Risk Management and Regulation

- GR5320 Project Report -

- Columbia University -

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Contents

Executive Summary

This is a review of a risk calculation system for portfolio including stocks and options. The risk model is used to calculate historical VaR, parametric VaR and Monte Carlo VaR.

Risk calculations have two components. The first component is the pricing model used for the calculation. The second component is how the pricing model is used to calculate risks.

For this project, we have three types of the portfolio: portfolio with only one stock, portfolio with two different stocks and portfolio with two stocks, one put and one call option.

Our historical VaR and expected shortfall (ES) models are based on applying historical perturbations of model inputs to the current market and repricing the portfolio. Parametric VaR and ES are based on two different assumptions to get the distribution of portfolio return. Monte Carlo model relies on heavy computations.

Software Description

The software we designed includes three VaR & ES calculation methods. There are four main calculation parts in this program - Historical VaR & ES, Parametric VaR & ES(Portfolio follows GBM), Parametric VaR(Underlying follows GBM) and Monte Carlo VaR & ES. Here we give a simple description of them.

2.1 Simple Description

Here we choose two stocks and two options in our portfolio to test the validity of our system. The stocks are Exxon Mobil Corporation (NYSE: XOM) and Intel Corporation (NASDAQ: INTC). For option part, we set the XOM as call option and INTC as put option.

2.1.1 Software Composition

There is one main.Rmd[1] file which includes all the inputs, functions, outputs and plots for three VaR & ES calculation methods.

We design the software for three type situations. For each situation, we calculated its VaR & ES by three methods respectively.

Type 1 is designed for individual stock. It is convenient for going through the performance of individual stock before constructing the portfolio.

Type 2 is designed for portfolio only with multiple stocks. Here, to make the results more widely applicable, we only include two stocks in the portfolio to validate our calculation methods.

Type 3 is applied to the portfolio which includes two stocks and two options. One call option with short positions and one put option with long positions.

2.1.2 Software Flexibility

2.1.2.1 Scope of use of the model and Assumptions of Models

Our software is a highly flexible calculation system. Users can construct any portfolio consisting of any two stocks and any two options. Our system is strongly flexible for users to use because all the parameters can be changed according to user's requirements. The stock weights, option weights, window, horizon, and length of input price data, the option maturity, option strike price, the put or call option type, the confidence level, and the risk free interest rate are all inputs input by users.

For each situation we mention above, it allows users to choose the specific method to calculate its VaR/ES, which may satisfy different users' preference accordingly:

For each method, we have below results and outputs:

- VaR and ES for all three methods
- Back test
    - Number of exceptions and VaR vs. actual P&L

2.1.2.2 Model limitations

It is user's responsibility to enter reasonable inputs following the criterias:

- Tickers must be consistent with Yahoo finance
- For portfolio parts, weights must sum up to exactly 1
- The inputs of each method are not consistent. Historical VaR plot only needs tickers, weights, start date and end date. The other functions need more inputs such as drift and volatility.
- For option hedging part, the implied volatility provided must be consistent with the maturity of option being invested in the portfolio
- There are only two type of portfolio constructions:
    - Two stocks
    - One stock + One put option + One call option

Model Description

3.1 Model Assumptions

3.1.1 Parameters

Before running the risk calculation steps, the system will automatically calibrate the necessary parameters (drift and volatility) to historical price data, using the window lengths requested by users.(“winEstGBM”)

3.1.2 Option Prices

We assume that the options we bought have the everlasting properties. In other words, the strike price and the time to maturity are unchanged on every day.

Two options are both at the money (ATM), which means the strike price is the same as the current spot price of the underlying security, i.e. S0.

3.1.3 Parametric Method

For individual stock, it assumes that stock prices follow the geometric Brownian motion.

For portfolio, there are two assumptions in terms of two different calculation logics. One is taking the portfolio as a whole and assumes it follows GBM. One is assuming that the underlying stocks or equities follow GBM, and the portfolio is normally distributed.

3.1.4 Historical Method

For historical VaR, the major assumption is that the performance of stock, portfolio and option price in the future is consistent with the one in the past. There are two methods to calculate historical VaR, absolute change and relative change method. In this project, we use relative change method, which means that all analysis is based on the log returns. By relative change method, it simple assumes the price of the asset follows Geometric Brownian Motion.

3.1.5 Monte Carlo Method

For Monte Carlo VaR, it shares the same assumptions with parametric method, for both the single stock and the portfolio case. In this project, we generate 10,000 paths for Monte Carlo simulation method.

3.2 Mathematical Description

3.2.1 Parametric VaR

a. For a single stock or a portfolio under Geometric Brownian Motion distribution, the Parametric VaR would be very simple:

$$dS = \mu S dt + \sigma S dW$$

$$E(S_T) = S_0 e^{\mu T}$$

$$\mathrm{Var}(S_T) = S_0^2 (e^{\sigma^2 T} - 1) e^{2\mu T}$$

$$\mathrm{VaR}(S, T, p) = S_0 - S_0 e^{\sigma\sqrt{T}\phi^{-1}(1-p) + (\mu - \frac{\sigma^2}{2})T}$$

b. If now we assume a portfolio, which following normal distribution, contains two stocks, and he underlying stock prices follow Geometric Brownian Motion. We generate two correlated random number and then calculated stock price based on below formulas at time t:

$$V_t = aS_{1.t} + bS_{2,t}$$

$$dS_i = \mu_i S_i dt + \sigma S_i dW_i$$

$$dW_1 dW_2 = \rho dt$$

$$E(S_{1.t} S_{1,t}) = S_{1,0} S_{2,0} e^{(\mu_1 + \mu_2 + \rho\sigma_1\sigma_2)t}$$

$$E(V_t) = aS_{1,0} e^{\mu_1 t} + bS_{2,0} e^{\mu_2 t}$$

$$E(V_t^2) = a^2 S_{1.0}^2 e^{(2\mu_1 + \sigma_1^2)} t + b^2 S_{2.0}^2 e^{(2\mu_2 + \sigma_2^2)} t + 2abS_{1,0} S_{2,0} e^{(\mu_1 + \mu_2 + \rho\sigma_1\sigma_2)t}$$

$$\mathrm{var}(V_t) = E(V_t^2) - E(V_t)^2$$

$$\mathrm{VaR}(V) = V_0 - \left(E(V_t) - 2.326\,\mathrm{sd}(V_t)\right)$$

3.2.2 Historical VaR

a. Decide the time span of VaR, (e.g. 5 days VaR)

b. Calculate a series of losses by log returns based on the chosen time span and shares of each stock in the portfolio

c. Sort the series of losses

d. Choose the top (1-VaRp) % losses and calculate the Historical VaR

3.2.3 Monte Carlo VaR

a. Calculate the drift and volatility for each stock in the portfolio

b. Generate a series of correlated random variables using correlation matrix

c. For each stock: : $S_T = S_0 e^{\left(\mu - \frac{\sigma^2}{2}\right) \times horizon\ days/252 + \sigma W}$

