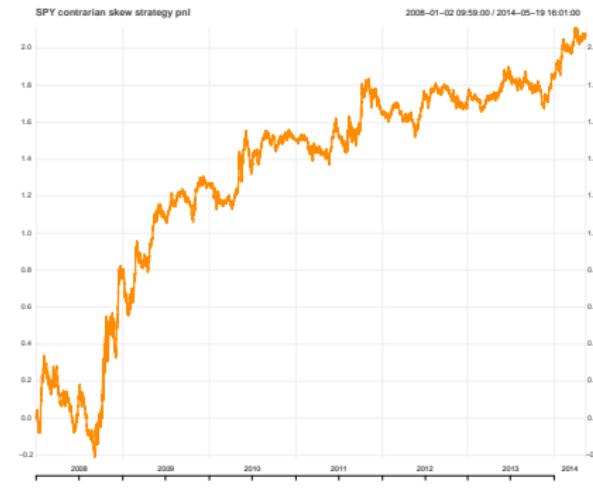
The contrarian skew trading strategy involves long or short positions in a single unit of stock, that is opposite to the sign of the skew.

Skew is calculated over one-minute bars, and trades are executed in the following period.

The contrarian strategy shows good hypothetical performance before transaction costs, and since it's a liquidity providing strategy, should have very low transaction costs.

The contrarian strategy is hyperactive, trading almost 46% of the time in each period.

```
> # Lag the skew to get positions
> posit <- -sign(skewl)
> posit[1, ] <- 0
> # Cumulative PnL
> pnl <- cumsum(posit*retpl[, 1])
> # Calculate frequency of trades
> 50*sum(abs(sign(skewn)-sign(skewl)))/nrow(skewn)
> # Calculate transaction costs
> bidask <- 0.001 # 10 bps for liquid ETFs
> bidask*sum(abs(sign(skewn)-sign(skewl)))
```



```
> chart_Series(pnl[endpoints(pnl, on="hours"), ],
+   name=paste(symboln, "Contrarian Skew Strategy PnL"))
```

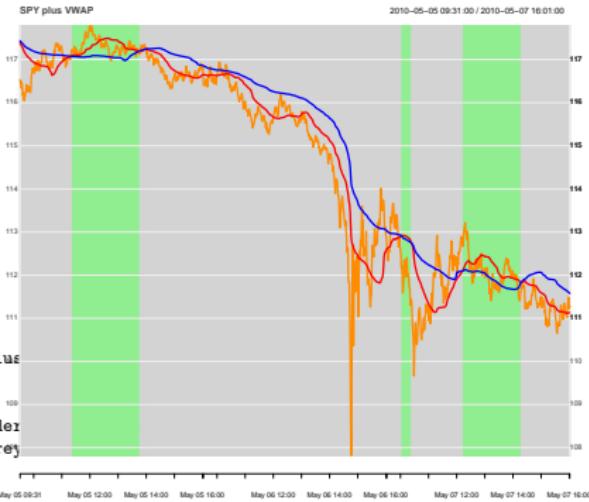
draft: Volume-Weighted Average Price Indicator

The Volume-Weighted Average Price (**VWAP**) is an indicator used for trend following strategies.

The fast-moving **VWAP** is calculated over a short look-back interval, while the slow-moving **VWAP** is calculated over a longer interval.

The trend following reverses direction when the fast-moving **VWAP** crosses the slow-moving one.

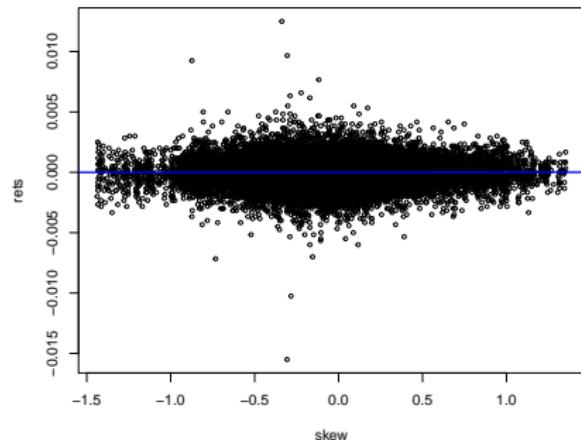
```
> vwapf <- vwapv(xtsv=SPY, lookb=70)
> vwaps <- vwapv(xtsv=SPY, lookb=225)
> vwapd <- vwapf - vwaps
> colnames(vwapd) <- paste0(symboln, ".vwap")
> interval <- "2010-05-05/2010-05-07"
> invisible(chart_Series(x=C1(SPY[interval]), name=paste(symboln, "plus"
> invisible(add_TA(vwapf[interval], on=1, col="red", lwd=2))
> invisible(add_TA(vwaps[interval], on=1, col="blue", lwd=2))
> invisible(add_TA(vwapd[interval] > 0, on=-1, col="lightgreen", border
> add_TA(vwapd[interval] < 0, on=-1, col="lightgrey", border="lightgrey")
```



draft: Regression of VWAP Versus Returns

A regression of the VWAP indicator versus returns appears to be statistically significant.

```
> lag_vwap <- rutils::lag_it(vwapd)
> lag_vwap[1, ] <- 0
> datav <- cbind(retp[, 1], sign(lag_vwap))
> formulav <- as.formula(paste(colnames(datav)[1],
+     paste(paste(colnames(datav)[-1],
+         collapse=" + "), "- 1"), sep="~"))
> formulav
> regmod <- lm(formulav, data=datav)
> summary(regmod)$coef
> summary(lm(formulav, data=datav["/2011-01-01"]))$coef
> summary(lm(formulav, data=datav["2011-01-01/"]))$coef
```



```
> interval <- "2013-12-01/"
> plot(formulav, data=cbind(retp[, 1], lag_vwap)[interval],
+       cex=0.6, xlab="skew", ylab="rets")
> abline(regmod, col="blue", lwd=2)
```

draft: Trend Following Strategy Using VWAP

The trend following trading strategy involves long or short positions in a single unit of stock, that is equal to the sign of the *VWAP* indicator.

The *VWAP* indicator is calculated over one-minute bars, and trades are executed in the following period.

The trend following strategy shows good hypothetical performance before transaction costs.

The trend following strategy is infrequent, trading only 0.56% of the time in each period.

```
> # Cumulative PnL
> pnl <- cumsum(sign(lag_vwap)*retpl[, 1])
> # Calculate frequency of trades
> 50*sum(abs(sign(vwapd)-sign(lag_vwap)))/nrow(vwapd)
> # Calculate transaction costs
> bidask <- 0.001 # 10 bps for liquid ETFs
> bidask*sum(abs(sign(vwapd)-sign(lag_vwap)))
```



```
> chart_Series(
+   pnl[endpoints(pnl, on="hours"), ],
+   name=paste(symbolin, "VWAP Trend Following Strategy PnL"))
```

draft: Estimating Hurst Exponent From OHLC Data

The Hurst exponent is a measure of long-term memory of a time series, and is related to its autocorrelation:

$$\mathbb{E}\left[\frac{(\max(p) - \min(p))}{\hat{\sigma}}\right] = t^H$$

$H = 0.5$ for Brownian motion (no autocorrelations),
 $H > 0.5$ for positive autocorrelations,
 $H < 0.5$ for negative autocorrelations.

