VIX computation for Indian Markets

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Abstract

This document contains a brief summary of VIX index that includes its derivation and `R` code to compute the same. An attempt has been made to verify the VIX quoted by NSE based on option prices with the intention of understanding the computation in a better way.

Contents

1 History

CBOE introduced VIX to measure the market's expectation of 30-day volatility implied by at-the-money S&P 100 Index option prices. This was in 1993. Ten years later in 2003, CBOE with Goldman Sachs updated the VIX to reflect a new way to measure expected volatility, one that continues to be widely used by financial theorists, risk managers and volatility traders. The new VIX is based on S&P 500 Index and is estimated via averaging the weighted prices of SPX puts and calls over a wide range of strike prices. In 2004, CBOE introduced VIX futures and two years later, in 2006, CBOE launched VIX options. VIX options is touted to be the most successful new product in CBOE history. What's the reason for its success ? Well, the most obvious one is that VIX futures and options act as hedge against volatility exposure. In the Indian Markets, NSE disseminates the VIX index and has archive of prices since 2007. More recently in Feb 2014, NSE has launched VIX futures with maturity varying from 1 to 3 weeks.

2 CBOE VIX and NSE VIX

VIX is a volatility index comprising option rather than stocks, with the price of each option reflecting the market's expectation of future volatility. It is calculated based on the following formula :

$$\sigma^2 = \frac{2}{T} \sum_i \frac{\Delta K_i}{K_i^2} e^{RT} Q(K_i) - \frac{1}{T} \left(\frac{F}{K_0} - 1 \right)^2$$

$\sigma =$ Expected volatility

$T =$ Time to expiration

$F =$ Forward index level derived from index option prices

$K_0 =$ First strike below the forward index level , F

$K_i =$ Strike price of i^{th}out-of-money option

$\Delta K_i =$ Interval between strike prices - half the difference between strike on either side of K_i

$R =$ Risk-free interest rate

$Q(K_i) =$ The midpoint of the bid-ask spread of each option with strike K_i

From a cursory reading of CBOE VIX and NSE VIX , here are the two differences that I could gather:

Parameter	CBOE VIX	NSE VIX
F	Forward level is computed by put call parity relation at a strike at which the absolute difference between call and put prices is the smallest	Nifty futures price from the market is used
$Q(K_i)$	The observed midpoint of the bid and ask is used	Since the liquidity of far month options is an issue in the Indian markets, a natural cubic spline interpolation is used to fill in the mid point prices where the bid-ask spread is unreasonable($\geq 30\%$) or not available

3 Formula Derivation

In this section, I will list down the steps to derive the VIX formula. The standard price process assumed for stocks is GBM and its SDE in the risk neutral world is

$$dS_t = (r-q)S_t dt + \sigma S_t d\tilde{W}_t$$

where $d\tilde{W}_t$ is the driftless Brownian motion.
The above equation implies

$$d\log S_t = (r-q-\sigma^2/2)dt + \sigma d\tilde{W}_t$$

$$\begin{aligned}
\int_0^T \frac{\sigma^2}{2}dt &= \int_0^T \frac{dS_t}{S_t} - \int_0^T d\log S_t \\
\frac{\sigma^2 T}{2} &= \int_0^T (r-q)dt + \sigma d\tilde{W}_t - \log\frac{S_t}{S_0} \\
&= \int_0^T (r-q)dt + \int_0^T \sigma d\tilde{W}_t - \log\frac{S_t}{S_0} \\
&= (r-q)T + \int_0^T \sigma d\tilde{W}_t - \log\frac{S_t}{S_0}
\end{aligned}$$

Consider the first moment of the above stochastic process, i.e. expectation under martingale measure is

$$\begin{aligned}
\tilde{\mathbb{E}}\left\{\frac{\sigma^2 T}{2}\right\} &= \tilde{\mathbb{E}}\left\{(r-q)T + \int_0^T \sigma d\tilde{W}_t - \log\frac{S_t}{S_0}\right\} \\
&= (r-q)T - \tilde{\mathbb{E}}\left\{\log\frac{S_t}{S_0}\right\}
\end{aligned}$$

Let F be the futures price and K be the strike just below the F, then

$$\begin{aligned}
\frac{\overline{\sigma}^2 T}{2} &= \log\frac{F}{S_0} - \tilde{\mathbb{E}}\left\{\log\frac{S_t}{S_0}\right\} \\
&= \log\frac{F}{S_0} - \tilde{\mathbb{E}}\left\{\log\frac{K}{S_0} + \log\frac{S_t}{K}\right\} \\
&= \log\frac{F}{S_0} - \tilde{\mathbb{E}}\left\{\log\frac{K}{S_0} + \log\frac{S_t}{K}\right\} \\
&= \log\frac{F}{K} - \tilde{\mathbb{E}}\left\{\log\frac{S_t}{K}\right\}
\end{aligned}$$