For option: Black-Scholes formula
Call option (C) and put option (P) prices are calculated using the following formulas:

$$C = S_0 e^{-qt} N(d_1) - Xe^{-rt} N(d_2)$$

$$P = Xe^{-rT} N(-d_2) - S_0 e^{-qt} N(-d_1)$$

Where $N(x)$ is the standard normal cumulative distribution function. The formulas for d_1 and d_2 are:

$$d_1 = \frac{ln\left(\frac{S_0}{X}\right) + t\left(r - q + \frac{\sigma^2}{2}\right)}{\sigma\sqrt{t}}$$

$$d_2 = d_1 - \sigma\sqrt{t}$$

d. Calculate the portfolio value by summing up each asset value based on its shares
e. Sort the series of portfolio losses (St - S0)

f. Choose the top (1-VaRp) % losses and calculate the Monte Carlo VaR

3.3 Advantages and Limitations

3.3.1 Parametric VaR

The advantage of Parametric VaR is that the calculation is very simple and straightforward. It will be the most suitable method for person to get start on learning VaR calculation.

The limitation of Parametric VaR is very obvious, it has a strict assumption (for a single stock, it has to follow Geometric Brownian Motion, while for a portfolio, the underlying assets should also follow GBM). In reality, it is not a common situation, and any small violation will low the accuracy of Parametric method.

3.3.2 Historical VaR

Compared to the others, the major advantage of Historical VaR is that assumptions based on historical method are very simple. Besides that, there is no need to estimate the drifts and volatilities, which makes the calculation simple.

The limitation of Historical VaR is also very obvious. Since it high depends on historical data, without sufficient historical data, this method would become very inaccurate. And any extreme past events will have a significant influence on Historical VaR result by this method.

3.3.3 Monte Carlo VaR

The advantage of Monte Carlo VaR is that the result generating by this method will be more general and insensitive to the distribution of the asset performance.

Since Monte Carlo VaR will simulate 10,000 paths in this project, the major weakness of it is the lowest calculation speed among all three methods.

Validation Methodology and Results

4.1 Test Plan

Here we choose two stocks and two options in our portfolio to test the validity of our system. The stocks are XOM and INTC respectively. And options are XOM and INTC respectively. Besides, the stocks are always in long position. For option part, we set XOM a call option and INTC as put option.

We give examples of setting parameters:

Window: 5 year

Horizon: 5 days

Confidence level: 99%

Risk-free interest rate: 0.5%

Weights：0.90stocks + 0.05call option + 0.05put option

4.1.1 Assumptions

- Stock weight and option weight represent the weights of each asset we hold.
- For the Monte Carlo VaR method and Parametric VaR, we will assume that each stock follows GBM. For option part, we model the underlying, then calculate the price.
- We assume that the options we bought have the everlasting properties. In other words, the strike price and the time to maturity are unchanged on every day.

- Two options are both at the money (ATM), which means the strike price is the same as the current spot price of the underlying security, i.e. S0.

4.1.2 Data Source

Sample Stocks: XOM

Sample Option: XOM; INTC

Time Period: 1990-01-02" to "2018-12-19", daily data

Source: Bloomberg (Implied Volatility of Options); Yahoo Finance (Stock Prices)

4.2 The Scope of the Validation

Each input file is in the format of csv. There are four input files for option, which corresponding to the underlying historical prices of two options and their implied volatilities. As the stock price is same as the underlying price of the one of the Option, no more additional input is needed. namely, there are totally four input files for our model validation. Date ranges from 1990-01-02" to "2018-12-19"

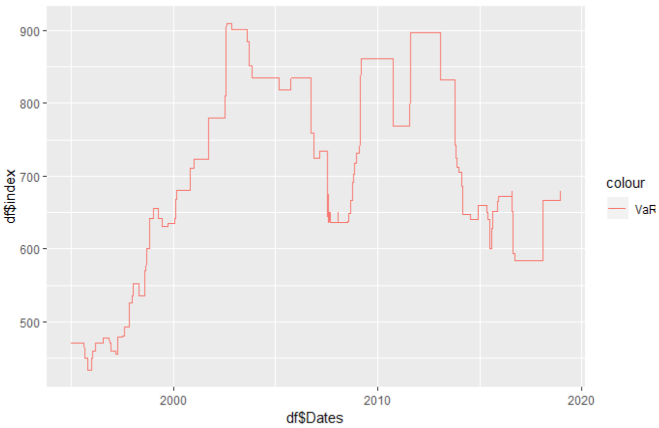
4.2.1 Validation Results

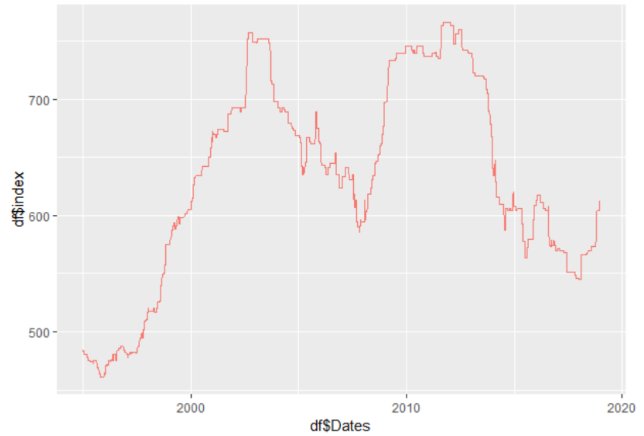
After conducting the test plan, we get the following figures:

For a single stock:

