Options

```
expry.date <- "2020-05-08"

options <- getOptionChain("AMZN", Exp = expry.date)

options
```

```
$calls
                     Strike   Last        Chg    Bid    Ask Vol  OI
AMZN200508C01620000   1620 321.70   0.000000 342.45 358.95   1   1
AMZN200508C01700000   1700 270.45   0.000000 273.80 292.00   8  NA
AMZN200508C01730000   1730 247.53   0.000000 248.95 266.15   8  NA
AMZN200508C01850000   1850 167.60   8.550003 159.65 178.00   6   0
AMZN200508C01880000   1880 147.50   0.000000 139.00 153.85   1   1
AMZN200508C01895000   1895 150.62  14.319992 130.40 148.50   2   5
AMZN200508C01900000   1900 138.60   0.000000 131.30 140.80   3   3
AMZN200508C01905000   1905 148.50  23.900002 123.10 137.65   2   2
AMZN200508C01910000   1910 131.05   6.050003 125.35 139.50   5   3
AMZN200508C01915000   1915 123.11  -5.089996 122.40 136.50   1   1
AMZN200508C01925000   1925 115.00   0.000000 116.65 130.50   3   1
AMZN200508C01935000   1935 117.52   0.000000 111.05 124.50   3   3
AMZN200508C01950000   1950 107.83 -18.299995 102.90 116.50   1   3
AMZN200508C01995000   1995  97.70   0.000000  80.55  87.30  NA   1
AMZN200508C02000000   2000  96.00   0.000000  78.25  90.85   5   4
AMZN200508C02050000   2050  68.68   3.680000  57.65  64.50   2   1
AMZN200508C02200000   2200  24.78  -5.269999  19.60  22.55   1  10
AMZN200508C02220000   2220  19.95  -5.779999  16.75  19.00   2   2
AMZN200508C02250000   2250  20.66   0.000000   4.80  15.30   7   7
AMZN200508C02260000   2260  19.37   0.000000   3.85  14.25   2   2
AMZN200508C02310000   2310  10.45   0.000000   8.15  19.50  NA   5
AMZN200508C02360000   2360   7.30  -5.250000   5.50  19.35   1   1
AMZN200508C02370000   2370  10.25   0.000000   5.05  18.95   1  20
AMZN200508C02390000   2390  10.60   0.000000   4.35  15.90  NA 103
AMZN200508C02410000   2410   9.65   0.000000   3.70   9.85  NA   1
AMZN200508C02420000   2420   9.15   0.000000   3.45   9.90  NA   9
AMZN200508C02430000   2430   8.70   0.000000   3.20   9.80  NA  73
AMZN200508C02500000   2500   5.30   0.000000   1.93   9.80  NA   1

$puts
                     Strike   Last        Chg    Bid    Ask Vol OI
AMZN200508P01130000   1130   2.40   0.000000   1.02   9.30   3  3
AMZN200508P01200000   1200   3.90   0.000000   1.95   9.80   1 12
AMZN200508P01560000   1560  13.55 -11.700000  15.55  18.00   1  2
```

AMZN200508P01570000	1570	28.50	0.000000	16.35	18.85	9	6
AMZN200508P01700000	1700	35.40	0.000000	31.50	35.10	76	70
AMZN200508P01860000	1860	73.48	0.000000	69.25	74.65	1	2
AMZN200508P01865000	1865	75.10	0.000000	70.85	76.35	1	2
AMZN200508P01870000	1870	65.37	-34.019997	72.50	78.10	1	1
AMZN200508P01905000	1905	107.40	0.000000	84.75	91.05	1	8
AMZN200508P01910000	1910	97.28	0.000000	86.60	98.80	1	8
AMZN200508P01920000	1920	101.15	0.000000	90.45	97.15	1	3
AMZN200508P01925000	1925	120.01	0.000000	92.45	99.25	1	2
AMZN200508P01950000	1950	103.90	-9.099998	102.80	110.35	12	13
AMZN200508P01980000	1980	120.75	-9.149994	116.65	125.00	6	3
AMZN200508P01990000	1990	111.95	-53.729996	121.50	130.75	1	1
AMZN200508P01995000	1995	160.00	0.000000	124.00	133.40	NA	NA

```
calls <- options$calls
calls
```

