FE 621 Homework 1

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2/13/2020

# Part 1

## 1. Data Gathering Component

library(quantmod)

library(jsonlite)

library(dplyr)

get\_option <- function(symbol,date){  
   
 ## Finding the end of the 3 month period  
 get\_3m\_unix <- function(date){  
 date <- as.Date(date)  
 date <- date+months(3)  
 date <- nth\_weekday(5,date,3)  
 expiry <- difftime(date,as.Date('1970-01-01'),units='secs')  
 return(expiry)  
 }  
   
 #to format JSON data  
 reformat\_table <- function(x){  
 if(is.null(x) || length(x) < 1)  
 return(NULL)  
 # reformat col names  
 names(x) <- tolower(gsub("[[:space:]]", "", names(x)))  
 # assigning the new col names  
 # Vol=volume, OI=openinterest,  
 d <- with(x, data.frame(Strike=strike, Last=lastprice, Chg=change,  
 Bid=bid, Ask=ask,  
 row.names=contractsymbol, stringsAsFactors=FALSE))  
 # removing commas from the data  
 d[] <- lapply(d, gsub, pattern=",", replacement="", fixed=TRUE)  
 d[] <- lapply(d, type.convert, as.is=TRUE)  
 d  
 }  
   
 #gets calls and puts for one expiry  
 get\_option\_data <- function(symbol,expiry){  
 # url for scraping Yahoo Finance for options data using JSON  
 base <- "https://query2.finance.yahoo.com/v7/finance/options/"  
 url <- paste(base,symbol,"?date=",expiry,sep='')  
 result <- fromJSON(url)  
 #creates table  
 tbl <- lapply(result$optionChain$result$options[[1]][,c('calls','puts')],'[[',1L)  
 calls <- mapply(reformat\_table,x=tbl,SIMPLIFY=F)$calls  
 # assign dates  
 calls['Expiry'] <- as.Date(as.POSIXct(expiry, origin="1970-01-01"), origin="1970-01-01")  
 puts <- mapply(reformat\_table,x=tbl,SIMPLIFY=F)$puts  
 puts['Expiry'] <- calls['Expiry']  
 return(list(calls,puts))  
 }  
 # calling all helper functions to pull chains for all expirations in next 3 months  
 date <- as.Date(date)  
 expiry <- as.Date("2020-04-16")  
 base <- "https://query2.finance.yahoo.com/v7/finance/options/"  
 url <- paste(base,symbol,"?date=",expiry,sep='')  
 result <- fromJSON(url)  
 underlying <- result$optionChain$result$quote  
 # finding all expirations for a given underlying  
 available.expiries <- result$optionChain$result$expirationDates  
 # filtering to those that are within the period defined above as 3 months  
 expiries <- available.expiries[[1]][available.expiries[[1]] <= expiry]  
 if(length(expiries)==0)  
 {expiries<-available.expiries[[1]][1]}  
 calls <- do.call(rbind,lapply(expiries,  
 function(x) get\_option\_data(symbol,x)[[1]]))  
 calls['date'] <- date  
 puts <- do.call(rbind,lapply(expiries,  
 function(x) get\_option\_data(symbol,x)[[2]]))  
 puts['date'] <- date  
 return(list('symbol'=symbol,'exDates'=unique(calls['Expiry']),  
 'underlyingP'=underlying,  
 'calls'=calls,'puts'=puts))  
}

## 2. Downloading Data for AMZN, SPY, and VIX

# Sampling Put and Call Data for first day: Feb 10, 2020  
#VIX1 <- get\_option("^VIX", date = Sys.Date())  
#SPY1 <- get\_option("SPY", date = Sys.Date())  
#AMZN1 <- get\_option("AMZN", date = Sys.Date())

# Sampling Put and Call Data for second day: Feb 11, 2020  
#VIX2 <- get\_option("^VIX", date = Sys.Date())  
#SPY2 <- get\_option("SPY", date = Sys.Date())  
#AMZN2 <- get\_option("AMZN", date = Sys.Date())

Commented out because as I explained to Professor Florescu I had some issues where I lost the data on friday and had to use Bloomberg data instead. The Bloomberg data is pulled for February 13 and 14.

setwd("/Users/Brendon/Documents/FE 621/HW 1")  
AMZNCall1 <- read.csv("AMZN Calls 2-13.csv")  
AMZNCall2 <- read.csv("AMZN Calls 2-14.csv")  
AMZNPut1 <- read.csv("AMZN Puts 2-13.csv")  
AMZNPut2 <- read.csv("AMZN Puts 2-14.csv")  
SPYCall1 <- read.csv("SPY Calls 2-13.csv")  
SPYCall2 <- read.csv("SPY Calls 2-14.csv")  
SPYPut1 <- read.csv("SPY Puts 2-13.csv")  
SPYPut2 <- read.csv("SPY Puts 2-14.csv")  
VIXCall1 <- read.csv("VIX Calls 2-13.csv")  
VIXCall2 <- read.csv("VIX Calls 2-14.csv")  
VIXPut1 <- read.csv("VIX Puts 2-13.csv")  
VIXPut2 <- read.csv("VIX Puts 2-14.csv")

At the time of downloading the data on 2/14 AMZN was at 2132.27, SPY was 336.69, and the VIX was at 14.30 and the 2/13 data is taken at close with AMZN at 2149.87, SPY at 337.06, and the VIX was 14.15

## 3. Description of the Assets

Each of the three underlying assets are unique with AMZN being the simplest as an equity of Amazon. SPY is the symbol for the SPDR S&P 500 ETF, which is a passive investment vehicle that is designed to track the movements of the entire market. This allows investors to gain exposure to the market as a whole without having to invest in every constituent or apply portfolio optimization to develop an asset allocation strategy to design a portfolio that tracks the market. The VIX is the symbol for the CBOE Volatility Index, which measures volatility in the S&P 500 in the coming 30 days. The VIX is an important indicator of investor sentiment as analyzing the activity of derivatives on this index can prove to be powerful in measuring how investors feel about market conditions and their expectations for the future. All three symbols are major assets with a multitude of derivatives that trade off of them with varying expirations and strike prices.

## 4. Interest Rate

I will be using the 6 Month Treasury Bill rate of 1.52%

# Part 2

## 5. Black-Scholes Implementation

r <- .0152  
BSMprice <- function(S0,K,T,r,sigma,opt='c'){  
 d1 <- (1/(sigma\*sqrt(T)))\*(log(S0/K)+(r+.5\*sigma^2)\*T)  
 d2 <- d1 - sigma\*sqrt(T)  
 # If Call  
 if(opt == "c"){  
 return(S0\*pnorm(d1)-K\*exp(-r\*T)\*pnorm(d2))  
 }  
 # Put  
 else{  
 return(K\*exp(-r\*T)\*pnorm(-d2)-S0\*pnorm(-d1))  
 }  
}  
BSMprice(100,105,1,r,.15)

## [1] 4.524136

BSMprice(100,105,1,r,.15,"p")

## [1] 7.940204

## 6. Bisection Method for Calculating Implied Volatility

bisection <- function(f,a,b,tol=10^-6){  
 c <- (a+b)/2  
 #while < tolerance and max iterations hasn't been reached  
 while(abs(b-a)>tol){  
 if(f(c)==0){return(c)}  
 if(f(a)\*f(c) < 0){  
 b <- c  
 }  
 else{  
 a <- c  
 }  
 c <- (a+b)/2  
 }  
 ifelse(abs(c)<.0000001,return(NA),return(c))  
}  
paste('Bisection:',round(bisection(function(x) cos(x),-1,2),3), "Check if answer is within the tolerance: ", round(cos(bisection(function(x) cos(x),-1,2)),7))

## [1] "Bisection: 1.571 Check if answer is within the tolerance: 2e-07"

# Cleaning expiration dates to calculate time to maturity  
library(lubridate)

##   
## Attaching package: 'lubridate'

## The following object is masked from 'package:base':  
##   
## date

library(DataCombine)  
add\_year <- function(x){  
 if (year(x) < 2000){  
 year(x) <- 2020  
 return(as.Date(x))  
 }  
 return(as.Date(x))  
}  
temp <- as.Date(sapply(SPYCall1$Ticker, function(x) paste(substr(toString(x), 5,11), "20", sep = "")), "%m/%d/%Y")  
SPYCall1$Exp <- temp  
SPYCall1 <- DropNA(SPYCall1, Var = "Exp")

## 0 rows dropped from the data frame because of missing values.

SPYCall1$Exp <- as.Date(sapply(SPYCall1$Exp, add\_year))  
SPYCall1$Date <- as.Date("02/13/2020", '%m/%d/%Y')  
  
temp <- as.Date(sapply(SPYCall2$Ticker, function(x) paste(substr(toString(x), 5,11), "20", sep = "")), "%m/%d/%Y")  
SPYCall2$Exp <- temp  
SPYCall2 <- DropNA(SPYCall2, Var = "Exp")

## 0 rows dropped from the data frame because of missing values.

SPYCall2$Exp <- as.Date(sapply(SPYCall2$Exp, add\_year))  
SPYCall2$Date <- as.Date("02/14/2020", '%m/%d/%Y')  
  
temp <- as.Date(sapply(SPYPut1$Ticker, function(x) paste(substr(toString(x), 5,11), "20", sep = "")), "%m/%d/%Y")  
SPYPut1$Exp <- temp  
SPYPut1 <- DropNA(SPYPut1, Var = "Exp")

## 1 rows dropped from the data frame because of missing values.

SPYPut1$Exp <- as.Date(sapply(SPYPut1$Exp, add\_year))  
SPYPut1$Date <- as.Date("02/13/2020", '%m/%d/%Y')  
  
temp <- as.Date(sapply(SPYPut2$Ticker, function(x) paste(substr(toString(x), 5,11), "20", sep = "")), "%m/%d/%Y")  
SPYPut2$Exp <- temp  
SPYPut2 <- DropNA(SPYPut2, Var = "Exp")

## 0 rows dropped from the data frame because of missing values.

SPYPut2$Exp <- as.Date(sapply(SPYPut2$Exp, add\_year))  
SPYPut2$Date <- as.Date("02/14/2020", '%m/%d/%Y')  
  
temp <- as.Date(sapply(AMZNCall1$Ticker, function(x) paste(substr(toString(x), 6,12), "20", sep = "")), "%m/%d/%Y")  
AMZNCall1$Exp <- temp  
AMZNCall1 <- DropNA(AMZNCall1, Var = "Exp")

## 0 rows dropped from the data frame because of missing values.

AMZNCall1$Exp <- as.Date(sapply(AMZNCall1$Exp, add\_year))  
AMZNCall1$Date <- as.Date("02/13/2020", '%m/%d/%Y')  
  
temp <- as.Date(sapply(AMZNCall2$Ticker, function(x) paste(substr(toString(x), 6,12), "20", sep = "")), "%m/%d/%Y")  
AMZNCall2$Exp <- temp  
AMZNCall2 <- DropNA(AMZNCall2, Var = "Exp")