The function `hurst_ohlc()` from package `HighFreq` calculates a Hurst-like indicator:

$$H = \frac{1}{n} \sum_{i=1}^n \log\left(\frac{H_i - L_i}{\text{abs}(C_i - O_i)}\right)$$

The function `agg_ohlc()` calculates a statistical estimator over an *OHLC* time series.



```
> # Daily Hurst exponents
> hurstd <- xts::apply.daily(x=HighFreq::SPY, FUN=agg_ohlc, agg.fun=hurst)
> colnames(hurstd) <- paste(colname(get(symbol)), ".Hurst")
> chart_Series(roll_sum(hurstd, 10)[-1:10])/10, name=paste(symbol,
> abline(h=0.5, col="blue", lwd=2)
```

draft: Conclusion

Open questions:

- is there an interaction between volatility, volume and skew?
- does kurtosis also have predictive value for market direction?
- how can higher moments (skew, kurtosis) help predict market crashes?
- what is the persistence of market anomalies over time?
- what is relationship between returns and cross-section of skew?
- This presentation is available on GitHub: <https://github.com/algoquant/presentations>

Acknowledgements:



- Snowfall Systems provides the *PortfolioEffect* system for:
 - real-time high frequency market data aggregations and risk metrics,
 - real-time portfolio analytics and optimization,
 - portfolio hosting,
 - <https://www.portfolioeffect.com/>
- Brian Peterson for Thomson Reuters tick data,
- Brian Peterson, Joshua Ulrich, and Jeffrey Ryan for packages *xts*, *quantmod*, *PerformanceAnalytics*, and *TTR*,

Package *IBrokers* for Using Interactive Brokers

Interactive Brokers (IB) is a brokerage company which provides an API for computer-driven trading, and it also provides extensive documentation:

[Interactive Brokers Main Page](#)

[Interactive Brokers Documentation](#)

[Interactive Brokers Course](#)

Disclosure: I do have a personal account with Interactive Brokers.

But I do not have any other relationship with Interactive Brokers, and I do not endorse or recommend them.

Warning: Active trading is extremely risky, and most people lose money.

I advise not to trade with your own capital!

The package *IBrokers* contains R functions for executing IB commands using the Interactive Brokers API.

The package *IBrokers* has extensive documentation.

```
> # Install package IBrokers
> install.packages("IBrokers")
> # Load package IBrokers
> library(IBrokers)
> # Get documentation for package IBrokers
> # Get short description
> packageDescription("IBrokers")
> # Load help page
> help(package="IBrokers")
> # List all datasets in "IBrokers"
> data(package="IBrokers")
> # List all objects in "IBrokers"
> ls("package:IBrokers")
> # Remove IBrokers from search path
> detach("package:IBrokers")
> # Install package IBrokers2
> devtools::install_github(repo="algoquant/IBrokers2")
```

The package *IBrokers2* is derived from package *IBrokers*, and contains additional functions for executing real time trading strategies via the Interactive Brokers API.

Configuring the IB Trader Workstation (TWS)

Connecting to Interactive Brokers via the API requires being logged into the IB Trader Workstation (TWS) or the IB Gateway (IBG).

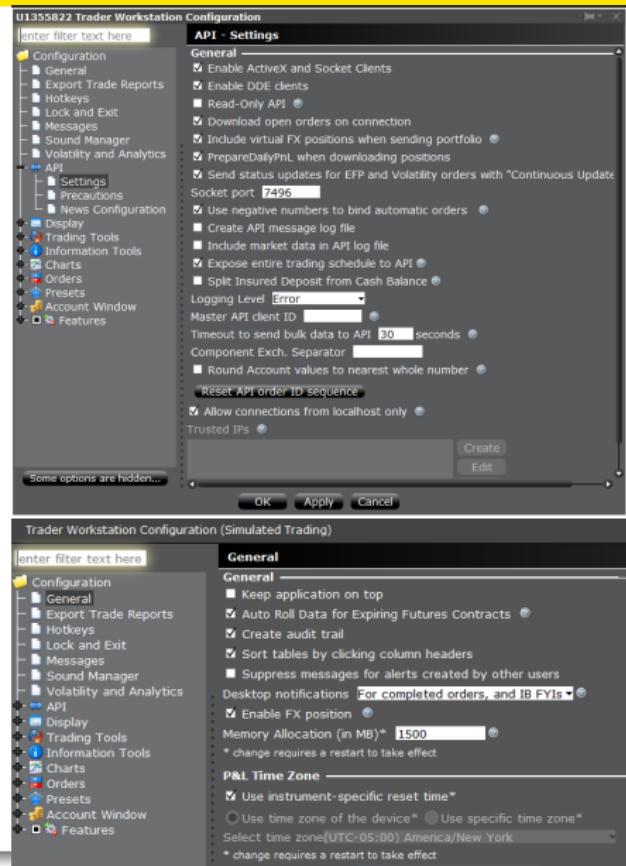
You should [Download the TWS](#) and install it.

Read about the [TWS initial setup](#).

The TWS settings must be configured to enable the API: *File* → *Global Configuration* → *API*

The TWS Java heap size should be increased to 1.5 GB: *File* → *Global Configuration* → *General*

Read more about the [required TWS memory allocation](#) and about [how to change the TWS heap size](#).



Connecting to Interactive Brokers via the API

Connecting to Interactive Brokers via the API requires being logged into the IB Trader Workstation (*TWS*) or the IB Gateway (*IBG*).

Interactive Brokers provides extensive [API Documentation](#).

The functions `twsConnect()` and `ibgConnect()` open a connection to the Interactive Brokers API, via either the *TWS* or the *IBG*.

The parameter `port` should be assigned to the value of the *socket port* displayed in *TWS* or *IBG*.

The function `twsDisconnect()` closes the Interactive Brokers API connection.

```
> # Connect to Interactive Brokers TWS
> ib_connect <- IBrokers::twsConnect(port=7497)
> # Or connect to IB Gateway
> # Ib_connect <- ibgConnect(port=4002)
> # Check connection
> IBrokers::isConnected(ib_connect)
> # Close the Interactive Brokers API connection
> IBrokers::twsDisconnect(ib_connect)
```

Downloading Account Information from Interactive Brokers

The function `reqAccountUpdates()` returns a list with the account information (requires an account code).

The first element of the list contains the account dollar balances, while the remaining elements contain contract information.

The function `twsPortfolioValue()` returns a data frame with commonly used account fields, such as the contract names, net positions, and realized and unrealized profits and losses (pnl's).

```
> # Connect to Interactive Brokers TWS
> ib_connect <- IBrokers::twsConnect(port=7497)
> # Or connect to IB Gateway
> # Ib_connect <- ibgConnect(port=4002)
> # Download account information from IB
> ac_count <- "DU1215081"
> ib_account <- IBrokers::reqAccountUpdates(conn=ib_connect,
+                                              acctCode=ac_count)
> # Extract account balances
> balance_s <- ib_account[[1]]
> balance_s$AvailableFunds
> # Extract contract names, net positions, and profits and losses
> IBrokers::twsPortfolioValue(ib_account)
> # Close the Interactive Brokers API connection
> IBrokers::twsDisconnect(ib_connect)
```

Defining Contracts Using Package *IBrokers*

The function `twsEquity()` defines a stock contract (IB contract object).