- Historical VaR & ES

VaR *ES*

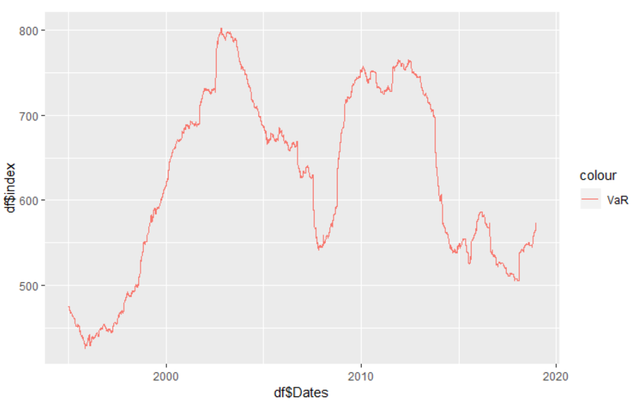


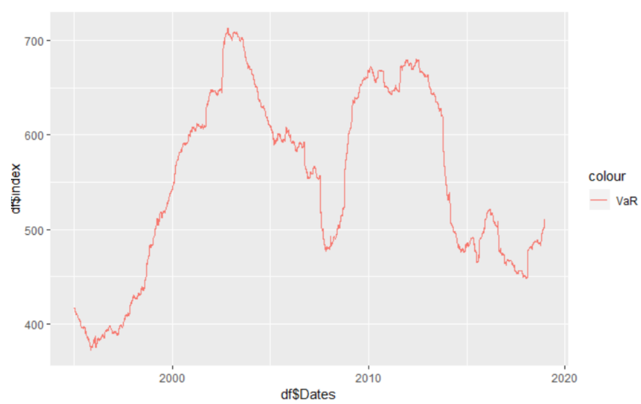


- Parametric VaR & ES

VaR

ES

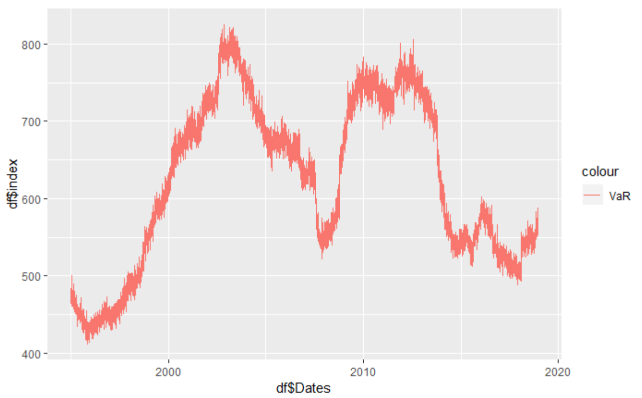


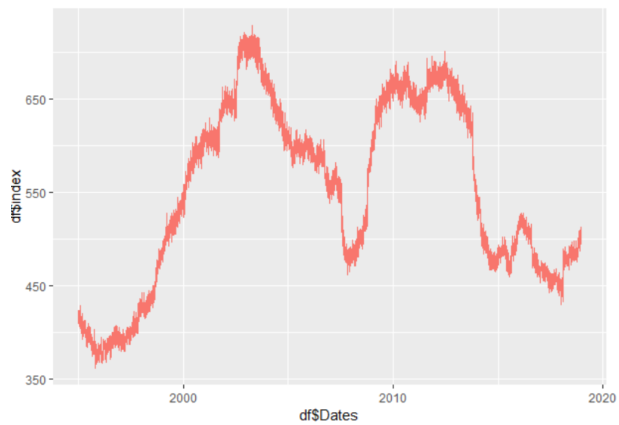


- Monte Carlo VaR & ES

VaR

ES

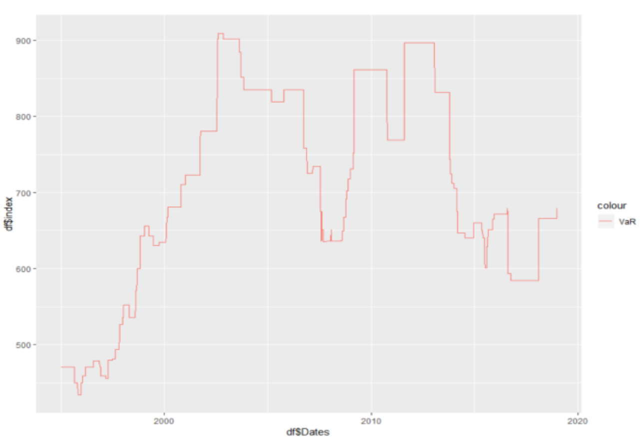




For a Portfolio with two stocks:

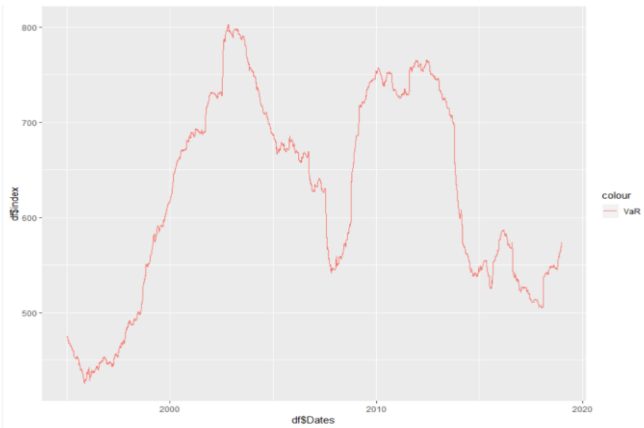
- Historical VaR & ES

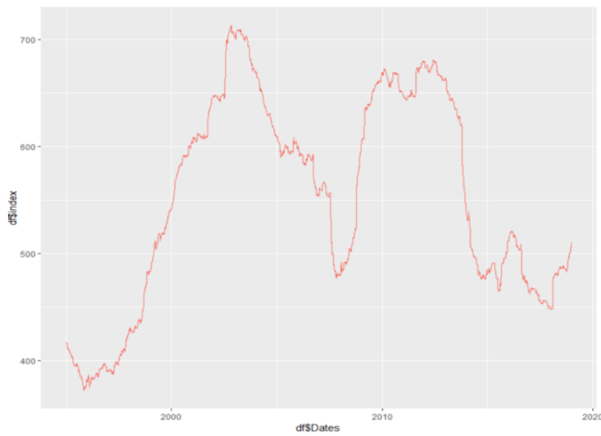
VaR *ES*



- Parametric VaR & ES (Portfolio follows GBM)