## 0 rows dropped from the data frame because of missing values.

AMZNCall2$Exp <- as.Date(sapply(AMZNCall2$Exp, add\_year))  
AMZNCall2$Date <- as.Date("02/14/2020", '%m/%d/%Y')  
  
temp <- as.Date(sapply(AMZNPut1$Ticker, function(x) paste(substr(toString(x), 6,12), "20", sep = "")), "%m/%d/%Y")  
AMZNPut1$Exp <- temp  
AMZNPut1 <- DropNA(AMZNPut1, Var = "Exp")

## 0 rows dropped from the data frame because of missing values.

AMZNPut1$Exp <- as.Date(sapply(AMZNPut1$Exp, add\_year))  
AMZNPut1$Date <- as.Date("02/13/2020", '%m/%d/%Y')  
  
temp <- as.Date(sapply(AMZNPut2$Ticker, function(x) paste(substr(toString(x), 6,12), "20", sep = "")), "%m/%d/%Y")  
AMZNPut2$Exp <- temp  
AMZNPut2 <- DropNA(AMZNPut2, Var = "Exp")

## 0 rows dropped from the data frame because of missing values.

AMZNPut2$Exp <- as.Date(sapply(AMZNPut2$Exp, add\_year))  
AMZNPut2$Date <- as.Date("02/14/2020", '%m/%d/%Y')  
  
temp <- as.Date(sapply(VIXCall1$Ticker, function(x) paste(substr(toString(x), 5,11), "20", sep = "")), "%m/%d/%Y")  
VIXCall1$Exp <- temp  
VIXCall1 <- DropNA(VIXCall1, Var = "Exp")

## 0 rows dropped from the data frame because of missing values.

VIXCall1$Exp <- as.Date(sapply(VIXCall1$Exp, add\_year))  
VIXCall1$Date <- as.Date("02/13/2020", '%m/%d/%Y')  
  
temp <- as.Date(sapply(VIXCall2$Ticker, function(x) paste(substr(toString(x), 5,11), "20", sep = "")), "%m/%d/%Y")  
VIXCall2$Exp <- temp  
VIXCall2 <- DropNA(VIXCall2, Var = "Exp")

## 0 rows dropped from the data frame because of missing values.

VIXCall2$Exp <- as.Date(sapply(VIXCall2$Exp, add\_year))  
VIXCall2$Date <- as.Date("02/14/2020", '%m/%d/%Y')  
  
temp <- as.Date(sapply(VIXPut1$Ticker, function(x) paste(substr(toString(x), 5,11), "20", sep = "")), "%m/%d/%Y")  
VIXPut1$Exp <- temp  
VIXPut1 <- DropNA(VIXPut1, Var = "Exp")

## 0 rows dropped from the data frame because of missing values.

VIXPut1$Exp <- as.Date(sapply(VIXPut1$Exp, add\_year))  
VIXPut1$Date <- as.Date("02/13/2020", '%m/%d/%Y')  
  
temp <- as.Date(sapply(VIXPut2$Ticker, function(x) paste(substr(toString(x), 5,11), "20", sep = "")), "%m/%d/%Y")  
VIXPut2$Exp <- temp  
VIXPut2 <- DropNA(VIXPut2, Var = "Exp")

## 0 rows dropped from the data frame because of missing values.

VIXPut2$Exp <- as.Date(sapply(VIXPut2$Exp, add\_year))  
VIXPut2$Date <- as.Date("02/14/2020", '%m/%d/%Y')

### Applying to DATA1 (at the money)

# First for the most at the money option  
# AMZN Price = 2149.87, closest strike is 2150   
# SPY = 337.06, closest strike is 335  
AMZN2150 <- AMZNCall1[AMZNCall1$Strike==2150,1:9][4,1:9]  
AMZN\_C1 <- (AMZN2150[1,3] + AMZN2150[1,4])/2  
AMZN\_S0 <- 2149.87  
AMZN\_K <- AMZN2150[1,1]  
AMZN\_T <- as.numeric(AMZN2150[1,8] - AMZN2150[1,9])/365  
AMZN\_ATM <- bisection(function(x) BSMprice(AMZN\_S0,AMZN\_K,AMZN\_T,r,x) - AMZN\_C1, 0, 1)  
  
SPY335 <- as.vector(SPYCall1[SPYCall1$Strike==335,1:9][4,1:9])  
SPY\_C1 <- (SPY335[1,3] + SPY335[1,4])/2  
SPY\_S0 <- 337.06  
SPY\_K <- 335  
SPY\_T <- as.numeric(SPY335[1,8] - SPY335[1,9])/365  
SPY\_ATM <- bisection(function(x) BSMprice(SPY\_S0,SPY\_K,SPY\_T,r,x) - SPY\_C1, 0, 1)  
  
print(paste("AMZN at the money implied volatility: ", round(AMZN\_ATM\*100, 2), "%; SPY at the money implied volatility: ", round(SPY\_ATM\*100, 2), "%", sep = ""))

## [1] "AMZN at the money implied volatility: 23.91%; SPY at the money implied volatility: 12.99%"

### Applying to DATA1 (in-the-money and out-of-the-money average)

# AMZN in-the-money defined as S0/K > 1.05  
AMZN\_in <- AMZNCall1[2149.87/AMZNCall1$Strike > 1.05, c(1,3,4,8,9)]  
AMZN\_in$C1 <- (AMZN\_in$Bid + AMZN\_in$Ask)/2  
AMZN\_in$S0 <- 2149.87  
AMZN\_in$T <- as.numeric(AMZN\_in$Exp - AMZN\_in$Date)/365  
#AMZN\_in$IV <- bisection(function(x) BSMprice(AMZN\_in$S0,AMZN\_in$Strike,AMZN\_in$T,r,x) - AMZN\_in$C1, 0, 1)  
AMZN\_IV\_in <- c()  
for (i in seq(1,nrow(AMZN\_in))) {  
 temp <- bisection(function(x) BSMprice(AMZN\_in$S0[i],AMZN\_in$Strike[i],AMZN\_in$T[i],r,x) - AMZN\_in$C1[i], 0, 2)  
 AMZN\_IV\_in <- c(AMZN\_IV\_in, temp)  
}  
AMZN\_in$IV <- AMZN\_IV\_in  
head(AMZN\_in)

## Strike Bid Ask Exp Date C1 S0  
## 1 1000 1147.90 1151.90 2020-02-14 2020-02-13 1149.900 2149.87  
## 2 1280 865.90 870.85 2020-02-14 2020-02-13 868.375 2149.87  
## 3 1650 495.15 501.30 2020-02-14 2020-02-13 498.225 2149.87  
## 4 1675 470.85 475.95 2020-02-14 2020-02-13 473.400 2149.87  
## 5 1715 430.90 436.85 2020-02-14 2020-02-13 433.875 2149.87  
## 6 1720 426.00 431.80 2020-02-14 2020-02-13 428.900 2149.87  
## T IV  
## 1 0.002739726 2  
## 2 0.002739726 2  
## 3 0.002739726 2  
## 4 0.002739726 2  
## 5 0.002739726 2  
## 6 0.002739726 2

print("About 30% of the data maxed out the bisection function suggesting an implied volatility greater than 200% the data frame below filters out such options")

## [1] "About 30% of the data maxed out the bisection function suggesting an implied volatility greater than 200% the data frame below filters out such options"

head(AMZN\_in[AMZN\_in$IV < 1.999, 1:9])

## Strike Bid Ask Exp Date C1 S0  
## 27 1985 165.1000 165.9000 2020-02-14 2020-02-13 165.5000 2149.87  
## 146 1640 508.5500 512.8999 2020-02-21 2020-02-13 510.7250 2149.87  
## 152 1740 410.3999 413.2000 2020-02-21 2020-02-13 411.7999 2149.87  
## 153 1750 399.3501 403.2000 2020-02-21 2020-02-13 401.2750 2149.87  
## 154 1760 391.3999 393.2500 2020-02-21 2020-02-13 392.3250 2149.87  
## 158 1830 322.0000 323.2000 2020-02-21 2020-02-13 322.6000 2149.87  
## T IV  
## 27 0.002739726 0.7343631  
## 146 0.021917808 0.7099652  
## 152 0.021917808 0.6884074  
## 153 0.021917808 0.6263013  
## 154 0.021917808 0.6902528  
## 158 0.021917808 0.5868115

print(paste("Therefore the mean in-the-money Implied Volatility is ", round(mean(AMZN\_in[AMZN\_in$IV < 1.9999, 9])\*100,2), "%", sep = ""))

## [1] "Therefore the mean in-the-money Implied Volatility is 31.07%"

# AMZN out-of-the-money defined as S0/K < .95  
AMZN\_out <- AMZNCall1[2149.87/AMZNCall1$Strike < .95, c(1,3,4,8,9)]  
AMZN\_out$C1 <- (AMZN\_out$Bid + AMZN\_out$Ask)/2  
AMZN\_out$S0 <- 2149.87  
AMZN\_out$T <- as.numeric(AMZN\_out$Exp - AMZN\_out$Date)/365  
AMZN\_IV\_out <- c()  
for (i in seq(1,nrow(AMZN\_out))) {  
 temp <- bisection(function(x) BSMprice(AMZN\_out$S0[i],AMZN\_out$Strike[i],AMZN\_out$T[i],r,x) - AMZN\_out$C1[i], 0, 2)  
 AMZN\_IV\_out <- c(AMZN\_IV\_out, temp)  
}  
AMZN\_out$IV <- AMZN\_IV\_out  
head(AMZN\_out)

## Strike Bid Ask Exp Date C1 S0 T  
## 91 2265 0.109999955 0.41 2020-02-14 2020-02-13 0.260 2149.87 0.002739726  
## 92 2270 0.100000024 0.32 2020-02-14 2020-02-13 0.210 2149.87 0.002739726  
## 93 2275 0.099999964 0.38 2020-02-14 2020-02-13 0.240 2149.87 0.002739726  
## 94 2280 0.099999964 0.36 2020-02-14 2020-02-13 0.230 2149.87 0.002739726  
## 95 2285 0.009999998 0.40 2020-02-14 2020-02-13 0.205 2149.87 0.002739726  
## 96 2290 0.100000024 0.21 2020-02-14 2020-02-13 0.155 2149.87 0.002739726  
## IV  
## 91 0.4537578  
## 92 0.4568963  
## 93 0.4812884  
## 94 0.4945769  
## 95 0.5029378  
## 96 0.5008912

print(paste("The maximum Implied Volatility for AMZN out-of-the-money is 137% so all data is included yielding a mean Implied Volatility of ", round(mean(AMZN\_out$IV)\*100,2), "%", sep = ""))

## [1] "The maximum Implied Volatility for AMZN out-of-the-money is 137% so all data is included yielding a mean Implied Volatility of 47.54%"

# SPY in-the-money defined as S0/K > 1.05  
SPY\_in <- SPYCall1[337.06/SPYCall1$Strike > 1.05, c(1,3,4,8,9)]  
SPY\_in$C1 <- (SPY\_in$Bid + SPY\_in$Ask)/2  
SPY\_in$S0 <- 337.06  
SPY\_in$T <- as.numeric(SPY\_in$Exp - SPY\_in$Date)/365  
SPY\_IV\_in <- c()  
for (i in seq(1,nrow(SPY\_in))) {  
 temp <- bisection(function(x) BSMprice(SPY\_in$S0[i],SPY\_in$Strike[i],SPY\_in$T[i],r,x) - SPY\_in$C1[i], 0, 2)  
 SPY\_IV\_in <- c(SPY\_IV\_in, temp)  
}  
SPY\_in$IV <- SPY\_IV\_in  
head(SPY\_in)