	Strike	Last	Chg	Bid	Ask	Vol	OI
AMZN200508C01620000	1620	321.70	0.000000	342.45	358.95	1	1
AMZN200508C01700000	1700	270.45	0.000000	273.80	292.00	8	NA
AMZN200508C01730000	1730	247.53	0.000000	248.95	266.15	8	NA
AMZN200508C01850000	1850	167.60	8.550003	159.65	178.00	6	0
AMZN200508C01880000	1880	147.50	0.000000	139.00	153.85	1	1
AMZN200508C01895000	1895	150.62	14.319992	130.40	148.50	2	5
AMZN200508C01900000	1900	138.60	0.000000	131.30	140.80	3	3
AMZN200508C01905000	1905	148.50	23.900002	123.10	137.65	2	2
AMZN200508C01910000	1910	131.05	6.050003	125.35	139.50	5	3
AMZN200508C01915000	1915	123.11	-5.089996	122.40	136.50	1	1
AMZN200508C01925000	1925	115.00	0.000000	116.65	130.50	3	1
AMZN200508C01935000	1935	117.52	0.000000	111.05	124.50	3	3
AMZN200508C01950000	1950	107.83	-18.299995	102.90	116.50	1	3
AMZN200508C01995000	1995	97.70	0.000000	80.55	87.30	NA	1
AMZN200508C02000000	2000	96.00	0.000000	78.25	90.85	5	4
AMZN200508C02050000	2050	68.68	3.680000	57.65	64.50	2	1
AMZN200508C02200000	2200	24.78	-5.269999	19.60	22.55	1	10
AMZN200508C02220000	2220	19.95	-5.779999	16.75	19.00	2	2
AMZN200508C02250000	2250	20.66	0.000000	4.80	15.30	7	7
AMZN200508C02260000	2260	19.37	0.000000	3.85	14.25	2	2
AMZN200508C02310000	2310	10.45	0.000000	8.15	19.50	NA	5
AMZN200508C02360000	2360	7.30	-5.250000	5.50	19.35	1	1
AMZN200508C02370000	2370	10.25	0.000000	5.05	18.95	1	20
AMZN200508C02390000	2390	10.60	0.000000	4.35	15.90	NA	103
AMZN200508C02410000	2410	9.65	0.000000	3.70	9.85	NA	1
AMZN200508C02420000	2420	9.15	0.000000	3.45	9.90	NA	9
AMZN200508C02430000	2430	8.70	0.000000	3.20	9.80	NA	73
AMZN200508C02500000	2500	5.30	0.000000	1.93	9.80	NA	1

```
puts <- options$puts
puts
```

```
                    Strike   Last        Chg    Bid    Ask Vol OI
AMZN200508P01130000   1130   2.40   0.000000   1.02   9.30   3  3
AMZN200508P01200000   1200   3.90   0.000000   1.95   9.80   1 12
AMZN200508P01560000   1560  13.55 -11.700000  15.55  18.00   1  2
AMZN200508P01570000   1570  28.50   0.000000  16.35  18.85   9  6
AMZN200508P01700000   1700  35.40   0.000000  31.50  35.10  76 70
AMZN200508P01860000   1860  73.48   0.000000  69.25  74.65   1  2
AMZN200508P01865000   1865  75.10   0.000000  70.85  76.35   1  2
AMZN200508P01870000   1870  65.37 -34.019997  72.50  78.10   1  1
AMZN200508P01905000   1905 107.40   0.000000  84.75  91.05   1  8
AMZN200508P01910000   1910  97.28   0.000000  86.60  98.80   1  8
AMZN200508P01920000   1920 101.15   0.000000  90.45  97.15   1  3
AMZN200508P01925000   1925 120.01   0.000000  92.45  99.25   1  2
AMZN200508P01950000   1950 103.90  -9.099998 102.80 110.35  12 13
AMZN200508P01980000   1980 120.75  -9.149994 116.65 125.00   6  3
AMZN200508P01990000   1990 111.95 -53.729996 121.50 130.75   1  1
AMZN200508P01995000   1995 160.00   0.000000 124.00 133.40  NA NA
```

```
calls <- options$calls[, c(1:2, 6)]

AMZN <- getSymbols("AMZN", from = "2020-3-30", to = "2020-3-31", auto.assign = F)
```

```
'getSymbols' currently uses auto.assign=TRUE by default, but will
use auto.assign=FALSE in 0.5-0. You will still be able to use
'loadSymbols' to automatically load data. getOption("getSymbols.env")
and getOption("getSymbols.auto.assign") will still be checked for
alternate defaults.

This message is shown once per session and may be disabled by setting
options("getSymbols.warning4.0"=FALSE). See ?getSymbols for details.
```

```
Warning in read.table(file = file, header = header, sep = sep,
quote = quote, : incomplete final line found by readTableHeader
on 'https://query1.finance.yahoo.com/v7/finance/download/AMZN?
period1=1585526400&period2=1585612800&interval=1d&events=history&crumb=KtRQHsmSOIs'
```

```
last <- AMZN$AMZN.Close
```