The functions `twsFuture()` and `twsCurrency()` define futures and currency contracts.

The function `reqContractDetails()` returns a list with information on the IB instrument.

The package `twsInstrument` contains utility functions for enhancing the package *IBrokers*.

To define an IB contract, first look it up by keyword in the online [IB Contract and Symbol Database](#), and find the *Conid* for that instrument.

Enter the *Conid* into the function

`twsInstrument::getContract()`, which will return the IB contract object for that instrument.

Interactive Brokers provides more information about financial contracts here: [IB Traded Products](#)

```
> # Define AAPL stock contract (object)
> contractobj <- IBrokers::twsEquity("AAPL", primary="SMART")
> # Define CHF currency contract
> contractobj <- IBrokers::twsCurrency("CHF", currency="USD")
> # Define S&P Emini future June 2019 contract
> contractobj <- IBrokers::twsFuture(symbol="ES",
+   exch="GLOBEX", expiry="201906")
> # Define 10yr Treasury future June 2019 contract
> contractobj <- IBrokers::twsFuture(symbol="ZN",
+   exch="ECBOT", expiry="201906")
> # Define euro currency future June 2019 contract
> contractobj <- IBrokers::twsFuture(symbol="EUR",
+   exch="GLOBEX", expiry="201906")
> # Define Gold future June 2019 contract
> contractobj <- IBrokers::twsFuture(symbol="GC",
+   exch="NYMEX", expiry="201906")
> # Define Oil future January 2019 contract
> contractobj <- IBrokers::twsFuture(symbol="QM",
+   exch="NYMEX", expiry="201901")
> # Test if contract object is correct
> IBrokers::is.twsContract(contractobj)
> # Get list with instrument information
> IBrokers::reqContractDetails(conn=ib_connect, Contract=contractobj)
> # Install the package twsInstrument
> install.packages("twsInstrument", repos="http://r-forge.r-project.org")
> # Define euro future using getContract() and Conid
> contractobj <- twsInstrument::getContract("317631411")
> # Get list with instrument information
> IBrokers::reqContractDetails(conn=ib_connect, Contract=contractobj)
```

Defining *VIX* Futures Contracts

VIX futures have both monthly and weekly contracts, with the monthly contracts being the most liquid.

In order to uniquely specify a *VIX* futures contract, the parameter "local" should be passed into the function `twsFuture()`, with the local security name.

For example, `VXV8` is the local security name (`symboln`) for the monthly *VIX* futures contract expiring on October 17th, 2018.

`VX40V8` is the local security name (`symboln`) for the weekly *VIX* futures contract expiring on October 3rd, 2018.

The function `reqContractDetails()` returns a list with information on the IB instrument.

VIX futures are traded on the *CFE* (CBOE Futures Exchange): <http://cfe.cboe.com/>

```
> # Define VIX monthly and weekly futures June 2019 contract
> symboln <- "VIX"
> contractobj <- IBrokers::twsFuture(symbol=symboln,
+   exch="CFE", expiry="201906")
> # Define VIX monthly futures June 2019 contract
> contractobj <- IBrokers::twsFuture(symbol=symboln,
+   local="VXV8", exch="CFE", expiry="201906")
> # Define VIX weekly futures October 3rd 2018 contract
> contractobj <- IBrokers::twsFuture(symbol=symboln,
+   local="VX40V8", exch="CFE", expiry="201906")
> # Get list with instrument information
> IBrokers::reqContractDetails(conn=ib_connect,
+   Contract=contractobj)
```

Downloading Historical Daily Data from Interactive Brokers

The function `reqHistoricalData()` downloads historical data to a .csv file.

The historical *daily* bar data fields are "Open", "High", "Low", "Close", "Volume", "WAP", "Count". ("WAP" is the weighted average price.)

Interactive Brokers provides more information about historical market data:

[IB Historical Market Data](#)

[IB Historical Bar Data Fields](#)

```
> # Define S&P Emini futures June 2019 contract
> symboln <- "ES"
> contractobj <- IBrokers::twsFuture(symbol=symboln,
+   exch="GLOBEX", expiry="201906")
> # Open file for data download
> dirn <- "/Users/jerzy/Develop/data/ib_data"
> dir.create(dirn)
> filen <- file.path(dirn, paste0(symboln, "201906.csv"))
> file_connect <- file(filen, open="w")
> # Connect to Interactive Brokers TWS
> ib_connect <- IBrokers::twsConnect(port=7497)
> # Write header to file
> cat(paste(paste(symboln, c("Index", "Open", "High", "Low", "Close",
> # Download historical data to file
> IBrokers::reqHistoricalData(conn=ib_connect,
+   Contract=contractobj,
+   barSize="1 day", duration="6 M",
+   file=file_connect)
> # Close data file
> close(file_connect)
> # Close the Interactive Brokers API connection
> IBrokers::twsDisconnect(ib_connect)
```

Downloading Historical Intraday Data for a Portfolio

Historical data for a portfolio of symbols can be downloaded in a loop.

The historical *intraday* bar data fields are "Open", "High", "Low", "Close", "Volume", "WAP", "XTRA", "Count". ("WAP" is the weighted average price.)

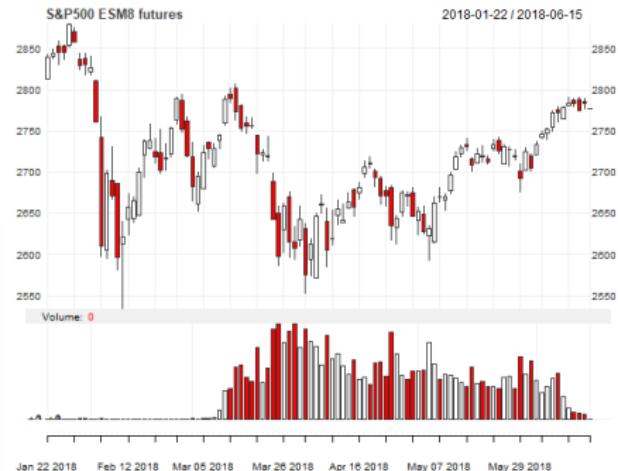
```
> # Define IB contract objects for stock symbols
> symbolv <- c("AAPL", "F", "MSFT")
> contractv <- lapply(symbolv, IBrokers::twsEquity, primary="SMART")
> names(contractv) <- symbolv
> # Open file connections for data download
> dirn <- "/Users/jerzy/Develop/data/ib_data"
> filens <- file.path(dirn, paste0(symbolv, format(Sys.time(), format="YMD-HM")))
> file_connects <- lapply(filens, function(filen) file(filen, open="r"))
> # Connect to Interactive Brokers TWS
> ib_connect <- IBrokers::twsConnect(port=7497)
> # Download historical 1-minute bar data to files
> for (it in 1:NROW(symbolv)) {
+   symboln <- symbolv[it]
+   file_connect <- file_connects[[it]]
+   contractobj <- contractv[[it]]
+   cat("Downloading data for: ", symboln, "\n")
+   # Write header to file
+   cat(paste(paste(symboln, c("Index", "Open", "High", "Low", "Close",
+   IBrokers:::reqHistoricalData(conn=ib_connect,
+                                 Contract=contractobj,
+                                 barSize="1 min", duration="2 D",
+                                 file=file_connect)
+   Sys.sleep(10) # 10s pause to avoid IB pacing violation
+ } # end for
> # Close data files
> for (file_connect in file_connects) close(file_connect)
> # Close the Interactive Brokers API connection
> IBrokers::twsDisconnect(ib_connect)
```

Downloading Historical Data for Expired Futures Contracts

Historical data for expired futures contracts can be downloaded using `reqHistoricalData()` with the appropriate expiry date, and the parameter `include_expired="1"`.