## Strike Bid Ask Exp Date C1 S0  
## 1 80 257.12988 257.4399 2020-02-21 2020-02-13 257.2849 337.06  
## 2 200 137.17999 137.4900 2020-02-21 2020-02-13 137.3350 337.06  
## 3 230 107.17999 107.5000 2020-02-21 2020-02-13 107.3400 337.06  
## 4 250 87.30000 87.4500 2020-02-21 2020-02-13 87.3750 337.06  
## 5 278 59.20999 59.5300 2020-02-21 2020-02-13 59.3700 337.06  
## 6 280 57.20999 57.5300 2020-02-21 2020-02-13 57.3700 337.06  
## T IV  
## 1 0.02191781 1.9999995  
## 2 0.02191781 1.5279059  
## 3 0.02191781 1.1510463  
## 4 0.02191781 0.9426503  
## 5 0.02191781 0.6375699  
## 6 0.02191781 0.6168199

print(paste("Again I filtered out the values greater than 1.999; however with this set that only represents less than 1% of the data so it is not nearly as significant. The filtered data is below:"))

## [1] "Again I filtered out the values greater than 1.999; however with this set that only represents less than 1% of the data so it is not nearly as significant. The filtered data is below:"

head(SPY\_in[SPY\_in$IV < 1.999,1:9])

## Strike Bid Ask Exp Date C1 S0  
## 2 200 137.17999 137.49001 2020-02-21 2020-02-13 137.33500 337.06  
## 3 230 107.17999 107.50000 2020-02-21 2020-02-13 107.34000 337.06  
## 4 250 87.30000 87.45000 2020-02-21 2020-02-13 87.37500 337.06  
## 5 278 59.20999 59.53000 2020-02-21 2020-02-13 59.37000 337.06  
## 6 280 57.20999 57.53000 2020-02-21 2020-02-13 57.37000 337.06  
## 7 286 51.23000 51.53999 2020-02-21 2020-02-13 51.38499 337.06  
## T IV  
## 2 0.02191781 1.5279059  
## 3 0.02191781 1.1510463  
## 4 0.02191781 0.9426503  
## 5 0.02191781 0.6375699  
## 6 0.02191781 0.6168199  
## 7 0.02191781 0.5610404

print(paste("This yields a mean in-the-money Implied Volatility for the SPY of ", round(mean(SPY\_in[SPY\_in$IV < 1.999,1:9]$IV)\*100,2), "%", sep = ""))

## [1] "This yields a mean in-the-money Implied Volatility for the SPY of 30.94%"

# SPY out-of-the-money defined as S0/K < .95  
SPY\_out <- SPYCall1[337.06/SPYCall1$Strike < .95, c(1,3,4,8,9)]  
SPY\_out$C1 <- (SPY\_out$Bid + SPY\_out$Ask)/2  
SPY\_out$S0 <- 337.06  
SPY\_out$T <- as.numeric(SPY\_out$Exp - SPY\_out$Date)/365  
SPY\_IV\_out <- c()  
for (i in seq(1,nrow(SPY\_out))) {  
 temp <- bisection(function(x) BSMprice(SPY\_out$S0[i],SPY\_out$Strike[i],SPY\_out$T[i],r,x) - SPY\_out$C1[i], 0, 2)  
 SPY\_IV\_out <- c(SPY\_IV\_out, temp)  
}  
SPY\_out$IV <- SPY\_IV\_out  
head(SPY\_out)

## Strike Bid Ask Exp Date C1 S0 T  
## 73 355.0 0.00 0.01 2020-02-21 2020-02-13 0.005000001 337.06 0.02191781  
## 127 355.0 0.02 0.03 2020-02-28 2020-02-13 0.025000001 337.06 0.04109589  
## 128 360.0 0.01 0.02 2020-02-28 2020-02-13 0.015000001 337.06 0.04109589  
## 174 355.0 0.05 0.06 2020-03-06 2020-02-13 0.055000000 337.06 0.06027397  
## 175 356.0 0.04 0.05 2020-03-06 2020-02-13 0.045000000 337.06 0.06027397  
## 176 357.5 0.03 0.04 2020-03-06 2020-02-13 0.034999998 337.06 0.06027397  
## IV  
## 73 0.12467527  
## 127 0.10819864  
## 128 0.12591314  
## 174 0.09900618  
## 175 0.10070181  
## 176 0.10384226

print(paste("The mean out-of-the-money Implied Volatility for the SPY is ", round(mean(SPY\_out$IV)\*100,2), "%, and I acknowledge that this value should be greater and have checked my results several times to find the same answer. The previous three mean implied volatilities are consistent with a volatility smirk with the in-the-money options being greater than the at the money options and less than the out of money options with respect to average implied vol.", sep = ""))

## [1] "The mean out-of-the-money Implied Volatility for the SPY is 10.13%, and I acknowledge that this value should be greater and have checked my results several times to find the same answer. The previous three mean implied volatilities are consistent with a volatility smirk with the in-the-money options being greater than the at the money options and less than the out of money options with respect to average implied vol."

## 7. Implementation of Newton/Secant Methods

# Vega function for option's derivative with respect to volatility  
Vega <- function(S0,K,T,r,sigma){  
 d1 <- (1/(sigma\*sqrt(T)))\*(log(S0/K)+(r+.5\*sigma^2)\*T)  
 return(S0\*dnorm(d1)\*sqrt(T))  
}  
  
#Newton implementation  
newton <- function(f,df,a,tol=10^-6){  
 b <- a - f(a)/df(a)  
 if(is.infinite(b) | is.na(b)){  
 return(NA)  
 }  
 while(abs(b-a)/abs(a)>tol & abs(f(a))>tol){  
 a <- b  
 b <- a - f(a)/df(a)  
 if(is.infinite(b) | is.na(b)){  
 return(NA)  
 }  
 }  
 return(b)  
}  
  
# Testing with at the money options  
AMZN\_ATM <- bisection(function(x) BSMprice(AMZN\_S0,AMZN\_K,AMZN\_T,r,x) - AMZN\_C1, 0, 1)  
SPY\_ATM <- bisection(function(x) BSMprice(SPY\_S0,SPY\_K,SPY\_T,r,x) - SPY\_C1, 0, 1)  
  
AMZN\_ATM2 <- newton(function(x) BSMprice(AMZN\_S0,AMZN\_K,AMZN\_T,r,x) - AMZN\_C1, function(x) Vega(AMZN\_S0,AMZN\_K,AMZN\_T,r,x), -.3)  
SPY\_ATM2 <- newton(function(x) BSMprice(SPY\_S0,SPY\_K,SPY\_T,r,x) - SPY\_C1, function(x) Vega(SPY\_S0,SPY\_K,SPY\_T,r,x), -.3)  
  
print(paste("As expected, both values are the same as those yielded from the bisection method with AMZN at ", round(AMZN\_ATM2\*100,2), "%, and the SPY at ", round(SPY\_ATM2\*100,2), "%", sep = ""))

## [1] "As expected, both values are the same as those yielded from the bisection method with AMZN at 23.91%, and the SPY at 12.99%"

### Timing Bisection Method vs Newton Method

# Bisect AMZN in-the-money  
time\_start1 <- proc.time()  
AMZN\_IV\_in <- c()  
for (i in seq(1,nrow(AMZN\_in))) {  
 temp <- bisection(function(x) BSMprice(AMZN\_in$S0[i],AMZN\_in$Strike[i],AMZN\_in$T[i],r,x) - AMZN\_in$C1[i], 0, 2)  
 AMZN\_IV\_in <- c(AMZN\_IV\_in, temp)  
}  
bisect\_time <- proc.time() - time\_start1  
bisect\_time

## user system elapsed   
## 0.388 0.002 0.397

# Newton AMZN in-the-money  
time\_start2 <- proc.time()  
AMZN\_IV\_in2 <- c()  
for (i in seq(1,nrow(AMZN\_in))) {  
 f <- function(x) {return(BSMprice(AMZN\_in$S0[i],AMZN\_in$Strike[i],AMZN\_in$T[i],r,x) - AMZN\_in$C1[i])}  
 df <- function(x) {return(Vega(AMZN\_in$S0[i],AMZN\_in$Strike[i],AMZN\_in$T[i],r,x))}  
 temp <- newton(f, df, -.3)  
 AMZN\_IV\_in2 <- c(AMZN\_IV\_in2, temp)  
}  
newton\_time <- proc.time() - time\_start2  
newton\_time

## user system elapsed   
## 0.092 0.001 0.094

print(paste("For AMZN in-the-money the bisection method took ", round(bisect\_time[3],3), " seconds whereas the Newton method required only ", round(newton\_time[3],3), " seconds. After removing the data that yielded NA for the Newton method, each method yielded a mean implied volatility of ", round(mean(AMZN\_IV\_in2[!is.na(AMZN\_IV\_in2)])\*100,2), "%", sep = ""))

## [1] "For AMZN in-the-money the bisection method took 0.397 seconds whereas the Newton method required only 0.094 seconds. After removing the data that yielded NA for the Newton method, each method yielded a mean implied volatility of 26.72%"

# Bisect SPY in-the-money  
time\_start1 <- proc.time()  
SPY\_IV\_in <- c()  
for (i in seq(1,nrow(SPY\_in))) {  
 temp <- bisection(function(x) BSMprice(SPY\_in$S0[i],SPY\_in$Strike[i],SPY\_in$T[i],r,x) - SPY\_in$C1[i], 0, 2)  
 SPY\_IV\_in <- c(SPY\_IV\_in, temp)  
}  
bisect\_time <- proc.time() - time\_start1  
bisect\_time

## user system elapsed   
## 0.334 0.002 0.341

# Newton SPY in-the-money  
time\_start2 <- proc.time()  
SPY\_IV\_in2 <- c()  
for (i in seq(1,nrow(SPY\_in))) {  
 f <- function(x) {return(BSMprice(SPY\_in$S0[i],SPY\_in$Strike[i],SPY\_in$T[i],r,x) - SPY\_in$C1[i])}  
 df <- function(x) {return(Vega(SPY\_in$S0[i],SPY\_in$Strike[i],SPY\_in$T[i],r,x))}  
 temp <- newton(f, df, -.3)  
 SPY\_IV\_in2 <- c(SPY\_IV\_in2, temp)  
}  
newton\_time <- proc.time() - time\_start2  
newton\_time

## user system elapsed   
## 0.077 0.001 0.078

print(paste("For the SPY in-the-money options the bisection method took ", round(bisect\_time[3],3), " seconds whereas the Newton method required only ", round(newton\_time[3],3), " seconds. After removing the data that yielded NA for the Newton method, each method yielded a mean implied volatility of ", round(mean(SPY\_IV\_in2[!is.na(SPY\_IV\_in2)])\*100,2), "%", sep = ""))

## [1] "For the SPY in-the-money options the bisection method took 0.341 seconds whereas the Newton method required only 0.078 seconds. After removing the data that yielded NA for the Newton method, each method yielded a mean implied volatility of 22.66%"