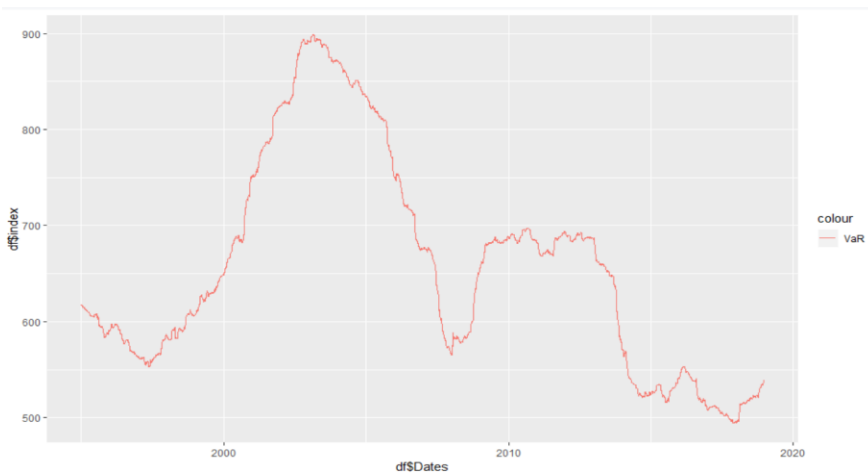
VaR *ES*





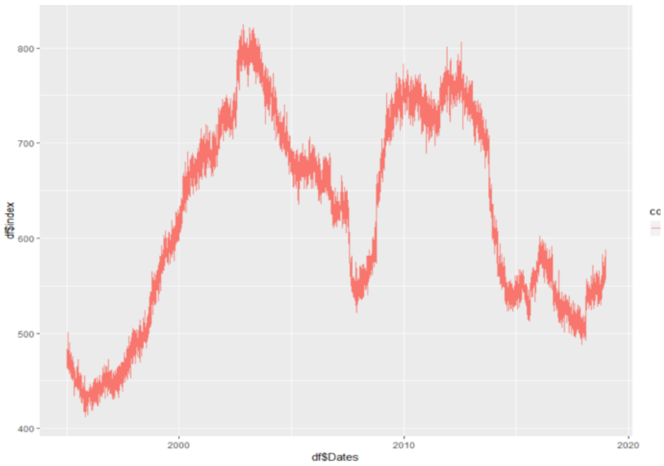
- Parametric VaR (Underlying follows GBM)

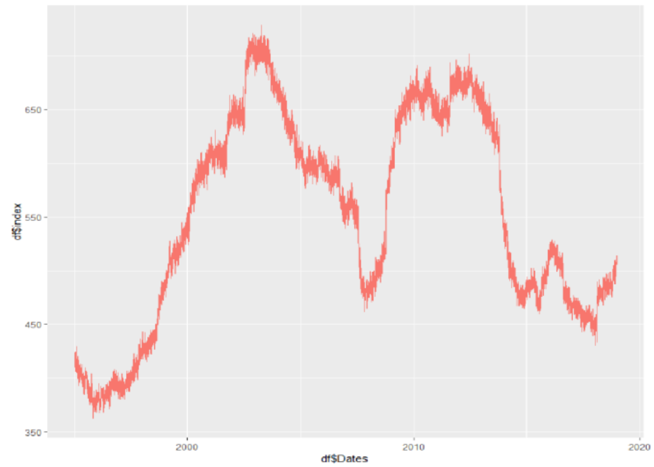
VaR



- Monte Carlo VaR & ES

VaR *ES*

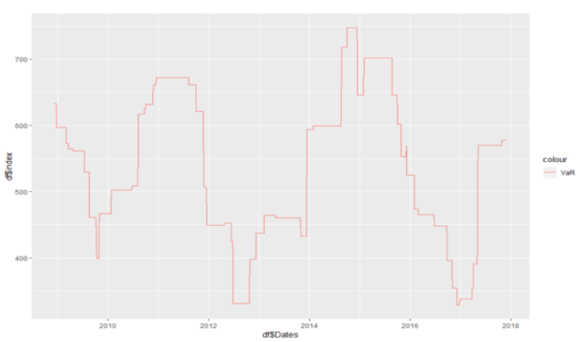


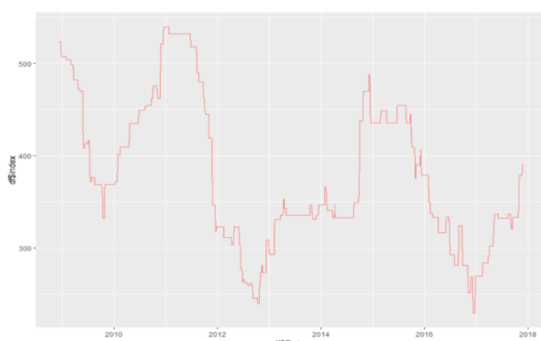


For a Portfolio with two stocks, one put and one call:

- Historical VaR & ES

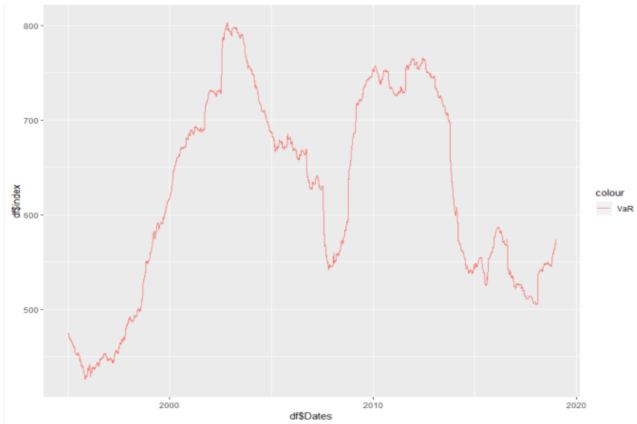
VaR *ES*

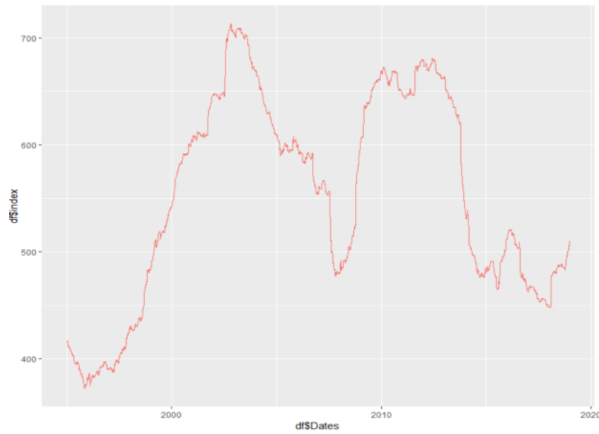




- Parametric VaR & ES

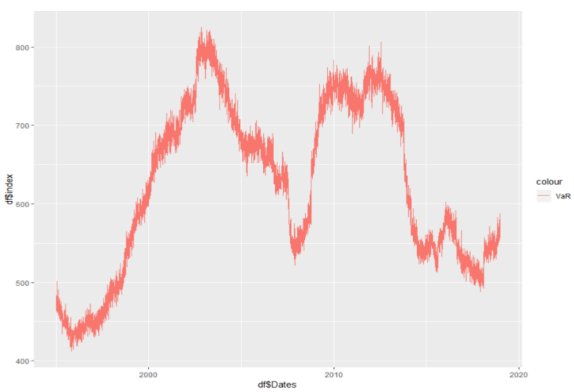
VaR *ES*



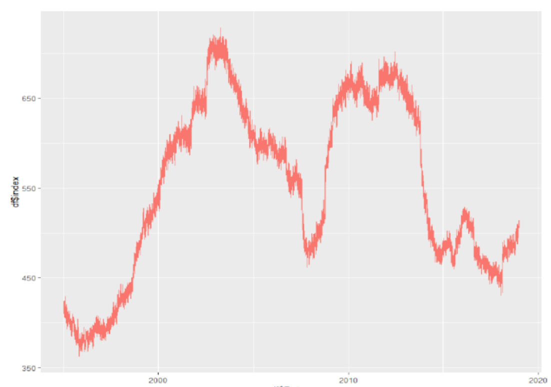


- Monte Carlo VaR & ES

VaR



ES



From the figures, we can find out that when we calibrate our VaR within 10000, the different approaches of calculating VaR are generally similar. Then we can take a look at the 2 sets results respectively. Timeline ranges 29 years, from 1990-01-02" to "2018-12-19".