The following relationship is used to simplify the above expression :

$$\log\frac{S_t}{K} = \frac{S_T}{K} - 1 - \int_0^K \frac{1}{k^2}\max(k-S_t,0)dk - \int_0^K \frac{1}{k^2}\max(S_t-k,0)dk$$

$$
\begin{aligned}
\frac{\overline{\sigma}^2 T}{2} &= \log\frac{F}{K} - \tilde{\mathbb{E}}\left\{\frac{S_T}{K} - 1 - \int_0^K \frac{1}{k^2}\max(k-S_t,0)dk - \int_0^K \frac{1}{k^2}\max(S_t-k,0)dk\right\} \\
&= \log\frac{F}{K} - \frac{F}{K} + 1 + \tilde{\mathbb{E}}\left\{\int_0^K \frac{1}{k^2}\max(k-S_t,0)dk + \int_0^K \frac{1}{k^2}\max(S_t-k,0)dk\right\} \\
&= -\frac{1}{2}\left(\frac{F}{K}-1\right)^2 + \tilde{\mathbb{E}}\left\{\int_0^K \frac{1}{k^2}\max(k-S_t,0)dk + \int_0^K \frac{1}{k^2}\max(S_t-k,0)dk\right\} \\
\overline{\sigma}^2 &= -\frac{1}{T}\left(\frac{F}{K}-1\right)^2 + \frac{2}{T}\tilde{\mathbb{E}}\left\{\int_0^K \frac{1}{k^2}\max(k-S_t,0)dk + \int_0^K \frac{1}{k^2}\max(S_t-k,0)dk\right\} \\
&= \frac{2}{T}\tilde{\mathbb{E}}\left\{\int_0^K \frac{1}{k^2}\max(k-S_t,0)dk + \int_0^K \frac{1}{k^2}\max(S_t-k,0)dk\right\} - \frac{1}{T}\left(\frac{F}{K}-1\right)^2
\end{aligned}
$$

The integrals are evaluated by discretizing at various strikes. The integrals under risk neutral expectation are nothing but undiscounted put and call prices adjusted accordingly. Hence the above expression simplifies to

$$
\overline{\sigma}^2 = \frac{2}{T}\sum_i \frac{\Delta K_i}{K_i^2} e^{RT} Q(K_i) - \frac{1}{T}\left(\frac{F}{K}-1\right)^2
$$

$\overline{\sigma}^2 =$ Expected volatility

$T =$ Time to expiration

$F =$ Forward index level derived from index option prices

$K =$ First strike below the forward index level , F

$K_i =$ Strike price of i^{th}out-of-money option

$\Delta K_i =$ Interval between strike prices - half the difference between strike on either side of K_i

$R =$ Risk-free interest rate of expiration

$Q(K_i) =$ The midpoint of the bid-ask spread of each option with strike K_i

4 Test Run

The main formula behind VIX and an example that shows the computations are given on the NSE site. To see to it that my elementary code is bug-free, I have replicated the numbers from that document.

Step 1 : Load the near month and far month option data.

```
x             <- read.csv("data/nm_demo.csv", stringsAsFactors = FALSE)
nm            <- matrix(data= x[,1], nrow = 20, ncol = 5, TRUE)
colnames(nm) <- c("K","Cb","Ca","Pb","Pa")
y             <- read.csv("data/fm_demo.csv", stringsAsFactors = FALSE)
fm            <- matrix(data= as.numeric(y[,1]), nrow = 18, ncol = 7, TRUE)
fm            <- fm[,c(1,2,3,5,6)]
colnames(fm) <- c("K","Cb","Ca","Pb","Pa")
nm.test       <- nm;fm.test      <- fm
```

K	Cb	Ca	Pb	Pa
3800	1290.10	1314.25	0.40	0.50
3900	1192.95	1212.80	0.35	0.80
4000	1103.00	1107.95	0.70	0.85
4100	1005.00	1017.10	0.80	1.10
4200	894.95	913.90	1.00	1.20
4300	800.00	809.95	1.20	1.70
4400	696.15	709.50	1.90	2.00
4500	601.25	609.55	3.30	3.45
4600	500.70	520.00	4.45	4.50
4700	410.00	416.55	7.70	8.00
4800	316.00	321.05	13.20	13.40
4900	226.00	228.00	22.50	22.65
5000	144.50	145.00	40.40	40.50
5100	79.00	79.10	74.40	74.50
5200	34.75	35.00	129.00	129.95
5300	11.50	11.55	200.55	206.00
5400	3.60	3.65	286.00	307.00
5500	1.70	1.95	340.00	396.00
5600	1.00	1.35	481.00	507.35
5700	0.70	1.00	577.35	606.65