# Bisect AMZN out-of-the-money  
time\_start1 <- proc.time()  
AMZN\_IV\_out <- c()  
for (i in seq(1,nrow(AMZN\_out))) {  
 temp <- bisection(function(x) BSMprice(AMZN\_out$S0[i],AMZN\_out$Strike[i],AMZN\_out$T[i],r,x) - AMZN\_out$C1[i], 0, 2)  
 AMZN\_IV\_out <- c(AMZN\_IV\_out, temp)  
}  
bisect\_time <- proc.time() - time\_start1  
bisect\_time

## user system elapsed   
## 0.583 0.004 0.597

# Newton AMZN in-the-money  
time\_start2 <- proc.time()  
AMZN\_IV\_out2 <- c()  
for (i in seq(1,nrow(AMZN\_out))) {  
 f <- function(x) {return(BSMprice(AMZN\_out$S0[i],AMZN\_out$Strike[i],AMZN\_out$T[i],r,x) - AMZN\_out$C1[i])}  
 df <- function(x) {return(Vega(AMZN\_out$S0[i],AMZN\_out$Strike[i],AMZN\_out$T[i],r,x))}  
 temp <- newton(f, df, -.3)  
 AMZN\_IV\_out2 <- c(AMZN\_IV\_out2, temp)  
}  
newton\_time <- proc.time() - time\_start2  
newton\_time

## user system elapsed   
## 0.110 0.001 0.114

print(paste("For AMZN out-of-the-money options the bisection method took ", round(bisect\_time[3],3), " seconds whereas the Newton method required only ", round(newton\_time[3],3), " seconds. After removing the data that yielded NA for the Newton method, each method yielded a mean implied volatility of ", round(mean(AMZN\_IV\_out2[!is.na(AMZN\_IV\_out2)])\*100,2), "%", sep = ""))

## [1] "For AMZN out-of-the-money options the bisection method took 0.597 seconds whereas the Newton method required only 0.114 seconds. After removing the data that yielded NA for the Newton method, each method yielded a mean implied volatility of 28.75%"

# Bisect SPY out-of-the-money  
time\_start1 <- proc.time()  
SPY\_IV\_out <- c()  
for (i in seq(1,nrow(SPY\_out))) {  
 temp <- bisection(function(x) BSMprice(SPY\_out$S0[i],SPY\_out$Strike[i],SPY\_out$T[i],r,x) - SPY\_out$C1[i], 0, 2)  
 SPY\_IV\_out <- c(SPY\_IV\_out, temp)  
}  
bisect\_time <- proc.time() - time\_start1  
bisect\_time

## user system elapsed   
## 0.171 0.001 0.177

# Newton SPY in-the-money  
time\_start2 <- proc.time()  
SPY\_IV\_out2 <- c()  
for (i in seq(1,nrow(SPY\_out))) {  
 f <- function(x) {return(BSMprice(SPY\_out$S0[i],SPY\_out$Strike[i],SPY\_out$T[i],r,x) - SPY\_out$C1[i])}  
 df <- function(x) {return(Vega(SPY\_out$S0[i],SPY\_out$Strike[i],SPY\_out$T[i],r,x))}  
 temp <- newton(f, df, -.3)  
 SPY\_IV\_out2 <- c(SPY\_IV\_out2, temp)  
}  
newton\_time <- proc.time() - time\_start2  
newton\_time

## user system elapsed   
## 0.070 0.000 0.071

print(paste("For SPY out-of-the-money options the bisection method took ", round(bisect\_time[3],3), " seconds whereas the Newton method required only ", round(newton\_time[3],3), " seconds. After removing the data that yielded NA for the Newton method, each method yielded a mean implied volatility of ", round(mean(SPY\_IV\_out2[!is.na(SPY\_IV\_out2)])\*100,2), "%", sep = ""))

## [1] "For SPY out-of-the-money options the bisection method took 0.177 seconds whereas the Newton method required only 0.071 seconds. After removing the data that yielded NA for the Newton method, each method yielded a mean implied volatility of 10.01%"

## 8. Summary Table of Implied Volatility for Each Option Type, Maturity, and Stock

#aggregate(SPY\_in[, 9],list(SPY\_in$Exp), mean)  
AMZNCall1$C1 <- (AMZNCall1$Bid + AMZNCall1$Ask)/2  
AMZNCall1$S0 <- 2149.87  
AMZNCall1$T <- as.numeric(AMZNCall1$Exp - AMZNCall1$Date)/365  
AMZN\_IV <- c()  
for (i in seq(1,nrow(AMZNCall1))) {  
 temp <- bisection(function(x) BSMprice(AMZNCall1$S0[i],AMZNCall1$Strike[i],AMZNCall1$T[i],r,x) - AMZNCall1$C1[i], 0, 2)  
 AMZN\_IV <- c(AMZN\_IV, temp)  
}  
AMZNCall1$IV <- AMZN\_IV  
temp <- AMZNCall1[AMZNCall1$IV < 1.999, 1:13]  
AMZNCall1table <- aggregate(temp[,13], list(temp$Exp), mean)  
colnames(AMZNCall1table) <- c("Maturity", "Implied Vol (%)")  
AMZNCall1table$`Implied Vol` <- round(100\*AMZNCall1table$`Implied Vol`,2)

#aggregate(SPY\_in[, 9],list(SPY\_in$Exp), mean)  
AMZNPut1$C1 <- (AMZNPut1$Bid + AMZNPut1$Ask)/2  
AMZNPut1$S0 <- 2149.87  
AMZNPut1$T <- as.numeric(AMZNPut1$Exp - AMZNPut1$Date)/365  
AMZN\_IV <- c()  
for (i in seq(1,nrow(AMZNPut1))) {  
 temp <- bisection(function(x) BSMprice(AMZNPut1$S0[i],AMZNPut1$Strike[i],AMZNPut1$T[i],r,x,"p") - AMZNPut1$C1[i], 0, 2)  
 AMZN\_IV <- c(AMZN\_IV, temp)  
}  
AMZNPut1$IV <- AMZN\_IV  
temp <- AMZNPut1[AMZNPut1$IV < 1.999, 1:13]  
AMZNPut1table <- aggregate(temp[,13], list(temp$Exp), mean)  
colnames(AMZNPut1table) <- c("Maturity", "Implied Vol (%)")  
AMZNPut1table$`Implied Vol` <- round(100\*AMZNPut1table$`Implied Vol`,2)

SPYCall1$C1 <- (SPYCall1$Bid + SPYCall1$Ask)/2  
SPYCall1$S0 <- 337.06  
SPYCall1$T <- as.numeric(SPYCall1$Exp - SPYCall1$Date)/365  
SPY\_IV <- c()  
for (i in seq(1,nrow(SPYCall1))) {  
 temp <- bisection(function(x) BSMprice(SPYCall1$S0[i],SPYCall1$Strike[i],SPYCall1$T[i],r,x) - SPYCall1$C1[i], 0, 2)  
 SPY\_IV <- c(SPY\_IV, temp)  
}  
SPYCall1$IV <- SPY\_IV  
temp <- SPYCall1[SPYCall1$IV < 1.999, 1:13]  
SPYCall1table <- aggregate(temp[,13], list(temp$Exp), mean)  
colnames(SPYCall1table) <- c("Maturity", "Implied Vol (%)")  
SPYCall1table$`Implied Vol` <- round(100\*SPYCall1table$`Implied Vol`,2)

### Average Volatilities

mean\_table <- data.frame(matrix(nrow = 3, ncol = 2))  
mean\_table[1,1] <- round(mean(SPY\_in[SPY\_in$IV < 1.999,1:9]$IV)\*100,2)  
mean\_table[2,1] <- round(SPY\_ATM\*100, 2)  
mean\_table[3,1] <- round(mean(SPY\_out$IV)\*100,2)  
mean\_table[1,2] <- round(mean(AMZN\_in[AMZN\_in$IV < 1.9999, 9])\*100,2)  
mean\_table[2,2] <- round(AMZN\_ATM\*100, 2)  
mean\_table[3,2] <- round(mean(AMZN\_out$IV)\*100,2)  
colnames(mean\_table) <- c("SPY", "AMZN")  
rownames(mean\_table) <- c("In-The-Money (%)", "At-The-Money (%)", "Out-Of-Money (%)")  
mean\_table

## SPY AMZN  
## In-The-Money (%) 30.94 31.07  
## At-The-Money (%) 12.99 23.91  
## Out-Of-Money (%) 10.13 47.54

Amazon clearly illustrates the volatility smirk with the out-of-money options having a far higher implied volatility than the at-the-money options and significantly greater than the in-the-money options as well. As I mentioned earlier the out-of-money calculation for the SPY seems to be off; however, the in-the-money calculation is more reasonable and the at-the-money implied volatility is close to the value of the VIX.

print(paste("Amazon Calls Summary Table"))

## [1] "Amazon Calls Summary Table"

AMZNCall1table[,c(1,3)]

## Maturity Implied Vol  
## 1 2020-02-14 63.47  
## 2 2020-02-21 38.07  
## 3 2020-02-28 31.18  
## 4 2020-03-06 29.76  
## 5 2020-03-13 28.18  
## 6 2020-03-20 28.36

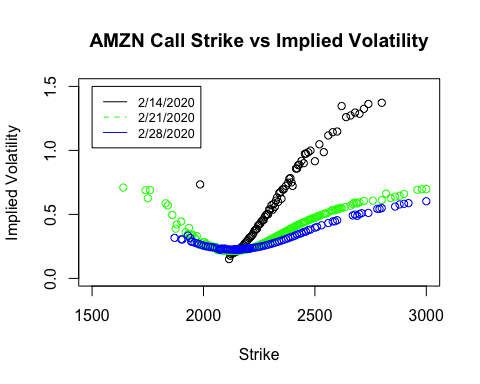
The implied volatility decreases as the maturity increases because the option has more time for the price of the underlying to reach the strike price in order for the option to become at or in the money. As I alluded to above the volatility smirk is evident with the data for Amazon where in the money options have a greater implied volatility than at the money options and the out of the money options yield the greatest implied volatility. The remaining tables for the other stocks and option types are included in the appendix.

## 9. Put-Call Parity Calculations

#P-C parity is C + Ke^-rT = S + P  
#SPYCall1$Put <- SPYCall1$C1 + SPYCall1$Strike\*exp(-r\*SPYCall1$T) - SPYCall1$S0  
#SPYPut1$Call <- SPYPut1$C1 + SPYPut1$S0 - SPYPut1$Strike\*exp(-r\*SPYPut1$T)  
  
#AMZNCall1$Put <- AMZNCall1$C1 + AMZNCall1$Strike\*exp(-r\*AMZNCall1$T) - AMZNCall1$S0  
#AMZNPut1$Call <- AMZNPut1$C1 + AMZNPut1$S0 - AMZNPut1$Strike\*exp(-r\*AMZNPut1$T)

## 10. Implied Volatility vs Strike Price

temp1 <- AMZNCall1[AMZNCall1$Exp == as.Date("2020-02-14"), 1:13]  
temp2 <- AMZNCall1[AMZNCall1$Exp == as.Date("2020-02-21"), 1:13]  
temp3 <- AMZNCall1[AMZNCall1$Exp == as.Date("2020-02-28"), 1:13]  
plot(temp1$Strike, temp1$IV, xlab = "Strike", ylab = "Implied Volatility", main = "AMZN Call Strike vs Implied Volatility", ylim = c(0,1.5), xlim = c(1500, 3000))  
lines(temp2$Strike, temp2$IV, type = "p", col = c("green"))  
lines(temp3$Strike, temp3$IV, type = "p", col = c("blue"))  
legend(1500, 1.5,legend = c("2/14/2020", "2/21/2020", "2/28/2020"), col = c("black", "green", "blue"), lty=1:2, cex=0.8)



The general pattern of the volatility smirk can be seen although and it is interesting to see how the shape differs for each maturity. The SPY graphs are included in the appendix.