4.2.2 Back Test

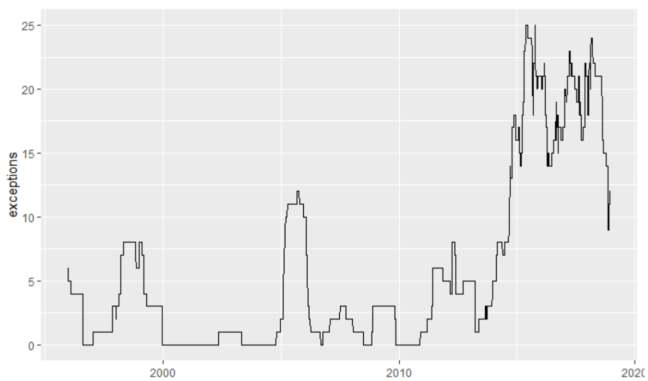
Through back test, we count the number of exceptions in periods of time, i.e. days when portfolio losses exceed VaR estimates. Since the Historical VaR used the historical data to calculate the VaR, there is no need of back test. There we conduct the back test on the Parametric VaR and Monte Carlo VaR.

Below are Back Test graphs we generated,

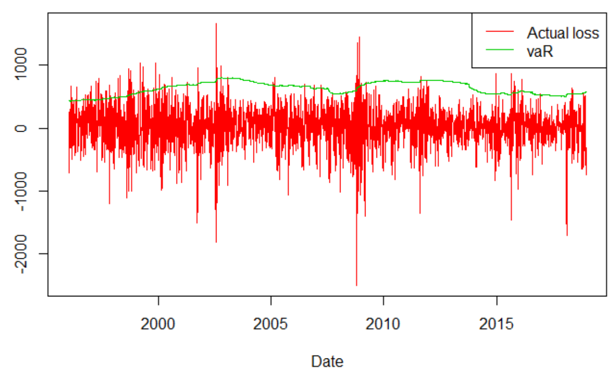
1. **Single Stock**

- Backtest of parametric VaR

Exceptions

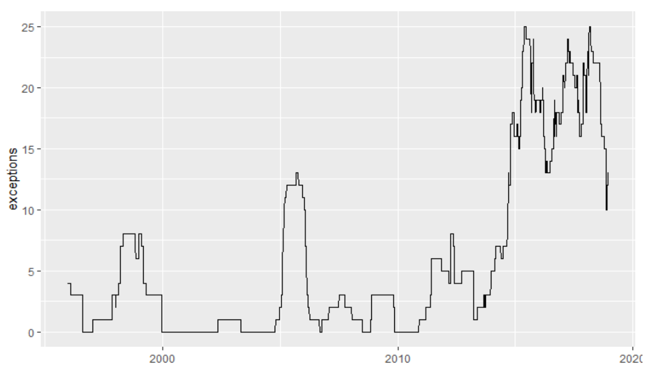


VaR vs actual P&L

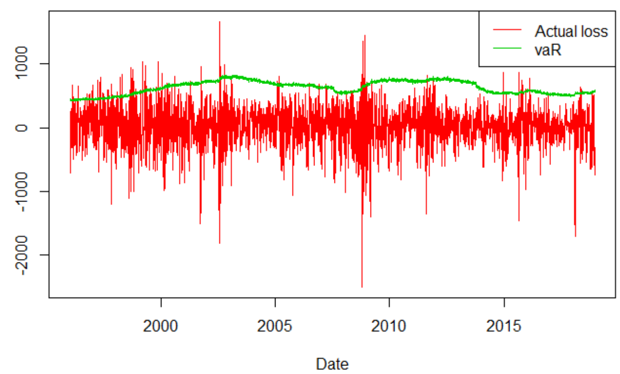


- Backtest of Monte Carlo VaR

Exceptions



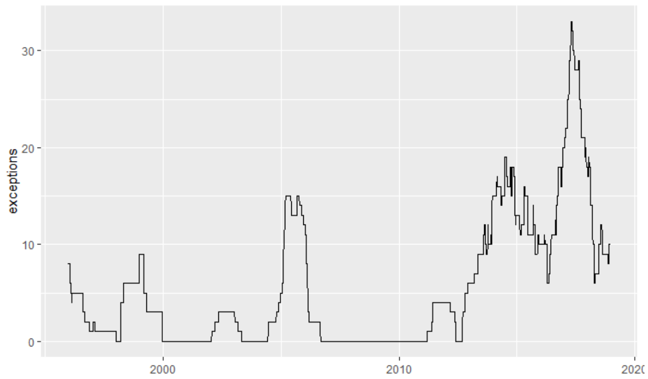
VaR vs actual P&L

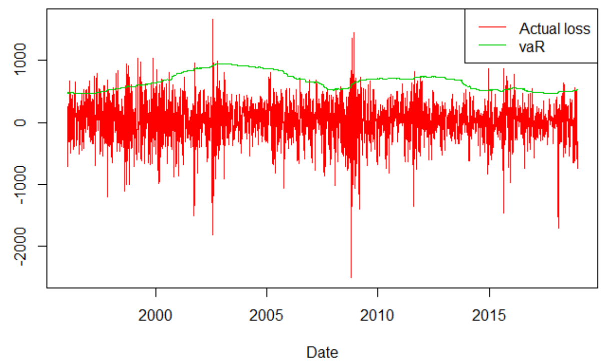


2. **Portfolio (Stocks only)**

- Back Test of Parametric VaR portfolio follows GBM

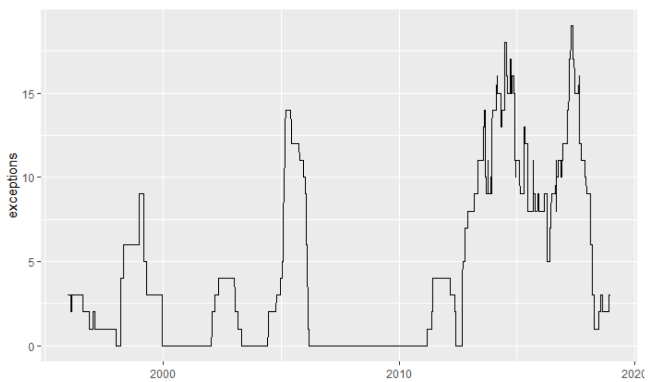
Exceptions *VaR vs actual P&L*

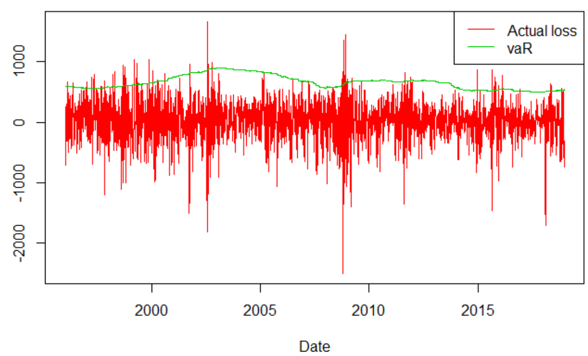




- Back Test of Parametric VaR underlying follows GBM

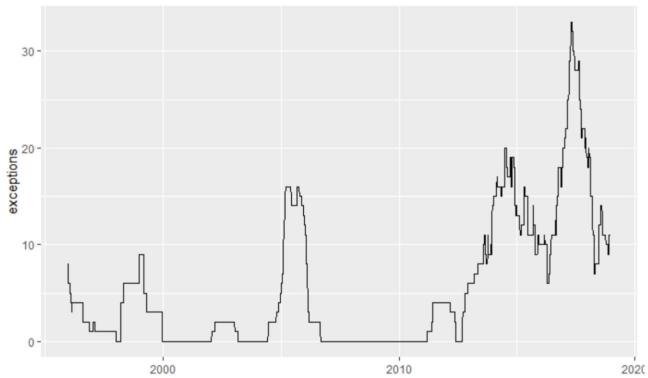
Exceptions *VaR vs actual P&L*

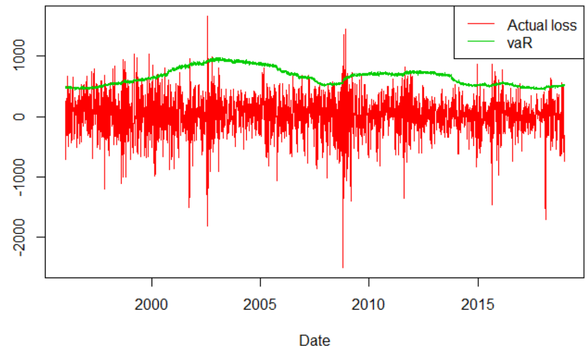




- Back Test of Monte Carlo VaR portfolio follows GBM

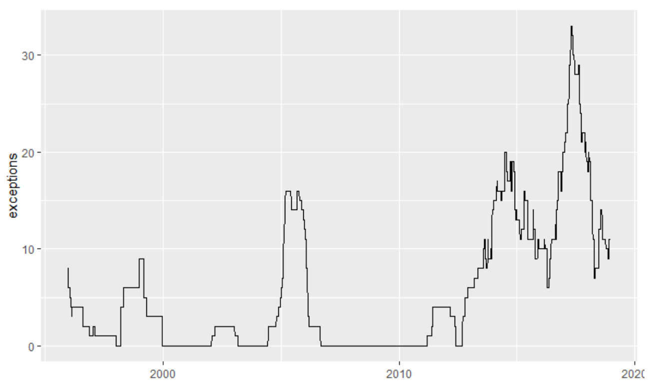
Exceptions *VaR vs actual P&L*

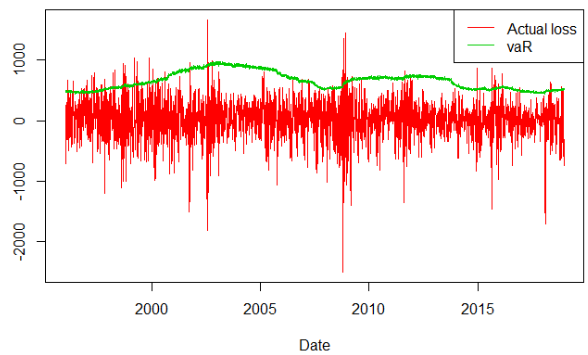




- Back Test of Monte Carlo VaR underlying follows GBM

Exceptions *VaR vs actual P&L*





Here we set the horizon equal to 5 days, and window length to one year. Data range 29 years, from 1990-01-02" to "2018-12-19".

Observation: As indicated by the range of bias from actual losses, the number of exceptions increases as volatility increases. Moreover, the VaR rises when the volatility increases. However, the rise of VaR doesn't rise fast enough to account for the increased market volatility. On the other hand, the VaR falls when the volatility drops, but it takes a long time to deflate to the new market behavior. We suspect that the overlapping periods contribute to the large number of exceptions. E.g. there is a high correlation between the 5-day loss on a given day and the 5 day loss on the following day.

Conclusions and Recommendations