Volatility

```
AMZN <- getSymbols("AMZN", from = "2017-3-30", to = "2020-3-31", auto.assign = F)
```

```
volatility <- data.table(AMZN$AMZN.Adjusted)
colnames(volatility) <- c("Adj")

volatility$Ret <- c(NA, diff(log(volatility$Adj)))

hist.vol <- sd(volatility[-1]$Ret) * sqrt(252)
hist.vol
```

```
[1] 0.2998559
```

```
price <- as.numeric(last$AMZN.Close)

call.delta <- abs(calls$Strike - price)
closest.calls <- head(sort(call.delta), 2)

bs.call <- calls[call.delta == closest.calls, 1:2]

put.delta <- abs(puts$Strike - price)
closest.puts <- head(sort(put.delta), 2)

bs.put <- puts[closest.puts, 1:2]

TTM <- as.numeric(as.Date(expry.date) - as.Date("2020-3-31"))
```

```
rfr <- 0.0007

d1 <- (log(price/bs.call$Strike) + (rfr+0.5*(hist.vol^2)) * TTM)/(hist.vol*sqrt(TTM))
d2 <- d1 - hist.vol * sqrt(TTM)

bs.call$optval <- price * pnorm(d1, mean = 0, sd = 1) -
   bs.call$Strike * exp(-rfr * TTM) * pnorm(d2, mean = 0, sd = 1)

nd1 =- d1
nd1
```

```
[1] -0.9466426 -0.9424650
```

```
nd2 =- d2
nd2
```

```
[1] 0.9017935 0.9059711
```

```
bs.put$optval <- bs.put$Strike *
   exp(-rfr*TTM)*pnorm(nd2, mean = 0, sd = 1) -
   price * pnorm(nd1, mean = 0, sd = 1)

bs.put
```

```
                    Strike  Last   optval
AMZN200508P01950000   1950 103.9 1212.600
AMZN200508P01995000   1995 160.0 1248.431
```

Black-Scholes-Merton OPM Function

```
bsm.option <- function(S, K, T, riskfree, sigma, type) {
   d1 <- (log(S/K) + (riskfree + 0.5*sigma^2)*T)/(sigma * sqrt(T))
   d2 <- d1 - sigma * sqrt(T)
   if(type == "C") {
      opt.val <- S * pnorm(d1) - K * exp(-riskfree*T) * pnorm(d2)
   }
   if(type == "P") {
      opt.val <- K * exp(-riskfree*T)*pnorm(-d2)-S*pnorm(-d1)
   }

   opt.val
}

cbind(bs.call, BSM = bsm.option(bs.call$Strike, price, TTM, rfr, hist.vol, "C"))
```

```
                    Strike   Last   optval      BSM
AMZN200508C01935000   1935 117.52 1280.417 1251.388
AMZN200508C01950000   1950 107.83 1277.744 1263.756
```

```
cbind(bs.put, BSM = bsm.option(bs.put$Strike, price, TTM, rfr, hist.vol, "P"))
```

```
                    Strike  Last   optval      BSM
AMZN200508P01950000   1950 103.9 1212.600 1226.154
AMZN200508P01995000   1995 160.0 1248.431 1218.352
```

Put-Call Parity

```
bs.call$optval.pcparity <- bs.put$optval - bs.put$Strike * exp(-rfr * TTM) + price
bs.call
```

```
                    Strike   Last   optval optval.pcparity
AMZN200508C01935000   1935 117.52 1280.417        1277.736
AMZN200508C01950000   1950 107.83 1277.744        1269.748
```

```
bs.put$optval.pcparity <- bs.call$optval + bs.call$Strike * exp(-rfr * TTM) - price
bs.put
```

```
                    Strike  Last   optval optval.pcparity
AMZN200508P01950000   1950 103.9 1212.600        1200.675
```

```
AMZN200508P01995000   1995 160.0 1248.431        1212.608
```