## 11. Greeks

theoretical\_greeks <- function(S0,K,tau,r,sigma,type='c'){  
 N <- function(x){pnorm(x)}  
 d1 <- (1/(sigma\*sqrt(tau)))\*(log(S0/K)+(r+.5\*sigma\*\*2)\*tau)  
 delta <- ifelse(type=='c',N(d1),N(d1)-1)  
 gamma <- 1/(S0\*sigma\*sqrt(tau))\*exp(-d1^2/2)/(sqrt(2\*pi))  
 vega <- S0\*sqrt(tau)\*exp(-d1^2/2)/sqrt(2\*pi)  
 x = data.frame(Delta=delta,Gamma=gamma,Vega=vega)  
 return(x)  
}  
numerical\_greeks <- function(S0,K,tau,r,sigma,type='c',e=10^-4){  
 delta <- (BSMprice(S0+e,K,tau,r,sigma)-BSMprice(S0-e,K,tau,r,sigma))/(2\*e)  
 gamma <- (BSMprice(S0+e,K,tau,r,sigma)-2\*BSMprice(S0,K,tau,r,sigma)+  
 BSMprice(S0-e,K,tau,r,sigma))/e^2  
 vega <- (BSMprice(S0,K,tau,r,sigma+e)-BSMprice(S0,K,tau,r,sigma-e))/(2\*e)  
 x = data.frame(Delta=delta,Gamma=gamma,Vega=vega)  
 return(x)  
}  
numerical\_greeks(100,100,1,0.05,0.3,'c')

## Delta Gamma Vega  
## 1 0.6242517 0.01264979 37.94329

theoretical\_greeks(100,100,1,0.05,0.3,'c')

## Delta Gamma Vega  
## 1 0.6242517 0.01264776 37.94329

num <- numerical\_greeks(AMZNCall1$S0,AMZNCall1$Strike,AMZNCall1$T,r,AMZNCall1$IV)  
theo <- theoretical\_greeks(AMZNCall1$S0,AMZNCall1$Strike,AMZNCall1$T,r,AMZNCall1$IV)  
num[80:90,1:3]

## Delta Gamma Vega  
## 80 0.05166667 0.0029316993 11.912774  
## 81 0.04334856 0.0024641622 10.349594  
## 82 0.03661931 0.0020975222 9.023430  
## 83 0.03375716 0.0018744117 8.440607  
## 84 0.03203902 0.0017081447 8.084887  
## 85 0.02719211 0.0014502177 7.055746  
## 86 0.02205571 0.0012057910 5.918775  
## 87 0.02319266 0.0011880275 6.174959  
## 88 0.01977186 0.0010125234 5.395675  
## 89 0.01734363 0.0008867573 4.826026  
## 90 0.01654460 0.0008228085 4.635280

theo[80:90,1:3]

## Delta Gamma Vega  
## 80 1 0.0029271715 11.912774  
## 81 1 0.0024714229 10.349594  
## 82 1 0.0020945290 9.023429  
## 83 1 0.0018687254 8.440607  
## 84 1 0.0017018866 8.084887  
## 85 1 0.0014538867 7.055746  
## 86 1 0.0012064742 5.918775  
## 87 1 0.0011817186 6.174959  
## 88 1 0.0010148353 5.395675  
## 89 1 0.0008879334 4.826026  
## 90 1 0.0008224522 4.635279

The Gamma and Vega values are very similar for each method; however it seems that my delta calculation is off for the theoretical method causing the discrepency. The full table is featured in the appendix.

# Part 2

## 1. Trapezoidal and Simpson’s Quadrature Rules for Approximation

fx <- function(x){  
 fx <- ifelse(x==0,1,sin(x)/x)  
 return(fx)  
}  
simpson <- function(f,a,b,n){  
 h <- (b-a)/(n)  
 x <- seq(a,b,by=h)  
 y <- f(x)  
 s <- y[1]+y[n+1]+4\*sum(y[seq(2,n,by=2)])+  
 2\*sum(y[seq(3,n-1,by=2)])  
 s <- (h/3)\*s  
 return(s)  
}  
trapezoidal <- function(f,a,b,n){  
 h <- (b-a)/n  
 x <- seq(a,b,by=h)  
 y <- f(x)  
 s <- (h/2)\*(y[1]+2\*sum(y[2:n])+y[n+1])  
 return(s)  
}  
trapezoidal(fx,-10^6,10^6,n=5000000)

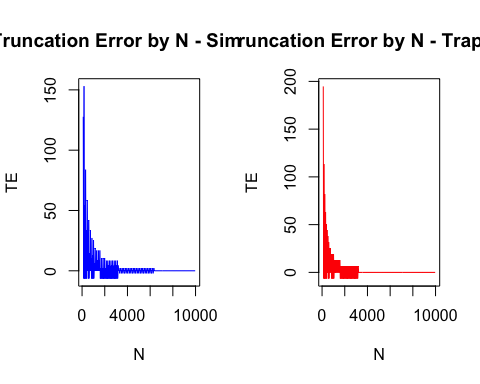
## [1] 3.141591

simpson(fx,-10^6,10^6,n=5000000)

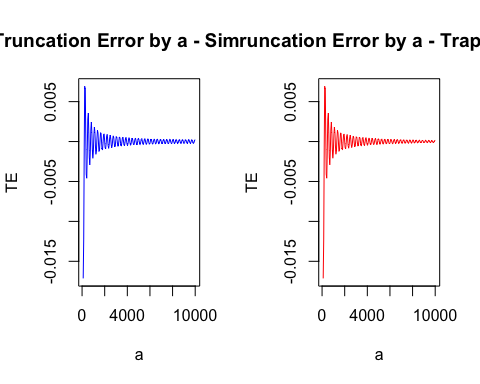
## [1] 3.141591

## 2. Computing Truncation Errror

calc\_TE <- function(func,fx,a,N){  
 val <- func(fx,-a,a,N)  
 te <- val-pi  
 return(te)  
}  
#Fixing a  
par(mfrow=c(1,2))  
a <- 1e4  
N <- seq(100,1e4,by=35)  
TE\_simp <- sapply(N,calc\_TE,a=a,func=simpson,fx=fx)  
TE\_trap <- sapply(N,calc\_TE,a=a,func=trapezoidal,fx=fx)  
plot(N,TE\_simp,type='l',col='blue',xlab='N',ylab = 'TE',  
 main = 'Truncation Error by N - Simpson')  
plot(N,TE\_trap,type='l',col='red',xlab='N',ylab = 'TE',  
 main = 'Truncation Error by N - Trapezoid')



#Fixing N  
N <- 1e4  
a <- seq(100,1e4,by=45)  
TE\_simp <- sapply(a,calc\_TE,N=N,func=simpson,fx=fx)  
TE\_trap <- sapply(a,calc\_TE,N=N,func=trapezoidal,fx=fx)  
plot(a,TE\_simp,type='l',col='blue',xlab='a',ylab = 'TE',  
 main = 'Truncation Error by a - Simpson')  
plot(a,TE\_trap,type='l',col='red',xlab='a',ylab = 'TE',  
 main = 'Truncation Error by a - Trapezoid')



From the first plots, we see that the Trapezoidal rule converges before the Simpson rule, though the errors for the Simpson rule appear to be lower for each N. We also see that as N increases, the Truncation Error approaches or equals zero, which is expected, as smaller partitions lead to increasingly miniscule error.

Holding N constant, we see that the choice of a causes the Truncation Error to fluctuate around zero. As a increases, we see that the magnitude of these flucations become less signficant until the error seems to converge to zero. The Truncation Error by a plots appear identical between the two methods. It is clear that as the boundaries of integration increase, the approximation becomes more accurate.

## 3. Evaluating Number of Steps Required to Converge

steps <- function(f,fx,a,b,tol=10^-4){  
 n <- 5  
 error <-100  
 v1 <- f(fx,a,b,n-1)  
 while(error>tol){  
 v2 <- f(fx,a,b,n)  
 error <- abs(v2-v1)  
 v1 <- v2  
 n <- n+1  
 }  
 l <- list(value=v2,steps=n-5)  
 return(l)  
}  
print(paste("Trapezoidal:"))

## [1] "Trapezoidal:"

steps(trapezoidal,fx,-1e3,1e3)

## $value  
## [1] 3.146739  
##   
## $steps  
## [1] 377

print(paste("Simpson:"))

## [1] "Simpson:"

steps(simpson,fx,-1e3,1e3)

## $value  
## [1] 3.140543  
##   
## $steps  
## [1] 1541

While the Simpson method is more accurate, it takes far more steps to reach that accuracy. Therein lies an important tradeoff between speed and accuracy.

# Part 4

## 1. Solving Integral for f1 and f2

f1 <- function(x,y) {return(x\*y)}  
f2 <- function(x,y) {return(exp(x+y))}  
  
print(paste("Anlytical Solution to f1"))

## [1] "Anlytical Solution to f1"

integrate(function(y) {   
 sapply(y, function(y) {  
 integrate(function(x) f1(x,y), 0, 3)$value  
 })  
 }, 0, 1)

## 2.25 with absolute error < 2.5e-14

print(paste("Anlytical Solution to f2"))

## [1] "Anlytical Solution to f2"

integrate(function(y) {   
 sapply(y, function(y) {  
 integrate(function(x) f2(x,y), 0, 3)$value  
 })  
 }, 0, 1)

## 32.79433 with absolute error < 3.6e-13

## 2. Numerical Solution

deltaX <- 0.001  
deltaY <- 0.003  
x0 <- 0  
xn1 <- 1  
y0 <- 0  
ym1 <- 3  
  
x<- seq(x0,xn1,deltaX)  
y<- seq(y0,ym1,deltaY)  
s <- 0  
for(i in seq(1,length(x))-1){  
 s <- s + f1(x[i],y[i]) + f1(x[i],y[i+1]) + f1(x[i+1],y[i]) + f1(x[i+1],y[i+1]) + 2\*(f1((x[i]+x[i+1])/2,y[i]) + f1((x[i]+x[i+1])/2,y[i+1]) + f1(x[i],(y[i] + y[i+1])/2) + f1(x[i+1],(y[i] + y[i+1])/2)) + 4\*f1((x[i] + x[i+1])/2, (y[i]+y[i+1])/2)  
}  
s\*deltaX\*deltaY/16

## numeric(0)

# Appendix

print(paste("Amazon Calls Summary Table"))

## [1] "Amazon Calls Summary Table"

AMZNCall1table[,c(1,3)]