In this project, we construct a risk calculation system based on VaR and ES values. The calculation methods we used are Parametric, Historical, and Monte Carlo. The advantage of this model is its portfolio flexibility since both stocks and options can be included in the portfolio. It is a user friendly system, since users can pick their own stocks and options portfolio. However, the limitation of our system is that all the stocks are required to be on the long short position.

Bibliography

For the detailed functions in our system, please visit our github, we include all the data, inputs, functions and documentations on github:

https://github.com/Fiona3308/risk-mgmt-GroupX

Here is the code of main.rmd:

```
### Step 1: Load Data (Equities in Portfolio)
We download our data from "Yahoo Finance" by using "tidyquant" package. Users can choose any tickers they want.
Here,for mathematical descriptions of model, we use "XOM"&"INTC" as example.Users can replace all the "XOM"&"INTC" in this Rmd file with tickers they want.
```{r,message=FALSE}
library(ggplot2)
library(MASS)
library(quantmod)
if (!require("quantmod")) {
    install.packages("quantmod")
    library(quantmod)
}
if (!require("tidyquant")) {
    install.packages("tidyquant")
    library(tidyquant)
}
```

Tickers

Stock price is orderd from newest to oldest. We set the start date of data is "1990-01-01", and the end date is system date.
```{r}
XOM <- tq_get("XOM", get = "stock.prices",from="1990-01-01")
XOM <- XOM[order(XOM$date,decreasing = T),]
INTC <- tq_get("INTC", get = "stock.prices",from="1990-01-01")
INTC <- INTC[order(INTC$date,decreasing = T),]
```

Options

We download data implied volatility of options from bloomberg.
```{r}
imp_vol <- read.csv("../data/volatility.csv")
imp_vol$Date <- as.Date(imp_vol$Date,"%m/%d/%Y")
intc.option <- read.csv("~/GitHub/risk-mgmt-GroupX/data/intc-option.csv")
xom.option <- read.csv("~/GitHub/risk-mgmt-GroupX/data/xom-option.csv")
```
Step 2: Source function and files
For the risk calculation system, we have three parts:

* Part 1: Calculate the risk for individual stock
* Part 2: Calculate the risk for portfolio that only including two stocks
* Part 3: Calculate the risk for portfolio that including two stocks and two options

We calculated parameters that calibrated to historical stock prices.
```{r}
# calculate parameter for stocks/portfolio return
source("../code/parameter/winEstGBM.R")
source("../code/parameter/expEstGBM.R")
source("../code/parameter/winEstGBM2.R") #estimated parameters and rho for two stocks
```