The Greeks

```
greeks.call <- bs.call[, 1:2]
greeks.call$delta <- pnorm(d1, mean=0, sd = 1)
greeks.call$gamma <- dnorm(d1, mean = 0, sd = 1) / (price*hist.vol*sqrt(TTM))
greeks.call$vega <- price * dnorm(d1, mean = 0, sd = 1) * sqrt(TTM)
greeks.call$theta <- -((price*hist.vol*dnorm(d1, mean =0, sd = 1)) /
   (2*sqrt(TTM))) - (rfr*greeks.call$Strike*exp(-rfr*TTM) *
      pnorm(d2))
greeks.call$rho <- greeks.call$Strike * TTM * exp(-rfr * TTM) *
   pnorm(d2)
greeks.call$type <- c("call")

greeks.call
```

```
                    Strike   Last     delta        gamma   vega     theta
AMZN200508C01935000   1935 117.52 0.8280895 7.020734e-05 3085.6 -12.41629
AMZN200508C01950000   1950 107.83 0.8270227 7.048493e-05 3097.8 -12.46483
                         rho type
AMZN200508C01935000 13144.54 call
AMZN200508C01950000 13166.51 call
```

```
greeks.put <- bs.put[, 1:2]
greeks.put$delta <- pnorm(d1) - 1
greeks.put$gamma <- dnorm(d1) / (price*hist.vol*sqrt(TTM))
greeks.put$vega <- price * dnorm(d1) * sqrt(TTM)
greeks.put$theta <- -((price*hist.vol*dnorm(d1))/2*sqrt(TTM)) +
   (rfr*greeks.put$Strike*exp(-rfr*TTM)) *
   pnorm(nd2)
greeks.put$rho <- -greeks.put$Strike * TTM * exp(-rfr * TTM)
greeks.put$type <- c("put")

greeks.put
```

```
                    Strike  Last      delta        gamma   vega     theta
AMZN200508P01950000   1950 103.9 -0.1719105 7.020734e-05 3085.6 -461.5326
AMZN200508P01995000   1995 160.0 -0.1729773 7.048493e-05 3097.8 -463.3351
                         rho type
AMZN200508P01950000 -72154.92  put
AMZN200508P01995000 -73820.04  put
```

Implied Volatility

```
iv.opt <- function(S, K, T, riskfree, price, type) {
   sigma <- hist.vol
   sigma.up <- 1
   sigma.down <- 0.001
   count <- 0
   epsilon <- bsm.option(S, K, TTM, riskfree, sigma, type) - price
   while(abs(epsilon) > 0.00001 && count < 1000) {
      if(epsilon < 0) {
         sigma.down <- -sigma
         sigma <- (sigma.up + sigma)/2
      } else {
         sigma.up <- sigma
         sigma <- (sigma.down+sigma)/2
      }
      epsilon <- bsm.option(S, K, TTM, riskfree, sigma, type) - price
      count <- count + 1

      if(count == 1000) {
         return(NA)
      } else {
         return(sigma)
      }
   }
}

bs.call
```

```
                    Strike   Last   optval optval.pcparity
AMZN200508C01935000   1935 117.52 1280.417        1277.736
AMZN200508C01950000   1950 107.83 1277.744        1269.748
```

```
iv.opt(price, 1935, TTM, rfr, 1280.417, "C")
```

```
[1] 0.150428
```

Market Risk

```
vix_raw <- data.table::fread(file.path(data.dir, "VIXCLS.csv"))

vix_raw$DATE <- as.Date(vix_raw$DATE)
vix_raw$VIXCLS <- as.numeric(vix_raw$VIXCLS)
```

```
Warning: NAs introduced by coercion
```

```
colnames(vix_raw) <- c("Date", "Price")

vix_raw <- na.omit(vix_raw)
vix_raw
```

```
            Date Price
   1: 2010-03-30 17.13
   2: 2010-03-31 17.59
   3: 2010-04-01 17.47
   4: 2010-04-05 17.02
   5: 2010-04-06 16.23
  ---
2514: 2020-03-24 61.67
2515: 2020-03-25 63.95
2516: 2020-03-26 61.00
2517: 2020-03-27 65.54
2518: 2020-03-30 57.08
```

```
spx_raw <- data.table::fread(file.path(data.dir, "SP500.csv"))

spx_raw$DATE <- as.Date(spx_raw$DATE)
spx_raw$SP500 <- as.numeric(spx_raw$SP500)
```

```
Warning: NAs introduced by coercion
```

```
colnames(spx_raw) <- c("Date", "Price")

spx_raw <- na.omit(spx_raw)

spx_raw
```

```
            Date   Price
   1: 2010-03-31 1169.43
   2: 2010-04-01 1178.10
   3: 2010-04-05 1187.44
   4: 2010-04-06 1189.44
   5: 2010-04-07 1182.45
  ---
2513: 2020-03-24 2447.33
2514: 2020-03-25 2475.56
2515: 2020-03-26 2630.07
2516: 2020-03-27 2541.47
2517: 2020-03-30 2626.65
```

```
spx <- data.table(Date = spx_raw$Date,
                  Return = c(NA, diff(log(spx_raw$Price))))
```