## Maturity Implied Vol  
## 1 2020-02-14 63.47  
## 2 2020-02-21 38.07  
## 3 2020-02-28 31.18  
## 4 2020-03-06 29.76  
## 5 2020-03-13 28.18  
## 6 2020-03-20 28.36

print(paste("Amazon Puts Summary Table"))

## [1] "Amazon Puts Summary Table"

AMZNPut1table[,c(1,3)]

## Maturity Implied Vol  
## 1 2020-02-14 78.08  
## 2 2020-02-21 43.60  
## 3 2020-02-28 31.46  
## 4 2020-03-06 28.30  
## 5 2020-03-13 27.83  
## 6 2020-03-20 29.76  
## 7 2020-03-27 26.35  
## 8 2020-04-03 23.86  
## 9 2020-04-17 26.69

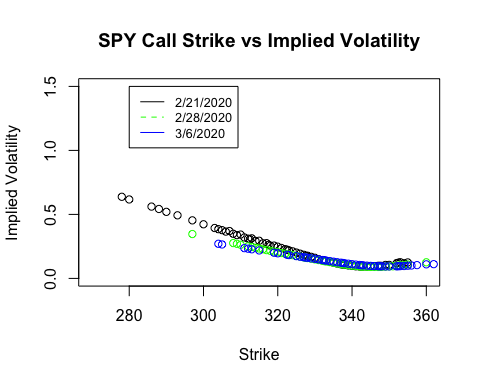
print(paste("SPY Calls Summary Table"))

## [1] "SPY Calls Summary Table"

SPYCall1table

## Maturity Implied Vol (%) Implied Vol  
## 1 2020-02-21 0.2751647 27.52  
## 2 2020-02-28 0.1522963 15.23  
## 3 2020-03-06 0.1395745 13.96  
## 4 2020-03-13 0.1284705 12.85  
## 5 2020-03-20 0.2206953 22.07  
## 6 2020-03-27 0.1125911 11.26  
## 7 2020-04-03 0.1026095 10.26  
## 8 2020-04-17 0.1239359 12.39

temp1 <- SPYCall1[SPYCall1$Exp == as.Date("2020-03-06"), 1:13]  
temp2 <- SPYCall1[SPYCall1$Exp == as.Date("2020-02-21"), 1:13]  
temp3 <- SPYCall1[SPYCall1$Exp == as.Date("2020-02-28"), 1:13]  
plot(temp2$Strike, temp2$IV, xlab = "Strike", ylab = "Implied Volatility", main = "SPY Call Strike vs Implied Volatility", xlim = c(270, 360), ylim = c(0,1.5))  
lines(temp3$Strike, temp3$IV, type = "p", col = c("green"))  
lines(temp1$Strike, temp1$IV, type = "p", col = c("blue"))  
legend(280, 1.5,legend = c("2/21/2020", "2/28/2020", "3/6/2020"), col = c("black", "green", "blue"), lty=1:2, cex=0.8)