```{r}
# historical VaR&ES
source("../code/stock/HVaR.R")        #for individual stock & portfolio1 two stocks
source("../code/stock/HES.R")         #for individual stock & portfolio1 two stocks
source("../code/Option_HVaR.R")       #for portfolio2 stock+options


# monte carlo VaR&ES
source("../code/stock/MC_update.R")  #for individual stock
source("../code/corrgbmsampset.R")   #for portfolio1 two stocks
source("../code/Option_MCVaR.R")      #for portfolio2 stock+options

# Parametric VaR&ES
source("../code/stock/gbmVaR.R")         #for individual stock
source("../code/stock/gbmES.R")          #for individual stock
source("../code/stocks_parametricVaR.R") #for portfolio1 two stocks
source("../code/Option_ParametricVaR.R") #for portfolio2 stock+options

# plot graph
source("../code/plotGraph.R")
source("../code/BTplot.R")

#others
source("../doc/calculation_measure.R")
source("../code/BlackScholesOption.R")

# Backtest
source("../code/BackTest.R")
source("../code/Loss.R")
```
```

```
### Step 3: Individual Stock Analysis

#### 3.0: Prepare Inputs
This part allows users to set arbitrary inputs.
```{r}
s1 <- XOM$adjusted
s2 <- INTC$adjusted
dRtn <- 5                               #horizon for day,eg:5 day VaR
year <- 5                               #window length, 5 years
par1 <- winEstGBM(s1,dRtn,year)         #estimated mu and sigma of stock price
par2 <- winEstGBM(s2,dRtn,year)
s0 <- 10000                             #$10,000 dollar position each day
VaRp <- 0.99
ESp <- 0.95
npaths <- 10000
```

3.1: Calculate Individual Stock VaR&ES
```{r,warning=FALSE}
# historical VaR&ES
Hvar <- HVaR_S(s1,VaRp,dRtn,year,s0)
Hes <- ES_S(s1,ESp,dRtn,year,s0)
plotGraph(Hvar,XOM$date)
plotGraph(Hes,XOM$date)

# paramentric VaR
GVaR <- gbmVaR(s0,par1$mu_gbm,par1$sigma_gbm,VaRp,dRtn)
GES <- gbmES(s0,par1$mu_gbm,par1$sigma_gbm,ESp,dRtn)
plotGraph(GVaR,XOM$date)
plotGraph(GES,XOM$date)

# Monte Carlo VaR
MVaR <- MCVaR(s0, par1$mu_gbm, par1$sigma_gbm, VaRp, npaths,year,dRtn)
MES <- MCES(s0, par1$mu_gbm, par1$sigma_gbm, ESp, npaths,year,dRtn)
plotGraph(MVaR,XOM$date)
plotGraph(MES,XOM$date)
```
Step 4: Portfolio Analysis

4.1: Part 1: Portfolio = weight1*s1 + weight2*s2
4.1.0: Prepare Inputs
```{r}
# This part is allowed to set arbitrary inputs
source("../code/portfolio_value.R")
prices <- comb.col(s1,s2)
positions <- c("long","long")
wgt <- c(0.6,0.4)
v0 <- 10000

# wgt <- c(156/(156+200),200/(156+200))
# price_date <- cbind.data.frame(XOM$date,prices)
# colnames(price_date) <- c("date","s1","s2")
```

```{r}
port_value <- portfolio_px(prices,wgt,positions,v0)
#estimated parameters of whole portfolio
port_par1 <- winEstGBM(port_value,dRtn,year)

#estimated parameters of each part and covariance matrix in portfolio
port_par2 <- winEstGBM2(prices,dRtn,year)

shares <- v0*wgt/prices[1,]       #shares number of s1,s2 (notes:set shares number using the newest price)
s0 <- prices[1,]                  #price at start day(eg,1997-01-01)
mu <- port_par2$mu_gbm
sigma <- port_par2$sigma_gbm
rho <- port_par2$rho
```
```

```
### Step 4: Portfolio Analysis

#### 4.1: Part 1: Portfolio = weight1*s1 + weight2*s2
##### 4.1.0: Prepare Inputs
```{r}
# This part is allowed to set arbitrary inputs
source("../code/portfolio_value.R")
prices <- comb.col(s1,s2)
positions <- c("long","long")
wgt <- c(0.6,0.4)
v0 <- 10000

# wgt <- c(156/(156+200),200/(156+200))
# price_date <- cbind.data.frame(XOM$date,prices)
# colnames(price_date) <- c("date","s1","s2")
```

```{r}
port_value <- portfolio_px(prices,wgt,positions,v0)
#estimated parameters of whole portfolio
port_par1 <- winEstGBM(port_value,dRtn,year)

#estimated parameters of each part and covariance matrix in portfolio
port_par2 <- winEstGBM2(prices,dRtn,year)

shares <- v0*wgt/prices[1,]      #shares number of s1,s2 (notes:set shares number using the newest price)
s0 <- prices[1,]                 #price at start day(eg,1997-01-01)
mu <- port_par2$mu_gbm
sigma <- port_par2$sigma_gbm
rho <- port_par2$rho
```

4.1.1: Calculate Portfolio VaR&ES
```{r}
# Historical VaR&ES
port_HVaR <- HVaR_S(port_value,VaRp,dRtn,year,v0)
port_HES <- ES_S(port_value,ESp,dRtn,year,v0)

#here,using XOM date for plot because the date of portfolio is same with XOM and INTC
plotGraph(port_HVaR,XOM$date)
plotGraph(port_HES,XOM$date)