For example, *ESM8* is the symbol for the *S&P500* emini futures expiring in June 2018.

```
> # Define S&P Emini futures June 2018 contract
> symboln <- "ES"
> contractobj <- IBrokers::twsFuture(symbol=symboln,
+   include_expired="1",
+   exch="GLOBEX", expiry="201806")
> # Open file connection for ESM8 data download
> filen <- file.path(dirn, paste0(symboln, "M8.csv"))
> file_connect <- file(filen, open="w")
> # Connect to Interactive Brokers TWS
> ib_connect <- IBrokers::twsConnect(port=7497)
> # Download historical data to file
> IBrokers::reqHistoricalData(conn=ib_connect,
+   Contract=contractobj,
+   barSize="1 day", duration="2 Y",
+   file=file_connect)
> # Close data file
> close(file_connect)
> # Close the Interactive Brokers API connection
> IBrokers::twsDisconnect(ib_connect)
```



```
> # Load OHLC data and coerce it into xts series
> pricev <- data.table::fread(filen)
> data.table::setDF(pricev)
> pricev <- xts::xts(pricev[, 2:6],
+   order.by=as.Date(as.POSIXct.numeric(pricev[, 1]),
+   tz="America/New_York", origin="1970-01-01")))
> colnames(pricev) <- c("Open", "High", "Low", "Close", "Volume")
> # Plot OHLC data in x11 window
> chart_Series(x=pricev, TA="add_Vo()", 
+   name="S&P500 ESM8 futures")
> # Plot dygraph
> dygraphs::dygraph(pricev[, 1:4], main="S&P500 ESM8 futures") %>%
+   dyCandlestick()
```

draft: Downloading Continuous Contract Futures Data

Note: Continuous futures require passing the parameter: `contract.secType = "CONTFUT"`, which isn't currently included in package *IBrokers*.

http://interactivebrokers.github.io/tws-api/basic_contracts.html

A continuous futures contract is a synthetic time series of prices, created by splicing together prices from several futures contracts with different expiration dates.

At any point in time, the price of the continuous contract is equal to the most liquid contract times a normalization factor.

When the next consecutive contract becomes more liquid, then the continuous contract price is rolled over to that contract.

The continuous price is multiplied by a normalization factor when the contract is rolled, to remove jumps caused by the shape of the futures curve.

So the continuous contract prices are not equal to the past futures prices.

Futures contracts trade at different prices (because of the futures convenience yield).

This cause price jumps between the currently expiring futures contract and the next futures contract. A continuous futures contract adjusts the prices to remove these jumps and time differences to create an artificial price series.

```
> # Define S&P Emini futures June 2018 contract
> symboln <- "ES"
> contractobj <- IBrokers::twsFuture(symbol=symboln,
+   include_expired="1",
+   exch="GLOBEX", expiry="201806")
> # Open file connection for data download
> dirn <- "/Users/jerzy/Develop/data/ib_data"
> dir.create(dirn)
> filen <- file.path(dirn, paste0(symboln, ".csv"))
> file_connect <- file(filen, open="w")
> # Connect to Interactive Brokers TWS
> ib_connect <- IBrokers::twsConnect(port=7497)
> # Download historical data to file
> IBrokers::reqHistoricalData(conn=ib_connect,
+   Contract=contractobj,
+   barSize="1 day", duration="6 M",
+   file=file_connect)
> # Close data file
> close(file_connect)
> # Close the Interactive Brokers API connection
> IBrokers::twsDisconnect(ib_connect)
```

Downloading Live *TAQ* Data from Interactive Brokers

The function `reqMktData()` downloads live (real-time) trades and quotes (*TAQ*) data from Interactive Brokers.

The function `eWrapper()` formats the real-time market events (trades and quotes), so they can be displayed or saved to a file.

The method `eWrapper.MktData.CSV()` formats the real-time *TAQ* data so it can be saved to a `.csv` file.

The real-time *TAQ* data fields are *BidSize*, *BidPrice*, *AskPrice*, *AskSize*, *Last*, *LastSize*, *Volume*.

BidPrice is the quoted bid price, *AskPrice* is the quoted offer price, and *Last* is the most recent traded price.

The *TAQ* data is spaced irregularly in time, with data recorded each time a new trade or quote arrives.

```
> # Define S&P Emini futures June 2019 contract
> symboln <- "ES"
> contractobj <- IBrokers::twsFuture(symbol=symboln,
+   exch="GLOBEX", expiry="201906")
> # Open file connection for data download
> dirn <- "/Users/jerzy/Develop/data/ib_data"
> # Dir.create(dirn)
> filen <- file.path(dirn, paste0(symboln, "_taq_live.csv"))
> file_connect <- file(filen, open="w")
> # Connect to Interactive Brokers TWS
> ib_connect <- IBrokers::twsConnect(port=7497)
> # Download live data to file
> IBrokers::reqMktData(conn=ib_connect,
+   Contract=contractobj,
+   eventWrapper=eWrapper.MktData.CSV(1),
+   file=file_connect)
> # Close data file
> close(file_connect)
> # Close the Interactive Brokers API connection
> IBrokers::twsDisconnect(ib_connect)
```

Downloading Live *OHLC* Data from Interactive Brokers

The function `reqRealTimeBars()` downloads live (real-time) *OHLC* market data from Interactive Brokers.

The method `eWrapper.RealTimeBars.CSV()` formats the real-time *OHLC* data so it can be saved to a `.csv` file.

Interactive Brokers by default only provides 5-second bars of real-time prices (but it also provides historical data at other frequencies).

```
> # Define S&P Emini futures June 2019 contract
> symboln <- "ES"
> contractobj <- IBrokers::twsFuture(symbol=symboln,
+   exch="GLOBEX", expiry="201906")
> # Open file connection for data download
> dirn <- "/Users/jerzy/Develop/data/ib_data"
> # Dir.create(dirn)
> filen <- file.path(dirn, paste0(symboln, "_ohlc_live.csv"))
> file_connect <- file(filen, open="w")
> # Connect to Interactive Brokers TWS
> ib_connect <- IBrokers::twsConnect(port=7497)
> # Download live data to file
> IBrokers::reqRealTimeBars(conn=ib_connect,
+   Contract=contractobj, barSize="1",
+   eventWrapper=eWrapper.RealTimeBars.CSV(1),
+   file=file_connect)
> # Close the Interactive Brokers API connection
> IBrokers::twsDisconnect(ib_connect)
> # Close data file
> close(file_connect)
> # Load OHLC data and coerce it into xts series
> library(data.table)
> pricev <- data.table::fread(filen)
> pricev <- xts::xts(pricev[, paste0("V", 2:6)],
+   as.POSIXct.numeric(as.numeric(pricev[, V1]), tz="America/New_York"))
> colnames(pricev) <- c("Open", "High", "Low", "Close", "Volume")
> # Plot OHLC data in x11 window
> x11()
> chart_Series(x=pricev, TA="add_Vo()", 
+   name="S&P500 ESM9 futures")
> # Plot dygraph
> library(dygraphs)
> dygraphs::dygraph(pricev[, 1:4], main="S&P500 ESM9 futures") %>%
+   dyCandlestick()
```

Downloading Live OHLC Data For Multiple Contracts

Live *OHLC* data can be downloaded for multiple instruments simultaneously.