num

## Delta Gamma Vega  
## 1 1.0000000020 0.000000e+00 0.000000e+00  
## 2 0.9999997224 0.000000e+00 1.622266e-04  
## 3 0.9950690674 9.094947e-05 1.607108e+00  
## 4 0.9925948791 2.273737e-05 2.304410e+00  
## 5 0.9865010520 1.818989e-04 3.891532e+00  
## 6 0.9855092810 1.591616e-04 4.136780e+00  
## 7 0.9499022553 5.002221e-04 1.162387e+01  
## 8 0.9381596897 5.911716e-04 1.372522e+01  
## 9 0.9332768354 5.911716e-04 1.456034e+01  
## 10 0.9315891623 6.139089e-04 1.484410e+01  
## 11 0.9245323486 6.366463e-04 1.600481e+01  
## 12 0.9169761734 6.821210e-04 1.720399e+01  
## 13 0.9130072283 7.048584e-04 1.781684e+01  
## 14 0.9089093783 6.821210e-04 1.843785e+01  
## 15 0.8912090448 8.185452e-04 2.099221e+01  
## 16 0.8765404880 9.322321e-04 2.296450e+01  
## 17 0.8739788279 9.322321e-04 2.329647e+01  
## 18 0.8660934054 9.549694e-04 2.429617e+01  
## 19 0.8606697054 9.777068e-04 2.496488e+01  
## 20 0.8579079633 1.023182e-03 2.529963e+01  
## 21 0.8494240012 1.023182e-03 2.630430e+01  
## 22 0.8376518520 1.068656e-03 2.764121e+01  
## 23 0.8253610952 1.159606e-03 2.896928e+01  
## 24 0.8190244171 1.227818e-03 2.962799e+01  
## 25 0.8125622207 1.182343e-03 3.028207e+01  
## 26 0.7992683231 1.273293e-03 3.157312e+01  
## 27 0.9819613740 5.229595e-04 4.990574e+00  
## 28 0.7854950752 1.250555e-03 3.283596e+01  
## 29 0.7784342733 1.318767e-03 3.345480e+01  
## 30 0.7712606407 1.409717e-03 3.406421e+01  
## 31 0.7639768182 1.318767e-03 3.466341e+01  
## 32 0.7565855947 1.386979e-03 3.525163e+01  
## 33 0.7490899031 1.432454e-03 3.582812e+01  
## 34 0.7414927995 1.455192e-03 3.639214e+01  
## 35 0.7337974819 1.477929e-03 3.694299e+01  
## 36 0.7260072653 1.500666e-03 3.747995e+01  
## 37 0.7181255887 1.500666e-03 3.800235e+01  
## 38 0.7141515573 1.568878e-03 3.825789e+01  
## 39 0.7101560004 1.455192e-03 3.850953e+01  
## 40 0.7021021634 1.546141e-03 3.900085e+01  
## 41 0.6980448234 1.546141e-03 3.924038e+01  
## 42 0.6939678383 1.591616e-03 3.947571e+01  
## 43 0.6898716981 1.568878e-03 3.970678e+01  
## 44 0.6857568872 1.659828e-03 3.993351e+01  
## 45 0.6816239045 1.568878e-03 4.015584e+01  
## 46 0.6774732537 1.637090e-03 4.037370e+01  
## 47 0.6733054374 1.591616e-03 4.058703e+01  
## 48 0.6691209728 1.637090e-03 4.079575e+01  
## 49 0.6649203692 1.591616e-03 4.099981e+01  
## 50 0.6607041519 1.682565e-03 4.119915e+01  
## 51 0.6564728392 1.637090e-03 4.139371e+01  
## 52 0.6522269678 1.637090e-03 4.158344e+01  
## 53 0.6479670628 1.682565e-03 4.176828e+01  
## 54 0.6436936621 1.614353e-03 4.194817e+01  
## 55 0.6351085381 1.728040e-03 4.229293e+01  
## 56 0.6264759384 1.750777e-03 4.261734e+01  
## 57 0.6178002536 1.728040e-03 4.292107e+01  
## 58 0.6090859097 1.682565e-03 4.320379e+01  
## 59 0.6003373539 1.750777e-03 4.346524e+01  
## 60 0.5915590646 1.773515e-03 4.370515e+01  
## 61 0.9811666723 2.728484e-03 5.177229e+00  
## 62 0.9351888491 6.343726e-03 1.423586e+01  
## 63 0.8816848162 9.322321e-03 2.228685e+01  
## 64 0.8167491455 1.186891e-02 2.986030e+01  
## 65 0.7506490351 1.418812e-02 3.570985e+01  
## 66 0.6704142811 1.573426e-02 4.073182e+01  
## 67 0.5847352611 1.639364e-02 4.387623e+01  
## 68 0.5015147940 1.687113e-02 4.489239e+01  
## 69 0.4221292539 1.570015e-02 4.403476e+01  
## 70 0.3501473185 1.447233e-02 4.168714e+01  
## 71 0.2881204585 1.285798e-02 3.840163e+01  
## 72 0.2352666067 1.118110e-02 3.460207e+01  
## 73 0.1910952815 9.623591e-03 3.064451e+01  
## 74 0.1561276548 8.151346e-03 2.694288e+01  
## 75 0.1290947773 6.923528e-03 2.369007e+01  
## 76 0.1057979404 5.780976e-03 2.057421e+01  
## 77 0.0887390550 4.899903e-03 1.808291e+01  
## 78 0.0736842338 4.098410e-03 1.571531e+01  
## 79 0.0636396791 3.524292e-03 1.403546e+01  
## 80 0.0516666689 2.931699e-03 1.191277e+01  
## 81 0.0433485589 2.464162e-03 1.034959e+01  
## 82 0.0366193093 2.097522e-03 9.023430e+00  
## 83 0.0337571618 1.874412e-03 8.440607e+00  
## 84 0.0320390173 1.708145e-03 8.084887e+00  
## 85 0.0271921121 1.450218e-03 7.055746e+00  
## 86 0.0220557070 1.205791e-03 5.918775e+00  
## 87 0.0231926582 1.188027e-03 6.174959e+00  
## 88 0.0197718588 1.012523e-03 5.395675e+00  
## 89 0.0173436290 8.867573e-04 4.826026e+00  
## 90 0.0165446004 8.228085e-04 4.635280e+00  
## 91 0.0145244696 7.247536e-04 4.145072e+00  
## 92 0.0119147204 6.036061e-04 3.493045e+00  
## 93 0.0128263181 6.107115e-04 3.723391e+00  
## 94 0.0120480123 5.620393e-04 3.526909e+00  
## 95 0.0106993012 4.977352e-04 3.181201e+00  
## 96 0.0083384288 4.032330e-04 2.558043e+00  
## 97 0.0107193218 4.682477e-04 3.186384e+00  
## 98 0.0087158261 3.868905e-04 2.659354e+00  
## 99 0.0103781385 4.263256e-04 3.097840e+00  
## 100 0.0054980770 2.602363e-04 1.770578e+00  
## 101 0.0079219700 3.318235e-04 2.445427e+00  
## 102 0.0048346218 2.239986e-04 1.579102e+00  
## 103 0.0072157919 2.929212e-04 2.252390e+00  
## 104 0.0079357766 3.065992e-04 2.449175e+00  
## 105 0.0043313083 1.884715e-04 1.431507e+00  
## 106 0.0079463266 2.920331e-04 2.452038e+00  
## 107 0.0073073390 2.673417e-04 2.277568e+00  
## 108 0.0033127028 1.421974e-04 1.125659e+00  
## 109 0.0065593510 2.360778e-04 2.070437e+00  
## 110 0.0054729124 1.998401e-04 1.763375e+00  
## 111 0.0052820408 1.890044e-04 1.708592e+00  
## 112 0.0049510830 1.698197e-04 1.612957e+00  
## 113 0.0057691261 1.870504e-04 1.847878e+00  
## 114 0.0052404812 1.719513e-04 1.696629e+00  
## 115 0.0031608312 1.135980e-04 1.079126e+00  
## 116 0.0019218884 7.576162e-05 6.881045e-01  
## 117 0.0051339892 1.531220e-04 1.665914e+00  
## 118 0.0045205255 1.369571e-04 1.487245e+00  
## 119 0.0049925933 1.445954e-04 1.624998e+00  
## 120 0.0045310957 1.330491e-04 1.490350e+00  
## 121 0.0045416996 1.287859e-04 1.493464e+00  
## 122 0.0029835670 8.997247e-05 1.024470e+00  
## 123 0.0049819093 1.312728e-04 1.621900e+00  
## 124 0.0044415288 1.190159e-04 1.464013e+00  
## 125 0.0038544567 1.032063e-04 1.289605e+00  
## 126 0.0034025653 9.130474e-05 1.153069e+00  
## 127 0.0008944010 2.948752e-05 3.419826e-01  
## 128 0.0020597601 5.533352e-05 7.327813e-01  
## 129 0.0006779126 2.120526e-05 2.649559e-01  
## 130 0.0015534190 4.027889e-05 5.669159e-01  
## 131 0.0012627577 3.228529e-05 4.691971e-01  
## 132 0.0008613737 2.291500e-05 3.303545e-01  
## 133 0.0028023471 5.684342e-05 9.681918e-01  
## 134 0.0010340117 2.433609e-05 3.907046e-01  
## 135 0.0007830997 1.887379e-05 3.026266e-01  
## 136 0.0006496158 1.565414e-05 2.547346e-01  
## 137 0.0004047949 1.013634e-05 1.644279e-01  
## 138 0.0003939517 9.570122e-06 1.603363e-01  
## 139 0.0003837916 9.092727e-06 1.564941e-01  
## 140 0.0001351837 3.408385e-06 5.910950e-02  
## 141 0.9988660793 2.273737e-05 1.202588e+00  
## 142 0.9968733366 4.547474e-05 3.022515e+00  
## 143 0.9449585650 1.364242e-04 3.542723e+01  
## 144 0.9138436315 2.501110e-04 5.003100e+01  
## 145 0.8742767886 3.637979e-04 6.578366e+01  
## 146 0.9957467614 4.547474e-05 3.983609e+00  
## 147 0.8515067793 3.637979e-04 7.371141e+01  
## 148 0.8369657110 4.320100e-04 7.839592e+01  
## 149 0.8269279431 3.865352e-04 8.146919e+01  
## 150 0.8140151920 3.865352e-04 8.523901e+01  
## 151 0.8113858837 3.865352e-04 8.598205e+01  
## 152 0.9834007994 1.591616e-04 1.314757e+01  
## 153 0.9883781740 1.818989e-04 9.668708e+00  
## 154 0.9779119887 2.728484e-04 1.676152e+01  
## 155 0.7870678940 4.774847e-04 9.247685e+01  
## 156 0.7842971797 4.320100e-04 9.317487e+01  
## 157 0.7730873165 4.320100e-04 9.591440e+01  
## 158 0.9713851227 3.183231e-04 2.082275e+01  
## 159 0.9706627714 3.410605e-04 2.125868e+01  
## 160 0.7442545109 5.229595e-04 1.023592e+02  
## 161 0.9781570054 3.410605e-04 1.660440e+01  
## 162 0.7324376941 5.229595e-04 1.047599e+02  
## 163 0.9920667139 1.364242e-04 6.925402e+00  
## 164 0.9854742632 2.955858e-04 1.172491e+01  
## 165 0.7204816995 5.229595e-04 1.070514e+02  
## 166 0.9724820848 4.092726e-04 2.015588e+01  
## 167 0.7114326149 5.456968e-04 1.086956e+02  
## 168 0.7084019001 5.684342e-04 1.092292e+02  
## 169 0.9840822645 3.183231e-04 1.268384e+01  
## 170 0.9840241694 3.865352e-04 1.272352e+01  
## 171 0.9669946928 5.684342e-04 2.343494e+01  
## 172 0.9805932700 4.092726e-04 1.502161e+01  
## 173 0.9847136050 3.865352e-04 1.225091e+01  
## 174 0.9752714720 5.684342e-04 1.843241e+01  
## 175 0.9776138813 5.911716e-04 1.695220e+01  
## 176 0.9776664831 5.229595e-04 1.691859e+01  
## 177 0.9652288293 7.958079e-04 2.446152e+01  
## 178 0.9837164157 5.002221e-04 1.293325e+01  
## 179 0.9718844660 7.958079e-04 2.051993e+01  
## 180 0.9763075252 7.048584e-04 1.778158e+01  
## 181 0.9593506991 1.023182e-03 2.778850e+01  
## 182 0.9546031185 9.777068e-04 3.038274e+01  
## 183 0.9577831725 1.045919e-03 2.865378e+01  
## 184 0.9499815269 1.227818e-03 3.283579e+01  
## 185 0.9466256517 1.386979e-03 3.457541e+01  
## 186 0.9388502906 1.523404e-03 3.848176e+01  
## 187 0.9394604558 1.455192e-03 3.818119e+01  
## 188 0.9258376849 1.773515e-03 4.466981e+01  
## 189 0.9186501586 1.887202e-03 4.791936e+01  
## 190 0.9173773208 2.023626e-03 4.848322e+01  
## 191 0.8971744546 2.228262e-03 5.700312e+01  
## 192 0.9042537306 2.387424e-03 5.410614e+01  
## 193 0.8967542453 2.501110e-03 5.717223e+01  
## 194 0.8788605385 2.842171e-03 6.409419e+01  
## 195 0.8670600016 3.069545e-03 6.837834e+01  
## 196 0.8519199662 3.296918e-03 7.357414e+01  
## 197 0.8314978174 3.569767e-03 8.008585e+01  
## 198 0.8175605001 3.888090e-03 8.422408e+01  
## 199 0.7990558220 4.138201e-03 8.935898e+01  
## 200 0.7763903068 4.320100e-03 9.512116e+01  
## 201 0.7540377453 4.524736e-03 1.002673e+02  
## 202 0.7303958512 4.706635e-03 1.051609e+02  
## 203 0.7054194498 5.047696e-03 1.097459e+02  
## 204 0.6796368416 5.275069e-03 1.138748e+02  
## 205 0.6526900177 5.388756e-03 1.175580e+02  
## 206 0.6249575551 5.525180e-03 1.206950e+02  
## 207 0.5966235892 5.661605e-03 1.232331e+02  
## 208 0.5678155571 5.729817e-03 1.251368e+02  
## 209 0.5388353361 5.820766e-03 1.263737e+02  
## 210 0.5097887401 5.775291e-03 1.269375e+02  
## 211 0.4809493265 5.809397e-03 1.268310e+02  
## 212 0.4525860305 5.695711e-03 1.260779e+02  
## 213 0.4246944081 5.616130e-03 1.247068e+02  
## 214 0.3975029540 5.525180e-03 1.227616e+02  
## 215 0.3714418534 5.377387e-03 1.203245e+02  
## 216 0.3463726449 5.195488e-03 1.174405e+02  
## 217 0.3222293100 4.968115e-03 1.141504e+02  
## 218 0.2998378011 4.820322e-03 1.106369e+02  
## 219 0.2782151802 4.627054e-03 1.068082e+02  
## 220 0.2575336379 4.422418e-03 1.027313e+02  
## 221 0.2385666238 4.240519e-03 9.862176e+01  
## 222 0.2209536157 3.984724e-03 9.447485e+01  
## 223 0.2047702122 3.774403e-03 9.037150e+01  
## 224 0.1894896218 3.569767e-03 8.622765e+01  
## 225 0.1751000602 3.370815e-03 8.207473e+01  
## 226 0.1629109309 3.200284e-03 7.835735e+01  
## 227 0.1513688343 3.018386e-03 7.466028e+01  
## 228 0.1407920203 2.779643e-03 7.111383e+01  
## 229 0.1311818909 2.637535e-03 6.775346e+01  
## 230 0.1229080743 2.478373e-03 6.474995e+01  
## 231 0.1145085940 2.319211e-03 6.159118e+01  
## 232 0.1078176568 2.185629e-03 5.899216e+01  
## 233 0.1013405252 2.054890e-03 5.640295e+01  
## 234 0.0950506590 1.952571e-03 5.381650e+01  
## 235 0.0900952108 1.813305e-03 5.172648e+01  
## 236 0.0853053726 1.728040e-03 4.966060e+01  
## 237 0.0806645751 1.628564e-03 4.761437e+01  
## 238 0.0765529906 1.548983e-03 