# Parametric VaR1(&ES): portfolio follows GBM
GVaR_p1 <- gbmVaR(v0,port_par1$mu_gbm,port_par1$sigma_gbm,VaRp,dRtn)
GES_p1 <- gbmES(v0,port_par1$mu_gbm,port_par1$sigma_gbm,ESp,dRtn)
plotGraph(GVaR_p1,XOM$date)
plotGraph(GES_p1,XOM$date)


# Parametric VaR2: underlying stock follows GBM
PVaR_p1 <- parametricVaR(shares,s0,mu,sigma,rho,VaRp,dRtn,v0)
plotGraph(rev(PVaR_p1),INTC$date)


# Monte Carlo VaR1: portfolio follows GBM
port_MVaR <- MCVaR(v0, port_par1$mu_gbm, port_par1$sigma_gbm, VaRp, npaths,year,dRtn)
port_MES <- MCES(v0, port_par1$mu_gbm, port_par1$sigma_gbm, ESp, npaths,year,dRtn)
plotGraph(port_MVaR,XOM$date)
plotGraph(port_MES,XOM$date)


# Monte Carlo (underlying stock follows GBM)
# MCVaR_p1 <- MCVaR_p(v0, port_par2$mu_gbm, port_par2$sigma, port_par2$rho,shares,VaRp, npaths,year,dRtn)
# plotGraph(MCVaR_p1,INTC$date)
```
```

```
#### 4.2: Part 2: Portfolio = Stocks + Options
Here, we only use one stock, a call option of the stock and a put option of the stock.

##### 4.2.0: Prepara Inputs
```{r}
wgt_s <- 0.9                          #weights of stocks in portfolio
wgt_call <- 0.05                      #weights of call option in portfolio
wgt_put <- 0.05                       #weights of put option in portfolio
v0 <- 10000
VaRp <- 0.99
horizon <- 5
year <- 1
rf <- 0.005
```

```{r}
option <- function(option,price){
  option <- option[,c(1,ncol(option))]
  colnames(option) <- c("date","Implied_Vol")
  option$date <- as.Date(option$date,"%m/%d/%y")
  px <- price[,c(1,ncol(price))]
  option_px <- merge(transform(px,date),transform(option,date))
  return(option_px)
}

option1 <- option(xom.option,XOM)
option2 <- option(intc.option,INTC)

price1 <- option1$adjusted

maturity1 <- 252                       #1 year
maturity2 <- 252                       #1 year
strike1 <- price1
strike2 <- price1
```
```

```
```{r}
iv1 <- option1$Implied_Vol
iv2 <- option1$Implied_Vol

putt <- Put(price1, strike1, rf, maturity1-horizon, iv1)
calll <- Call(price1, strike2, rf, maturity2-horizon, iv2)

nstocks <- wgt_s*v0/option1$adjusted[1]
ncalls <- 0.05*v0/calll[1]
nputs <- 0.05*v0/putt[1]

mu <- par1$mu_gbm
sigma <- par1$sigma_gbm
npath <- 1000
price0<- price1[length(price1)]
s0 <- 10000
```

4.2.1: Calculate Portfolio VaR&ES
```{r,warning=FALSE}
# Historical VaR&ES
OP_HVaR <- Option_HVaR(price1, price1, year, rf, nstocks, iv1, strike1, maturity1,
                     iv2, strike2, maturity2, ncalls, nputs,
                     VaRp, horizon)
plotGraph(OP_HVaR,option1$date)


s0 <- price1
# Parametric
OP_PVaR <- Option_ParametricVaR(price0,s0, mu, sigma, rf, nstocks, iv1, maturity1,
                      iv2, maturity2, ncalls, nputs,
                      VaRp, horizon)
plotGraph(OP_PVaR,option1$date)


# Monte Carlo VaR&ES
OP_MCVaR <- Option_MCVaR(s0, mu, sigma, rf, nstocks, iv1, maturity1,
                      iv2, maturity2, ncalls, nputs,VaRp, horizon, npath)
plotGraph(OP_MCVaR,option1$date)
```
```

```
### Step 5: Back Test

#### 5.1: Individual Stock
```{r,warning=FALSE}
#Backtest of parametric VaR
GBT<-BackTest(s1,GVaR,1,10000)
BTplot(GBT,XOM$date)
GLoss<-Loss(s1,GVaR,1,10000)
plot(XOM$date[1:length(GLoss[,1])],GLoss[,1],type="l",col="2",xlab = "Date",ylab = "")
lines(XOM$date[1:length(GLoss[,1])],GLoss[,2],y=,type="l",col="3")
legend("topright",legend=c("Actual loss","VaR"),col=2:3,lty=1)

#Backtest of Monte Carlo VaR
MBT<-BackTest(s1,MVaR,1,10000)
BTplot(MBT,XOM$date)
MLoss<-Loss(s1,MVaR,1,10000)
plot(XOM$date[1:length(GLoss[,1])],MLoss[,1],type="l",col="2",xlab = "Date",ylab = "")
lines(XOM$date[1:length(GLoss[,1])],MLoss[,2],y=,type="l",col="3")
legend("topright",legend=c("Actual loss","VaR"),col=2:3,lty=1)
```

5.2: Two stocks in the portfolio
```{r, warning=FALSE}
#Backtest of Parametric VaR portfolio follows GBM
GBT_p1<-BackTest(port_value,GVaR_p1,1,10000)
BTplot(GBT_p1,XOM$date)
GLoss_p1<-Loss(port_value,GVaR_p1,1,10000)
plot(XOM$date[1:length(GLoss_p1[,1])],GLoss_p1[,1],type="l",col="2",xlab = "Date",ylab = "")
lines(XOM$date[1:length(GLoss_p1[,1])],GLoss_p1[,2],y=,type="l",col="3")
legend("topright",legend=c("Actual loss","VaR"),col=2:3,lty=1)

#Back Test of  Parametric VaR underlying follows GBM
PBT_p1<-BackTest(port_value,PVaR_p1,1,10000)
BTplot(PBT_p1,XOM$date)
PLoss_p1<-Loss(port_value,PVaR_p1,1,10000)
plot(XOM$date[1:length(PLoss_p1[,1])],PLoss_p1[,1],type="l",col="2",xlab = "Date",ylab = "")
lines(XOM$date[1:length(PLoss_p1[,1])],PLoss_p1[,2],y=,type="l",col="3")
legend("topright",legend=c("Actual loss","VaR"),col=2:3,lty=1)

#Back Test of  Monte Carlo VaR portfolio follows GBM
MBT_port<-BackTest(port_value,port_MVaR,1,10000)
BTplot(MBT_port,XOM$date)
MLoss_port<-Loss(port_value,port_MVaR,1,10000)
plot(XOM$date[1:length(MLoss_port[,1])],MLoss_port[,1],type="l",col="2",xlab = "Date",ylab = "")
```

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```