Table 1: Near Month Options

K	Cb	Ca	Pb	Pa
4000	1100.15	1110.00	5.90	6.50
4100	1006.25	1026.90	7.15	8.50
4200	905.15	931.15	10.00	10.70
4300	809.15	844.75	13.55	14.00
4400	713.10	732.85	18.00	18.75
4500	615.70	668.35	22.35	25.00
4600	526.80	572.05	32.00	33.30
4700	444.35	464.15	41.00	45.00
4800	366.60	408.60	61.50	62.00
4900	300.00	307.30	84.55	86.50
5000	231.00	232.00	116.00	117.00
5100	171.10	171.50	156.00	158.00
5200	120.05	121.80	203.00	209.35
5300	79.60	80.50	252.85	265.00
5400	48.10	48.50	322.45	345.65
5500	29.00	32.00	405.00	437.10
5600	15.90	19.85	477.85	509.00
5700	9.15	9.75	575.25	609.00

Table 2: Far Month Options

Step 2 : Compute the spreads and remove the spread that are more than 30%

```
calculate.spreads <- function(data){
  data          <- as.data.frame(data)
  data$Cmid     <- with(data, Ca + Cb)*0.5
  data$Pmid     <- with(data, Pa + Pb)*0.5
  data$Cspread <- with(data, (Ca - Cb)/Cmid)
  data$Pspread <- with(data, (Pa- Pb)/Pmid)
  data$Pvalid  <- with(data, Pspread <=0.3)
  data$Cvalid  <- with(data, Cspread <=0.3)
  data          <- data[,c("K","Cmid","Pmid","Pvalid","Cvalid")]
  data$Pvalid[is.na(data$Pvalid)] <- FALSE
  data$Cvalid[is.na(data$Cvalid)] <- FALSE
  data[data$Pvalid == FALSE, c("Pmid")] <- NA
  data[data$Cvalid == FALSE, c("Cmid")] <- NA
  data          <- data[,c("K","Cmid","Pmid")]
  return(data)
}
nm.spread      <- calculate.spreads(nm)
fm.spread      <- calculate.spreads(fm)
```

Step 3 : Do a natural spline interpolation for the strikes whose mid quotes are not available/ more than 30%

```
interpolate      <- function(data, var){
  data            <- data[,c("K",var)]
  pred            <- rep(NA, dim(data)[1])
  valid.knots     <- which(!is.na(data[,var]))
  boundary.knots <- data$K[range(valid.knots)]
  internal.knots <- valid.knots[2:(length(valid.knots)-1)]
  X               <- ns(x   = data$K,
                         knots  =data$K[internal.knots],
                         Boundary.knots= boundary.knots )
  fit             <- lm(data[,var]~X)
  fitted          <- predict(fit, newdata = list(K = c(data$K)))
  idx             <- range(valid.knots)[1]:range(valid.knots)[2]
  pred[idx]       <- fitted[idx]
  pred
}
nm.spread$Pmid.i <- interpolate(nm.spread, "Pmid")
nm.spread$Cmid.i <- interpolate(nm.spread, "Cmid")
fm.spread$Pmid.i <- interpolate(fm.spread, "Pmid")
fm.spread$Cmid.i <- interpolate(fm.spread, "Cmid")
```

Step 4 : Compute the out of money Put and Call option mid quote prices

```r
K0                    <- 5100
K1                    <- 5100
nm.spread$delta       <- with(nm.spread, ifelse(K < K0, Pmid.i , Cmid.i))
idx                   <- which(nm.spread$K == K0)
nm.spread$delta[idx] <- with(nm.spread, Pmid.i[idx] + Cmid.i[idx])/2
nm.spread             <- nm.spread[!is.na(nm.spread$delta),]
nm.spread             <- nm.spread[,c("K","delta")]

fm.spread$delta       <- with(fm.spread, ifelse(K < K0, Pmid.i , Cmid.i))
idx                   <- which(fm.spread$K == K0)
fm.spread$delta[idx] <- with(fm.spread, Pmid.i[idx] + Cmid.i[idx])/2
fm.spread             <- fm.spread[!is.na(fm.spread$delta),]
fm.spread             <- fm.spread[,c("K","delta")]
K                     <- c(K0,K1)
n                     <- length(nm.spread$K)
delta.K               <- c(nm.spread$K[2]- nm.spread$K[1], diff(nm.spread$K , lag = 2)/2,
                           nm.spread$K[n] - nm.spread$K[n-1] )
nm.spread$delta.K     <- delta.K
n                     <- length(fm.spread$K)
delta.K               <- c(fm.spread$K[2]- fm.spread$K[1], diff(fm.spread$K , lag = 2)/2,
                           fm.spread$K[n] - fm.spread$K[n-1] )
fm.spread$delta.K     <- delta.K
temp1                 <- nm.spread
colnames(temp1)       <- c("K","Q(K)","Delta(K)")
temp2                 <- fm.spread
colnames(temp2)       <- c("K","Q(K)","Delta(K)")
```