This requires passing a *list* of contracts and file connections to `reqRealTimeBars()`, and also passing the number of contracts to `eWrapper.RealTimeBars.CSV()`.

The bar prices for each contract are written into a separate file.

```
> library(IBrokers)
> # Define list of S&P futures and 10yr Treasury contracts
> contractv <- list(ES=IBrokers::twsFuture(symbol="ES", exch="GLOBE",
+ ZN=IBrokers::twsFuture(symbol="ZN", exch="ECBOT", exp="2019-06"))
> # Open the file connection for storing the bar data
> dirn <- "/Users/jerzy/Develop/data/ib_data"
> filens <- file.path(dirn, paste0(c("ES", "ZN_"), format(Sys.time(),
+ "%Y-%m-%d-%H-%M-%S")))
> file_connects <- lapply(filens, function(filen) file(filen, open="w"))
> # Connect to Interactive Brokers TWS
> ib_connect <- IBrokers::twsConnect(port=7497)
> # Download live data to file
> IBrokers::reqRealTimeBars(conn=ib_connect,
+ Contract=contractv,
+ barSize="1", useRTH=FALSE,
+ eventWrapper=eWrapper.RealTimeBars.CSV(NROW(file_connects),
+ file=file_connects))
> # Close the Interactive Brokers API connection
> IBrokers::twsDisconnect(ib_connect)
> # Close data files
> for (file_connect in file_connects)
+ close(file_connect)
> library(data.table)
> # Load ES futures June 2019 contract and coerce it into xts series
> pricev <- data.table:::fread(filens[1])
> pricev <- xts::xts(pricev[, paste0("V", 2:6)],
+ as.POSIXct.numeric(as.numeric(pricev[, V1]), tz="America/New_York"))
> colnames(pricev) <- c("Open", "High", "Low", "Close", "Volume")
> # Plot dygraph
> library(dygraphs)
> dygraphs::dygraph(pricev[, 1:4], main="S&P500 ESM9 futures") %>%
+ dyCandlestick()
> # Load ZN 10yr Treasury futures June 2019 contract
> pricev <- data.table:::fread(filens[2])
> pricev <- xts::xts(pricev[, paste0("V", 2:6)],
+ as.POSIXct.numeric(as.numeric(pricev[, V1]), tz="America/New_York"))
> colnames(pricev) <- c("Open", "High", "Low", "Close", "Volume")
> # Plot dygraph
> dygraphs::dygraph(pricev[, 1:4], main="ZN 10yr Treasury futures") %>%
```

Event Processing Using *eWrapper()* and *twsCALLBACK()*

Functions which process real-time market events (like *reqMktData()* and *reqRealTimeBars()*) rely on the functions *eWrapper()* and *twsCALLBACK()*.

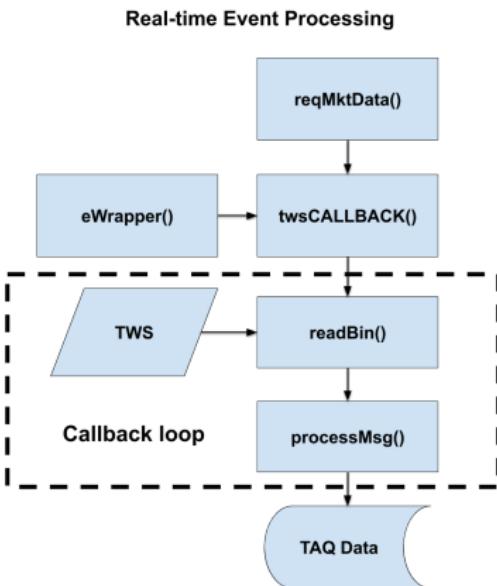
The function *eWrapper()* creates an *eWrapper* object, consisting of a data environment and handler (methods) for formatting and adding new data to it.

The function *reqMktData()* accepts an *eWrapper* object and passes it into *twsCALLBACK()*.

The function *twsCALLBACK()* processes market events by calling functions *readBin()* and *processMsg()* in a *while()* loop.

The *TWS* broadcasts real-time market events in the form of character strings, which are captured by *readBin()*.

The character strings are then parsed by *processMsg()*, and copied to the data environment of the *eWrapper* object.



Placing Market Trade Orders on TWS

The function `reqIds()` requests a trade order ID from Interactive Brokers TWS.

The function `twsOrder()` creates a trade order object.

The parameter `orderType` specifies the type of trade order: market order (MKT), limit order (LMT), etc.

Each trade order requires its own ID generated by `reqIds()`.

The function `placeOrder()` places a trade order.

```
> # Define Japanese yen currency futures June 2019 contract 6JZ8
> contractobj <- IBrokers::twsFuture(symbol="JPY", exch="GLOBEX", exchName="GLOBEX")
> # Connect to Interactive Brokers TWS
> ib_connect <- IBrokers::twsConnect(port=7497)
> IBrokers::reqContractDetails(conn=ib_connect, Contract=contractobj)
> # Request trade order ID
> order_id <- IBrokers::reqIds(ib_connect)
> # Create buy market order object
> ib_order <- IBrokers::twsOrder(order_id,
+   orderType="MKT", action="BUY", totalQuantity=1)
> # Place trade order
> IBrokers::placeOrder(ib_connect, contractobj, ib_order)
> # Execute sell market order
> order_id <- IBrokers::reqIds(ib_connect)
> ib_order <- IBrokers::twsOrder(order_id,
+   orderType="MKT", action="SELL", totalQuantity=1)
> IBrokers::placeOrder(ib_connect, contractobj, ib_order)
> # Execute buy market order
> order_id <- IBrokers::reqIds(ib_connect)
> ib_order <- IBrokers::twsOrder(order_id,
+   orderType="MKT", action="BUY", totalQuantity=1)
> IBrokers::placeOrder(ib_connect, contractobj, ib_order)
```

Placing and Cancelling Limit Trade Orders on *TWS*

The function `twsOrder()` with `orderType=LMT` creates a limit trade order object.