4.576325e+01  
## 239 0.0728815697 1.458034e-03 4.407871e+01  
## 240 0.0687681370 1.386979e-03 4.215450e+01  
## 241 0.0657930997 1.313083e-03 4.073757e+01  
## 242 0.0631533334 1.256240e-03 3.946192e+01  
## 243 0.0600436741 1.173817e-03 3.793619e+01  
## 244 0.0575729421 1.129763e-03 3.670558e+01  
## 245 0.0551767124 1.077183e-03 3.549599e+01  
## 246 0.0529277808 1.034550e-03 3.434586e+01  
## 247 0.0512960727 9.819701e-04 3.350207e+01  
## 248 0.0489329530 9.407586e-04 3.226572e+01  
## 249 0.0473333382 8.967049e-04 3.141892e+01  
## 250 0.0457041898 8.611778e-04 3.054800e+01  
## 251 0.0438089568 8.256507e-04 2.952374e+01  
## 252 0.0420355306 7.901235e-04 2.855415e+01  
## 253 0.0410038643 7.588596e-04 2.798499e+01  
## 254 0.0392323709 7.190692e-04 2.699865e+01  
## 255 0.0378844982 6.906475e-04 2.624031e+01  
## 256 0.0369537824 6.707523e-04 2.571259e+01  
## 257 0.0358213189 6.465939e-04 2.506587e+01  
## 258 0.0342592753 6.309619e-04 2.416529e+01  
## 259 0.0334122262 6.053824e-04 2.367267e+01  
## 260 0.0315984954 5.684342e-04 2.260747e+01  
## 261 0.0319346255 5.542233e-04 2.280597e+01  
## 262 0.0310767224 5.428547e-04 2.229833e+01  
## 263 0.0300907280 5.215384e-04 2.171076e+01  
## 264 0.0290509742 5.087486e-04 2.108623e+01  
## 265 0.0281788315 4.867218e-04 2.055838e+01  
## 266 0.0273246057 4.646949e-04 2.003774e+01  
## 267 0.0254453608 4.412470e-04 1.887925e+01  
## 268 0.0249332948 4.185097e-04 1.856033e+01  
## 269 0.0242147792 4.085621e-04 1.811043e+01  
## 270 0.0230714900 3.950618e-04 1.738856e+01  
## 271 0.0223073609 3.765876e-04 1.690187e+01  
## 272 0.0212523888 3.545608e-04 1.622416e+01  
## 273 0.0207404313 3.446132e-04 1.589279e+01  
## 274 0.0200941504 3.304024e-04 1.547209e+01  
## 275 0.0193857669 3.197442e-04 1.500782e+01  
## 276 0.0190468722 3.147704e-04 1.478452e+01  
## 277 0.0181416212 2.948752e-04 1.418415e+01  
## 278 0.0170981824 2.849276e-04 1.348485e+01  
## 279 0.0170041999 2.813749e-04 1.342147e+01  
## 280 0.0165549607 2.700062e-04 1.311758e+01  
## 281 0.0161129893 2.557954e-04 1.281708e+01  
## 282 0.0159626969 2.565059e-04 1.271455e+01  
## 283 0.0151063110 2.422951e-04 1.212682e+01  
## 284 0.0139995907 2.192024e-04 1.135817e+01  
## 285 0.0136652227 2.131628e-04 1.112383e+01  
## 286 0.0126242144 1.989520e-04 1.038760e+01  
## 287 0.0123389053 1.961098e-04 1.018401e+01  
## 288 0.0121735839 1.854517e-04 1.006567e+01  
## 289 0.0114546179 1.769251e-04 9.547785e+00  
## 290 0.0101588717 1.584510e-04 8.600356e+00  
## 291 0.0101494856 1.563194e-04 8.593423e+00  
## 292 0.0103482666 1.559641e-04 8.740023e+00  
## 293 0.0094358480 1.442402e-04 8.063223e+00  
## 294 0.0092241279 1.460165e-04 7.904712e+00  
## 295 0.0092938940 1.442402e-04 7.957008e+00  
## 296 0.0085282062 1.332268e-04 7.379578e+00  
## 297 0.0077146532 1.193712e-04 6.757207e+00  
## 298 0.0064733886 1.001865e-04 5.788148e+00  
## 299 0.0067337695 1.030287e-04 5.993523e+00  
## 300 0.0072323835 1.053380e-04 6.383638e+00  
## 301 0.0063285005 9.467982e-05 5.673356e+00  
## 302 0.0055950712 8.490986e-05 5.086357e+00  
## 303 0.0055234715 8.277823e-05 5.028498e+00  
## 304 0.0049757801 7.531753e-05 4.582400e+00  
## 305 0.0031511083 4.973799e-05 3.043777e+00  
## 306 0.0020674675 3.321787e-05 2.079655e+00  
## 307 0.0032876233 4.760636e-05 3.162161e+00  
## 308 0.0016093833 2.615685e-05 1.656053e+00  
## 309 0.0015020194 2.384759e-05 1.555022e+00  
## 310 0.0013233517 2.087219e-05 1.385201e+00  
## 311 0.0012981466 2.029488e-05 1.361062e+00  
## 312 0.0010873900 1.656453e-05 1.157283e+00  
## 313 0.0009256793 1.429967e-05 9.983149e-01  
## 314 0.0007653369 1.183498e-05 8.380612e-01  
## 315 0.8245533718 3.183231e-04 1.125265e+02  
## 316 0.7217819564 4.320100e-04 1.462539e+02  
## 317 0.7206570365 3.410605e-04 1.465414e+02  
## 318 0.9865791003 2.728484e-04 1.499657e+01  
## 319 0.7071090499 4.092726e-04 1.498763e+02  
## 320 0.7037094838 3.637979e-04 1.506764e+02  
## 321 0.9791885714 3.637979e-04 2.182516e+01  
## 322 0.9774029218 3.637979e-04 2.339707e+01  
## 323 0.9489542697 7.503331e-04 4.569637e+01  
## 324 0.9506353183 7.503331e-04 4.449272e+01  
## 325 0.9608207347 7.275958e-04 3.692870e+01  
## 326 0.9570742952 6.593837e-04 3.976768e+01  
## 327 0.9527799727 8.412826e-04 4.293957e+01  
## 328 0.9465948847 8.640200e-04 4.736596e+01  
## 329 0.9398207749 1.045919e-03 5.203806e+01  
## 330 0.9324104838 1.159606e-03 5.695731e+01  
## 331 0.9236874519 1.296030e-03 6.251412e+01  
## 332 0.9130207127 1.500666e-03 6.899632e+01  
## 333 0.8984383646 1.614353e-03 7.735563e+01  
## 334 0.8842991349 1.841727e-03 8.496065e+01  
## 335 0.8647008622 2.000888e-03 9.476922e+01  
## 336 0.8440863746 2.250999e-03 1.042550e+02  
## 337 0.8252856435 2.569323e-03 1.122283e+02  
## 338 0.8049005021 2.796696e-03 1.201979e+02  
## 339 0.7982302361 2.933120e-03 1.226609e+02  
## 340 0.7917132598 2.910383e-03 1.250007e+02  
## 341 0.7825025500 2.955858e-03 1.281979e+02  
## 342 0.7687531797 3.001333e-03 1.327376e+02  
## 343 0.7561837288 3.092282e-03 1.366506e+02  
## 344 0.7412117441 3.296918e-03 1.410255e+02  
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## 346 0.7074772600 3.478817e-03 1.497888e+02  
## 347 0.6717880501 3.592504e-03 1.574885e+02  
## 348 0.6340104289 3.842615e-03 1.639644e+02  
## 349 0.5946934857 3.910827e-03 1.689475e+02  
## 350 0.5646289503 3.979039e-03 1.715822e+02  
## 351 0.5545193528 3.979039e-03 1.722426e+02  
## 352 0.5444010219 4.069989e-03 1.727908e+02  
## 353 0.5342799966 4.069989e-03 1.732264e+02  
## 354 0.5241626639 4.024514e-03 1.735497e+02  
## 355 0.5140687688 4.024514e-03 1.737606e+02  
## 356 0.5039638847 4.024514e-03 1.738601e+02  
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## 358 0.4838763971 4.069989e-03 1.737267e+02  
## 359 0.4739056067 4.001777e-03 1.734967e+02  
## 360 0.4640228394 4.024514e-03 1.731612e+02  
## 361 0.4540908327 3.967671e-03 1.727162e+02  
## 362 0.4442001443 3.956302e-03 1.721652e+02  
## 363 0.4344638268 3.967671e-03 1.715174e+02  
## 364 0.4248662839 3.944933e-03 1.707761e+02  
## 365 0.4153010678 3.899459e-03 1.699353e+02  
## 366 0.4058283776 3.888090e-03 1.690018e+02  
## 367 0.3964544220 3.853984e-03 1.679789e+02  
## 368 0.3780307372 3.797140e-03 1.656781e+02  
## 369 0.3691838327 3.740297e-03 1.644353e+02  
## 370 0.3601841291 3.717560e-03 1.630783e+02  
## 371 0.3513059113 3.694822e-03 1.616472e+02  
## 372 0.3426680814 3.615241e-03 1.601659e+02  
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## 374 0.3263307718 3.512923e-03 1.571216e+02  
## 375 0.3176647908 3.524292e-03 1.553762e+02  
## 376 0.3096579303 3.456080e-03 1.536820e+02  
## 377 0.3016871278 3.410605e-03 1.519167e+02  
## 378 0.2937445083 3.365130e-03 1.500786e+02  
## 379 0.2645627893 3.149125e-03 1.426316e+02  
## 380 0.2376658668 2.972911e-03 1.347637e+02  
## 381 0.2133906031 2.717115e-03 1.267881e+02  
## 382 0.1917275935 2.552270e-03 1.189262e+02  
## 383 0.1719288812 2.336265e-03 1.110858e+02  
## 384 0.1547283475 2.165734e-03 1.037313e+02  
## 385 0.1397518005 1.983835e-03 9.688740e+01  
## 386 0.1262766128 1.790568e-03 9.035427e+01  
## 387 0.1148191852 1.656986e-03 8.449992e+01  
## 388 0.1043104699 1.543299e-03 7.887112e+01  
## 389 0.0952646944 1.389822e-03 7.381344e+01  
## 390 0.0873933159 1.276135e-03 6.924141e+01  
## 391 0.0803882206 1.173817e-03 6.502986e+01  
## 392 0.0745150135 1.080025e-03 6.138865e+01  
## 393 0.0688755389 1.011813e-03 5.779191e+01  
## 394 0.0640291293 9.379164e-04 5.461765e+01  
## 395 0.0599569282 8.782308e-04 5.188749e+01  
## 396 0.0563437776 8.071765e-04 4.941434e+01  
## 397 0.0527570138 7.602807e-04 4.690959e+01  
## 398 0.0497139479 6.977530e-04 4.474378e+01  
## 399 0.0480157292 6.721734e-04 4.351815e+01  
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## 405 0.0359323956 4.732215e-04 3.441002e+01  
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## 416 0.0146676142 1.712408e-04 1.618985e+01  
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## 426 0.0038915702 4.263256e-05 5.037691e+00  
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## 428 0.9739705229 3.183231e-04 3.190811e+01  
## 429 0.9581252846 4.774847e-04 4.720499e+01  
## 430 0.9517360513 6.821210e-04 5.292099e+01  
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## 473 0.3132411524 2.739853e-03 1.870481e+02  
## 474 0.2887339991 2.603429e-03 1.803003e+02  
## 475 0.2656069006 2.489742e-03 1.730814e+02  
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## 477 0.2246865651 2.256684e-03 1.581716e+02  
## 478 0.2067354134 2.074785e-03 1.507160e+02  
## 479 0.1892728810 1.995204e-03 1.428917e+02  
## 480 0.1732825632 1.887202e-03 1.352060e+02  
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## 486 0.1063133263 1.256240e-03 9.684105e+01  
## 487 0.0990038062 1.151079e-03 9.195433e+01  
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## 542 0.4790542113 2.762590e-03 2.414214e+02  
## 543 0.4730686516 2.671641e-03 2.412036e+02  
## 544 0.4652896104 2.762590e-03 2.408390e+02  
## 545 0.4596985707 2.660272e-03 2.405200e+02  
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## 548 0.4383882606 2.751221e-03 2.388658e+02  
## 549 0.4332704697 2.717115e-03 2.383648e+02  
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## 552 0.3990886512 2.683009e-03 2.339788e+02  
## 553 0.3862893556 2.648903e-03 2.318665e+02  
## 554 0.3754237503 2.569323e-03 2.298698e+02  
## 555 0.3616409930 2.535216e-03 2.270655e+02  
## 556 0.3376148851 2.489742e-03 2.214398e+02  
## 557 0.3148567191 2.387424e-03 2.152281e+02  
## 558 0.2930650192 2.296474e-03 2.084520e+02  
## 559 0.2725349583 2.239631e-03 2.013031e+02  
## 560 0.2526609632 2.148681e-03 1.936500e+02  
## 561 0.2340710094 2.052047e-03 1.858136e+02  
## 562 0.2168796638 1.949729e-03 1.779593e+02  
## 563 0.2009033818 1.864464e-03 1.701137e+02  
## 564 0.1860491983 1.739409e-03 1.623251e+02  
## 565 0.1721985913 1.631406e-03 1.546131e+02  
## 566 0.1595489758 1.551825e-03 1.471722e+02  
## 567 0.1483272987 1.472245e-03 1.402374e+02  
## 568 0.1369489055 1.381295e-03 1.328689e+02  
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## 570 0.1188200399 1.230660e-03 1.203801e+02  
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## 572 0.1029735904 1.085709e-03 1.086442e+02  
## 573 0.0969130691 1.008971e-03 1.039362e+02  
## 574 0.0910159397 9.549694e-04 9.923045e+01  
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## 576 0.0760408065 8.242296e-04 8.668666e+01  
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## 690 0.1054558270 1.014655e-03 1.231565e+02  
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## 694 0.0827192174 7.929657e-04 1.029389e+02  
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## 701 0.0396045316 3.780087e-04 5.771440e+01  
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## 712 0.0100190372 8.135714e-05 1.802479e+01  
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## 714 0.0080232943 6.394885e-05 1.483745e+01  
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theo

## Delta Gamma Vega  
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## 2 1 6.405520e-09 1.622243e-04  
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## 560 1 2.137143e-03 1.936500e+02  
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