K	Q(K)	Delta(K)
3800.00	0.45	100.00
3900.00	0.60	100.00
4000.00	0.78	100.00
4100.00	0.96	100.00
4200.00	1.10	100.00
4300.00	1.23	100.00
4400.00	1.95	100.00
4500.00	3.38	100.00
4600.00	4.48	100.00
4700.00	7.85	100.00
4800.00	13.30	100.00
4900.00	22.58	100.00
5000.00	40.45	100.00
5100.00	76.75	100.00
5200.00	34.87	100.00
5300.00	11.52	100.00
5400.00	3.62	100.00
5500.00	1.83	100.00
5600.00	1.17	100.00

Table 3: Near Month Options

K	Q(K)	Delta(K)
4000.00	6.20	100.00
4100.00	7.82	100.00
4200.00	10.35	100.00
4300.00	13.78	100.00
4400.00	18.37	100.00
4500.00	23.68	100.00
4600.00	32.65	100.00
4700.00	43.00	100.00
4800.00	61.75	100.00
4900.00	85.53	100.00
5000.00	116.50	100.00
5100.00	164.15	100.00
5200.00	120.93	100.00
5300.00	80.05	100.00
5400.00	48.30	100.00
5500.00	30.50	100.00
5600.00	17.88	100.00
5700.00	9.45	100.00

Table 4: Far Month Options

Step 5 : Compute the volatility from near month and far month option prices

```
T          <- c(0.02466, 0.10137)
F          <- c(5129, 5115)
R          <- c(0.039, 0.0465)
data      <- nm.spread
idx       <- 1
sig1      <- sum(with(data, delta.K/K^2 * exp(R[idx]*T[idx])*delta))*2 / T[idx] -
             1/T[idx]*(F[idx]/K[idx]-1)^2

data      <- fm.spread
idx       <- 2
sig2      <- sum(with(data, delta.K/K^2 * exp(R[idx]*T[idx])*delta))*2 / T[idx] -
             1/T[idx]*(F[idx]/K[idx]-1)^2
```

Step 6 : Interpolate between near month and far month volatility to obtain VIX

```
NT1       <- 12960
NT2       <- 53280
N30       <- 43200
N365      <- 525600
sig       <- sqrt(T[1]*sig1*(NT2-N30)/(NT2-NT1) +
               T[2]*sig2*(N30-NT1)/(NT2-NT1))*sqrt(N365/N30)*100
```

Near Month σ	Far Month σ	Interpolated σ
27.0114	26.6432	26.671

5 Verifying the quoted VIX

VIX quoted by NSE on May 15, 2014 at 12.21 PM was 35.83. The day was one day before 2014 election results.The next day when early trends started coming, the VIX slumped by 30%. In any case, the objective of this section is to use the option prices, compute VIX and verify whether the computation comes any close to the quoted index value.

The following are the relevant parameters for computing VIX

- T_0 : Quoted prices on May 15, 2014 at 12:21 PM
- T_1 : Near Month expiry on May 29, 2014 at 3:30 PM
- T_2 : Far Month expiry on June 26, 2014 at 3:30 PM
- F_1 : Futures price for near month expiry 7043
- F_2 : Futures price for near month expiry 7137
- r_1 : 1-month Risk free rate 3.9%
- r_2 : 2-month Risk free rate 4.65%

Step 1 : Load the near month and far month option data. Call and Put option quotes for May 15, 2014 at 12.21 PM are included in section 6.

```
x            <- read.csv("data/nm_may_15_2014.csv", stringsAsFactors = FALSE)
nm           <- x[c(3,1,2,4,5)]
colnames(nm) <- c("K","Cb","Ca","Pb","Pa")
y            <- read.csv("data/fm_may_15_2014.csv", stringsAsFactors = FALSE)
fm           <- y[c(3,1,2,4,5)]
colnames(fm) <- c("K","Cb","Ca","Pb","Pa")
nm.may12     <- nm ; fm.may12     <- fm
```