The function `cancelOrder()` with the parameter `orderId=order_id` cancels a trade order with the ID equal to `order_id`.

```
> # Request trade order ID
> order_id <- IBrokers::reqIds(ib_connect)
> # Create buy limit order object
> ib_order <- IBrokers::twsOrder(order_id, orderType="LMT",
+   lmtPrice="1.1511", action="BUY", totalQuantity=1)
> # Place trade order
> IBrokers::placeOrder(ib_connect, contractobj, ib_order)
> # Cancel trade order
> IBrokers::cancelOrder(ib_connect, order_id)
> # Execute sell limit order
> order_id <- IBrokers::reqIds(ib_connect)
> ib_order <- IBrokers::twsOrder(order_id, orderType="LMT",
+   lmtPrice="1.1512", action="SELL", totalQuantity=1)
> IBrokers::placeOrder(ib_connect, contractobj, ib_order)
> # Cancel trade order
> IBrokers::cancelOrder(ib_connect, order_id)
> # Close the Interactive Brokers API connection
> IBrokers::twsDisconnect(ib_connect)
```

Placing Limit Orders in a Programmatic Loop

The function `reqRealTimeBars()` creates data objects and then calls `twsCALLBACK()` and passes the objects to `twsCALLBACK()`.

`twsCALLBACK()` calls `processMsg()` in a loop, and passes the `eWrapper()` to it.

`processMsg()` performs if-else statements and calls `eWrapper` methods.

`eWrapper()` creates an environment for data, and methods (handlers) for formatting the data.

`eWrapper.RealTimeBars.CSV()` calls `eWrapper()` to create a closure (function) and returns it.

Closures allow creating mutable states for persistent data objects.

Limit trade orders can be placed inside a modified `eWrapper()` function.

```
> eWrapper_realtimebars <- function(n = 1) {
+   eW <- eWrapper_new(NULL)
+   # eW <- IBrokers::eWrapper(NULL)
+   eW$assign.Data("data", rep(list(structure(.xts(matrix(rep(NA, 1, 1), 1, 1), .Dim = c(1, 1))), .Dimnames = list(NULL, NULL))), 1)
+   eW$realtimeBars <- function(curMsg, msg, timestamp, file, ...)
+     id <- as.numeric(msg[2])
+     file <- file[[id]]
+     data <- eW$get.Data("data")
+     attr(data[[id]], "index") <- as.numeric(msg[3])
+     nr.data <- NROW(data[[id]])
+     # Write to file
+     cat(paste(msg[3], msg[4], msg[5], msg[6], msg[7], msg[8], msg[9]), file = file, sep = "\n")
+     # Write to console
+     # eW$countn <- eW$countn + 1
+     eW$assign.Data("countn", eW$get.Data("countn") + 1)
+     cat(paste0("countn=", eW$get.Data("countn"), "\tOpen=", msg[4], "\tHigh=", msg[5], "\tLow=", msg[6], "\tClose=", msg[7], "\tVolume=", msg[8], "\tCountn=", msg[9]), file = file, sep = "\n")
+     # cat(paste0("Open=", msg[4], "\tHigh=", msg[5], "\tLow=", msg[6], "\tClose=", msg[7], "\tVolume=", msg[8], "\tCountn=", msg[9]), file = file, sep = "\n")
+     ### Trade
+     # Cancel previous trade orders
+     buy_id <- eW$get.Data("buy_id")
+     sell_id <- eW$get.Data("sell_id")
+     if (buy_id>0) IBrokers::cancelOrder(ib_connect, buy_id)
+     if (sell_id>0) IBrokers::cancelOrder(ib_connect, sell_id)
+     # Execute buy limit order
+     buy_id <- IBrokers::reqIds(ib_connect)
+     buy_order <- IBrokers::twsOrder(buy_id, orderType="LMT",
+                                     lmtPrice=msg[6]-0.25, action="BUY",
+                                     IBrokers::placeOrder(ib_connect, contractobj, buy_order))
+     # Execute sell limit order
+     sell_id <- IBrokers::reqIds(ib_connect)
+     sell_order <- IBrokers::twsOrder(sell_id, orderType="LMT",
+                                     lmtPrice=msg[5]+0.25, action="SELL",
+                                     IBrokers::placeOrder(ib_connect, contractobj, sell_order))
+     # Copy new trade orders
+     eW$assign.Data("buy_id", buy_id)
+     eW$assign.Data("sell_id", sell_id)
+     ### Trade finished
+     data[[id]]$data <- data[[id]]$data[-1:-1]
+     data[[id]]$data <- as.numeric(data[[id]]$data[4:10])
```

draft: Advanced Order Types and Execution Algos

Interactive Brokers provides many different Order Types and Execution Algos.

The function `reqRealTimeBars()` creates data objects and then calls `twsCALLBACK()` and passes the objects to `twsCALLBACK()`.

`twsCALLBACK()` calls `processMsg()` in a loop, and passes the `eWrapper()` to it.

`processMsg()` performs if-else statements and calls `eWrapper` methods.

`eWrapper()` creates an environment for data, and methods (functions) for handling (formatting) the data.

`eWrapper.RealTimeBars.CSV()` calls `eWrapper()` to create a closure (function) and returns it.

Closures allow creating mutable states for persistent data objects.

Limit trade orders can be placed inside a modified eWrapper() function.

```

+ eWrapper_realtimebars <- function(n = 1) {
+   eW <- eWrapper_new(NULL)
+   # eW <- IBrokers::eWrapper(NULL)
+   eW$assign.Data("data", rep(list(structure(.xts(matrix(rep(NA, 1000, 1), 1000), 
+   eW$realtimeBars <- function(cumMsg, msg, timestamp, file, ...) {
+     id <- as.numeric(msg[2])
+     file <- file[[id]]
+     data <- eW$get.Data("data")
+     attr(data[[id]], "index") <- as.numeric(msg[3])
+     nr.data <- nROW(data[[id]])
+     # Write to file
+     cat(paste(msg[3], msg[4], msg[5], msg[6], msg[7], msg[8], msg[9], "\n"))
+     # Write to console
+     # eW$countn <- eW$countn + 1
+     eW$assign.Data("countn", eW$get.Data("countn") + 1)
+     cat(paste0("countn=", eW$get.Data("countn"), "\tOpen=", msg[4], "\tHigh=", msg[5], "\tLow=", msg[6], "\tClose=", msg[7], "\tVolume=", msg[8], "\tTime=", msg[9], "\n"))
+     ### Trade
+     # Cancel previous trade orders
+     buy_id <- eW$get.Data("buy_id")
+     sell_id <- eW$get.Data("sell_id")
+     if (buy_id > 0) IBrokers::cancelOrder(ib_connect, buy_id)
+     if (sell_id > 0) IBrokers::cancelOrder(ib_connect, sell_id)
+     # Execute buy limit order
+     buy_id <- IBrokers::reqIds(ib_connect)
+     buy_order <- IBrokers::twsOrder(buy_id, orderType = "LMT",
+                                     lmtPrice = msg[6] - 0.25, action = "BUY"),
+     IBrokers::placeOrder(ib_connect, contractobj, buy_order)
+     # Execute sell limit order
+     sell_id <- IBrokers::reqIds(ib_connect)
+     sell_order <- IBrokers::twsOrder(sell_id, orderType = "LMT",
+                                     lmtPrice = msg[5] + 0.25, action = "SELL"),
+     IBrokers::placeOrder(ib_connect, contractobj, sell_order)
+     # Copy new trade orders
+     eW$assign.Data("buy_id", buy_id)
+     eW$assign.Data("sell_id", sell_id)
+     ### Trade finished
+ }

```

draft: Downloading Live TAQ Data and Replaying It

Note: The script downloads the raw data, but doesn't replay the bar data properly.