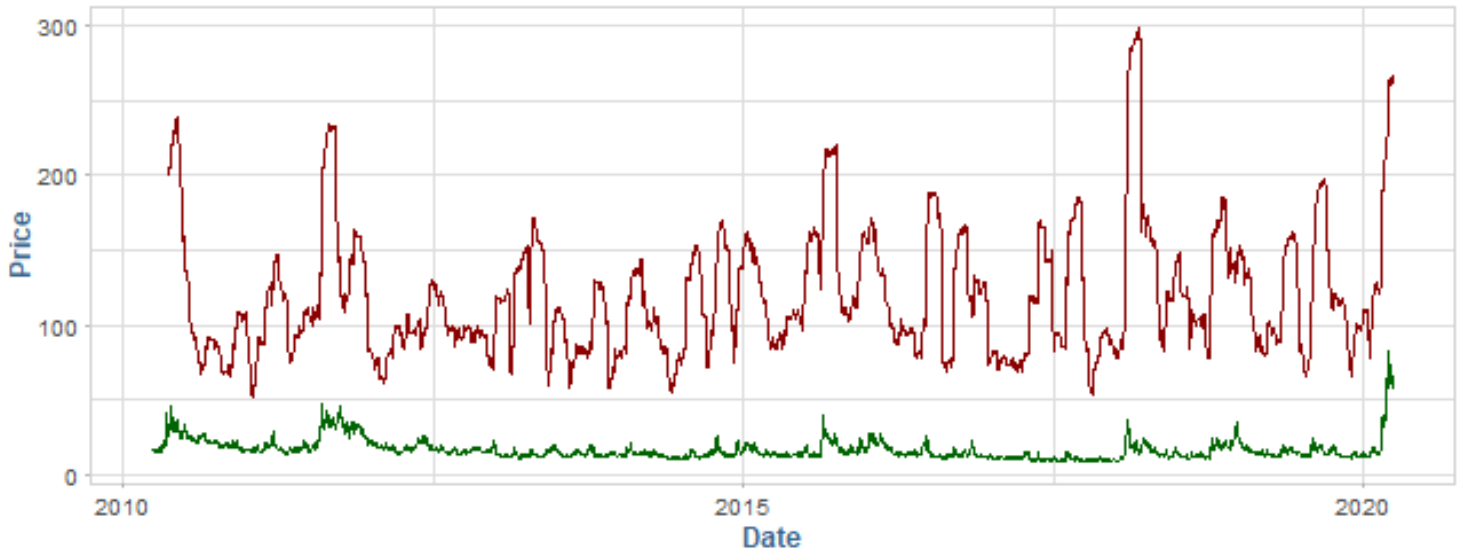
```
vix <- data.table(Date = vix_raw$Date,
                  Return = c(NA, diff(log(vix_raw$Price))))
```

```
spx$sd <- c(rep(NA, 29), rollapply(spx$Return, 30, sd, na.rm = T) * sqrt(252) * 100)
vix$sd <- c(rep(NA, 29), rollapply(vix$Return, 30, sd, na.rm = T) * sqrt(252) * 100)

combined <- merge(spx, vix, by = "Date")
colnames(combined) <- c("Date", "SPX", "SPX.Vol", "VIX", "VIX.Vol")

combined
```

```
            Date          SPX  SPX.Vol          VIX  VIX.Vol
   1: 2010-03-31           NA       NA  0.026499246       NA
   2: 2010-04-01  0.007386521       NA -0.006845435       NA
   3: 2010-04-05  0.007896758       NA -0.026096001       NA
   4: 2010-04-06  0.001682879       NA -0.047527742       NA
   5: 2010-04-07 -0.005894051       NA  0.023745408       NA
  ---
2513: 2020-03-24  0.089683157 77.74591  0.001298069 263.9141
2514: 2020-03-25  0.011468999 77.93048  0.036303939 263.6941
2515: 2020-03-26  0.060543829 80.46820 -0.047227664 261.5728
2516: 2020-03-27 -0.034267808 80.78649  0.071786779 261.5757
2517: 2020-03-30  0.032966616 81.66323 -0.138206851 266.2298
```

```
ggplot(combined) +
   geom_line(data = vix_raw, aes(Date, Price), col = "darkgreen") +
   geom_line(aes(Date, VIX.Vol), col = "darkred")
```

```
Warning: Removed 28 row(s) containing missing values (geom_path).
```



Binomial OPM