<https://offerm.wordpress.com/2015/05/21/market-data-recording-and-playback-with-ibrokers-and-r-2/>

The function `reqMktData()` downloads live (real-time) trades and quotes (TAQ) data from Interactive Brokers.

The function `eWrapper()` formats the real-time market events (trades and quotes), so they can be displayed or saved to a file.

The method `eWrapper.MktData.CSV()` formats the real-time TAQ data so it can be saved to a .csv file.

The real-time TAQ data fields are *BidSize*, *BidPrice*, *AskPrice*, *AskSize*, *Last*, *LastSize*, *Volume*.

BidPrice is the quoted bid price, *AskPrice* is the quoted offer price, and *Last* is the most recent traded price.

The TAQ data is spaced irregularly in time, with data recorded each time a new trade or quote arrives.

```
> # Define S&P Emini futures June 2019 contract
> snp_contract <- IBrokers::twsFuture(symbol="ES",
+   exch="GLOBEX", expiry="201906")
> # Define VIX futures June 2019 contract
> vix_contract <- IBrokers::twsFuture(symbol="VIX",
+   local="VXZ8", exch="CFE", expiry="201906")
> # Define 10yr Treasury futures June 2019 contract
> trs_contract <- IBrokers::twsFuture(symbol="ZN",
+   exch="ECBOT", expiry="201906")
> # Define Emini gold futures June 2019 contract
> gold_contract <- IBrokers::twsFuture(symbol="YG",
+   exch="NYSELIFFE", expiry="201906")
> # Define euro currency future June 2019 contract
> euro_contract <- IBrokers::twsFuture(symbol="EUR",
+   exch="GLOBEX", expiry="201906")
> IBrokers::reqContractDetails(conn=ib_connect, Contract=euro_contract)
>
> # Define data directory
> dirn <- "/Users/jerzy/Develop/data/ib_data"
> # Dir.create(dirn)
>
> # Open file for error messages
> file_root <- "replay"
> filen <- file.path(dirn, paste0(file_root, "_error.csv"))
> error_connect <- file(filen, open="w")
>
> # Open file for raw data
> filen <- file.path(dirn, paste0(file_root, "_raw.csv"))
> raw_connect <- file(filen, open="w")
>
> # Create empty eWrapper to redirect error messages to error file
> error_ewrapper <- eWrapper(debug=NULL, errfile=error_connect)
>
> # Create eWrapper for raw data
> raw_ewrapper <- eWrapper(debug=TRUE)
>
> # Redirect error messages to error eWrapper (error_ewrapper),
> # by replacing handler function errorMessage() in raw_ewrapper
```

draft: Defining Instrument Pairs in TWS

Users can **Define Pairs of Instruments** in the *TWS*, using the *Combo Selection* window.

To open the *Combo Selection* window, right-click on a blank contract field and select *Generic Combo*.

Or enter the symbol for one of the instruments and select *Combinations* followed by *Option Combos* from the drop down menu, and then click the tab *Pair or Leg-by-leg*.

The pairs can be traded as a single instrument, but the execution is not guaranteed, and the bid-ask spread may be very large.

The tab *Multiple* allows selecting a group of combination quotes on the same underlying for comparison.

First access the *Combo Selection* window, enter the symbol for one of the instruments and select *Combinations* followed by *Option Combos* from the drop down menu, and then click the tab *Pair or Leg-by-leg*.

Interactive Brokers provides more information about financial contracts here: [IB Traded Products](#)

```
> # Define AAPL stock contract (object)
> contractobj <- IBrokers::twsEquity("AAPL", primary="SMART")
> # Define CHF currency contract
> contractobj <- IBrokers::twsCurrency("CHF", currency="USD")
> # Define S&P Emini future June 2019 contract
> contractobj <- IBrokers::twsFuture(symbol="ES",
+   exch="GLOBEX", expiry="201906")
> # Define 10yr Treasury future June 2019 contract
> contractobj <- IBrokers::twsFuture(symbol="ZN",
+   exch="ECBOT", expiry="201906")
> # Define euro currency future June 2019 contract
> contractobj <- IBrokers::twsFuture(symbol="EUR",
+   exch="GLOBEX", expiry="201906")
> # Define Gold future June 2019 contract
> contractobj <- IBrokers::twsFuture(symbol="GC",
+   exch="NYMEX", expiry="201906")
> # Test if contract object is correct
> IBrokers::is.twsContract(contractobj)
> # Get list with instrument information
> IBrokers::reqContractDetails(conn=ib_connect, Contract=contractobj)
> # Install the package twsInstrument
> install.packages("twsInstrument", repos="http://r-forge.r-project.org")
> # Define euro future using getContract() and Conid
> contractobj <- twsInstrument::getContract("317631411")
> # Get list with instrument information
> IBrokers::reqContractDetails(conn=ib_connect, Contract=contractobj)
```

draft: Defining Investment Strategies in TWS

Users can **Define Investment Strategies** in the *TWS*, using the *Portfolio Builder* window.

To open the *Portfolio Builder* window, left-click on the New Window dropdown on the upper-left of *TWS*, and select *Portfolio Builder*.

Click "Create New Strategy" to open and edit Investment Rules in the sidebar populated with sample data based on the last sorting option you selected. The main Portfolio Builder reflects changes made in the sidebar in real time.

Or enter the symbol for one of the instruments and select *Combinations* followed by *Option Combos* from the drop down menu, and then click the tab *Pair or Leg-by-leg*.

The pairs can be traded as a single instrument, but the execution is not guaranteed, and the bid-ask spread may be very large.

The tab *Multiple* allows selecting a group of combination quotes on the same underlying for comparison.

First access the *Combo Selection* window, enter the symbol for one of the instruments and select *Combinations* followed by *Option Combos* from the drop down menu, and then click the tab *Pair or Leg-by-leg*.

Interactive Brokers provides more information about

```
> # Define AAPL stock contract (object)
> contractobj <- IBrokers::twsEquity("AAPL", primary="SMART")
> # Define CHF currency contract
> contractobj <- IBrokers::twsCurrency("CHF", currency="USD")
> # Define S&P Emini future June 2019 contract
> contractobj <- IBrokers::twsFuture(symbol="ES",
+   exch="GLOBEX", expiry="201906")
> # Define 10yr Treasury future June 2019 contract
> contractobj <- IBrokers::twsFuture(symbol="ZN",
+   exch="ECBOT", expiry="201906")
> # Define euro currency future June 2019 contract
> contractobj <- IBrokers::twsFuture(symbol="EUR",
+   exch="GLOBEX", expiry="201906")
> # Define Gold future June 2019 contract
> contractobj <- IBrokers::twsFuture(symbol="GC",
+   exch="NYMEX", expiry="201906")
> # Test if contract object is correct
> IBrokers::is.twsContract(contractobj)
> # Get list with instrument information
> IBrokers::reqContractDetails(conn=ib_connect, Contract=contractobj)
> # Install the package twsInstrument
> install.packages("twsInstrument", repos="http://r-forge.r-project.org")
> # Define euro future using getContract() and Conid
> contractobj <- twsInstrument::getContract("317631411")
> # Get list with instrument information
> IBrokers::reqContractDetails(conn=ib_connect, Contract=contractobj)
```

draft: Linux

Advanced Package Tool, or apt, is a free software user interface that works with core libraries to handle the installation and removal of software on Debian, Ubuntu and other Linux distributions. Debian uses the dpkg packaging system apt is a more friendly way to handle packaging than dpkg. apt-get is similar to apt. apt consists some of the most widely used features from apt-get and apt-cache leaving aside obscure and seldom used features. apt provides the most common used commands from apt-get and apt-cache.

<https://itsfoss.com/apt-command-guide/>

<https://itsfoss.com/apt-vs-apt-get-difference/>

Get Debian version and release cat /etc/issue cat /etc/os-release

Install GNOME Debian Desktop Environment

<https://www.gnome.org/>

<https://wiki.debian.org/Gnome>

<https://wiki.debian.org/DesktopEnvironment> Install

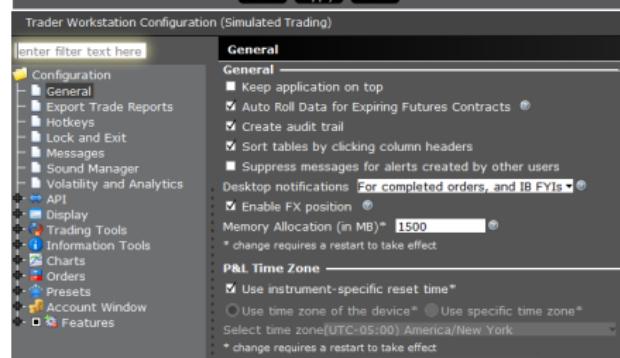
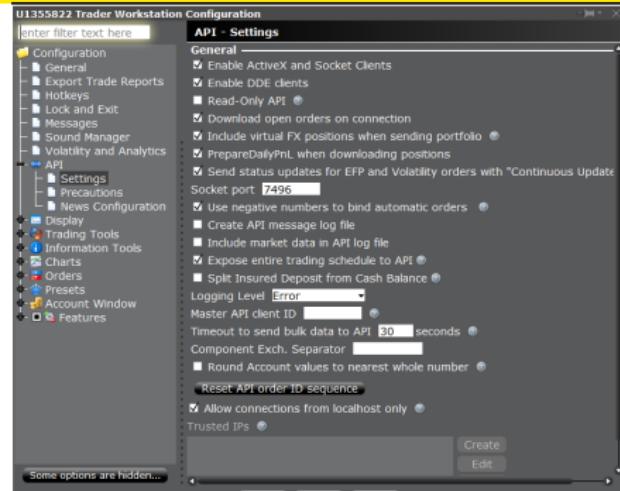
VNC server <https://medium.com/google-cloud/graphical-user-interface-gui-for-google-compute-engine-instance-78fccda09e5c> sudo apt-get install vnc4server vncserver

Install Windows RDP to Debian remote desktop

<http://blog.technotesdesk.com/how-to-use-rdp-from-windows-to-connect-to-debian-or-ubuntu-machine>

apt-get install xrdp Run Windows RDP to Static IP

Address <https://cloud.google.com/compute/docs/ip-addresses/reserve-static-external-ip-address>



draft: Creating Google Cloud Project

Install R

<https://www.rstudio.com/products/rstudio/download-server/> <https://cran.rstudio.com/bin/linux/debian/>

```
sudo apt-get update
sudo apt-get install r-base
r-base-dev
sudo apt-get install libopenblas-base
sudo apt-get install libssl-dev
sudo apt-get install libgit2-dev
sudo apt-get install libssh2-1-dev
sudo apt-get install libcurl4-openssl-dev
```

Change R lib permission
 cd /usr/local/lib/R
 sudo chmod o+w site-library

```
Type "R" In R
install.packages("openssl")
install.packages("git2r") install.packages("curl")
install.packages("httr") install.packages("usethis")
install.packages("devtools")
```

Upgrade R
 sudo apt-get remove r-base cat
 /etc/apt/sources.list
 sudo nano /etc/apt/sources.list
 deb http://cran.rstudio.com/bin/linux/debian

```
stretch-cran35/
sudo apt-get install dirmngr gpg
-keyserver keyserver.ubuntu.com -recv-key
```

FCAE2A0E115C3D8A gpg -a -export

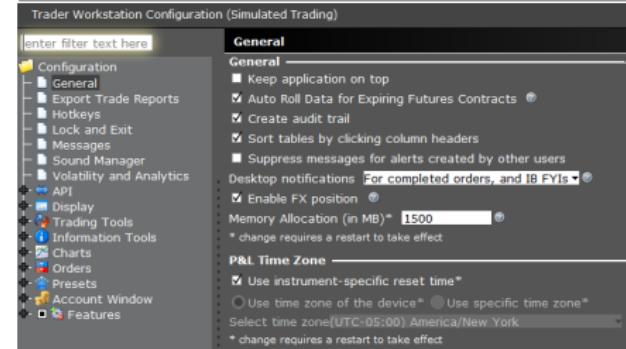
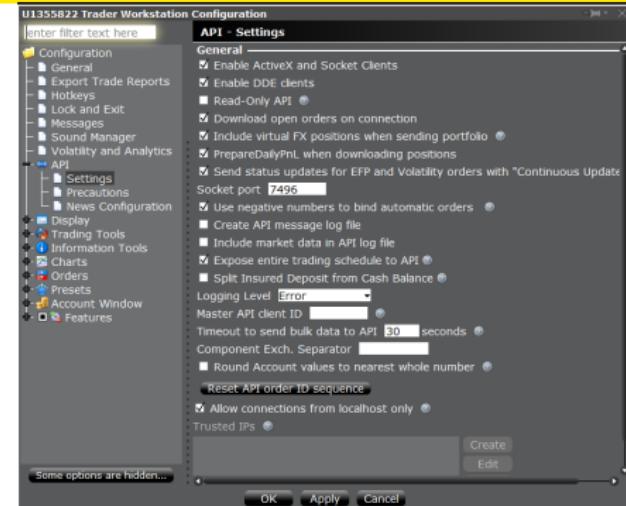
```
FCAE2A0E115C3D8A — sudo apt-key add -
sudo apt-get update
sudo apt-get install r-base
sudo apt-get install r-base-dev
```

sudo apt update
 sudo apt upgrade

<https://www.rstudio.com/products/rstudio/download-server/>

Connecting to Interactive Brokers via the API requires being logged into the IB Trader Workstation (TWS) or

Jerzy Pawlowski (NYU Tandon)



draft: Pursuing a Career in Portfolio Management

Becoming a portfolio manager (PM) is very difficult:

- Portfolio management jobs are more difficult than they appear because of survivorship bias among portfolio managers. There are very few successful portfolio managers, and most of the others get fired. But you never hear about those.
- Becoming a portfolio manager (PM) is very difficult because it requires experience and a track record.
- Funds only want to hire experienced PMs with a track record. But how to gain experience and a track record without working as a PM?
- The best way to start is by getting a job as a quant supporting portfolio managers.
- Strong programming skills will drastically improve your chances.
- The best way to get a good job is through networking (personal contacts). Personal contacts are the most valuable resource in pursuing a career in portfolio management.
- Networking techniques: Create a Github account with your projects (it's your calling card), Collaborate on open-source projects.