Step 2 : Compute the spreads and remove the spread that are more than 30%

```
calculate.spreads <- function(data){
  data          <- as.data.frame(data)
  data$Cmid     <- with(data, Ca + Cb)*0.5
  data$Pmid     <- with(data, Pa + Pb)*0.5
  data$Cspread <- with(data, (Ca - Cb)/Cmid)
  data$Pspread <- with(data, (Pa- Pb)/Pmid)
  data$Pvalid  <- with(data, Pspread <=0.3)
  data$Cvalid  <- with(data, Cspread <=0.3)
  data          <- data[,c("K","Cmid","Pmid","Pvalid","Cvalid")]
  data$Pvalid[is.na(data$Pvalid)] <- FALSE
  data$Cvalid[is.na(data$Cvalid)] <- FALSE
  data[data$Pvalid == FALSE, c("Pmid")] <- NA
  data[data$Cvalid == FALSE, c("Cmid")] <- NA
  data          <- data[,c("K","Cmid","Pmid")]
  return(data)
}
nm.spread       <- calculate.spreads(nm)
fm.spread       <- calculate.spreads(fm)
```

Step 3 : Do a natural spline interpolation for the strikes whose mid quotes are not available/ more than 30%

```
interpolate      <- function(data, var){
  data           <- data[,c("K",var)]
  pred           <- rep(NA, dim(data)[1])
  valid.knots    <- which(!is.na(data[,var]))
  boundary.knots <- data$K[range(valid.knots)]
  internal.knots <- valid.knots[2:(length(valid.knots)-1)]
  X              <- ns(x  = data$K, knots  =data$K[internal.knots],
                      Boundary.knots= boundary.knots )
  fit            <- lm(data[,var]~X)
  fitted         <- predict(fit, newdata = list(K = c(data$K)))
  idx            <- range(valid.knots)[1]:range(valid.knots)[2]
  pred[idx]      <- fitted[idx]
  pred
}
nm.spread$Pmid.i <- interpolate(nm.spread, "Pmid")
nm.spread$Cmid.i <- interpolate(nm.spread, "Cmid")
fm.spread$Pmid.i <- interpolate(fm.spread, "Pmid")
fm.spread$Cmid.i <- interpolate(fm.spread, "Cmid")
```

Step 4 : Compute the out of money Put and Call option mid quote prices

```
K0                   <- 7100
K1                   <- 7200
nm.spread$delta      <- with(nm.spread, ifelse(K < K0, Pmid.i , Cmid.i))
idx                  <- which(nm.spread$K == K0)
nm.spread$delta[idx] <- with(nm.spread, Pmid.i[idx] + Cmid.i[idx])/2
nm.spread            <- nm.spread[!is.na(nm.spread$delta),]
nm.spread            <- nm.spread[,c("K","delta")]
fm.spread$delta      <- with(fm.spread, ifelse(K < K0, Pmid.i , Cmid.i))
idx                  <- which(fm.spread$K == K0)
fm.spread$delta[idx] <- with(fm.spread, Pmid.i[idx] + Cmid.i[idx])/2
fm.spread            <- fm.spread[!is.na(fm.spread$delta),]
fm.spread            <- fm.spread[,c("K","delta")]
K                    <- c(K0,K1)
n                    <- length(nm.spread$K)
delta.K              <- c(nm.spread$K[2]- nm.spread$K[1], diff(nm.spread$K , lag = 2)/2,
                        nm.spread$K[n] - nm.spread$K[n-1] )
nm.spread$delta.K    <- delta.K
n                    <- length(fm.spread$K)
delta.K              <- c(fm.spread$K[2]- fm.spread$K[1], diff(fm.spread$K , lag = 2)/2,
                        fm.spread$K[n] - fm.spread$K[n-1] )
fm.spread$delta.K    <- delta.K
```

Step 5 : Compute the volatility from near month and far month option prices

```
VIX.quoted <- 35.83
d1         <- "2014-05-15"
d2         <- "2014-05-29"
d3         <- "2014-06-26"

t1         <- "12:21:00"
t2         <- "15:30:00"
t3         <- "15:30:00"

times      <- chron(dates = c(d1,d2,d3), times = c(t1,t2,t3), format = c("y-m-d","h:m:s"))

NT1        <- as.numeric(difftime(times[2],times[1],units="min"))
NT2        <- as.numeric(difftime(times[3],times[1],units="min"))
N30        <- 43200
N365       <- 525600

T          <- c(NT1,NT2)/N365
F          <- c(7043,7137)
R          <- c(0.039, 0.0465)
K          <- c(K0,K1)

data       <- nm.spread
idx        <- 1
sig1       <- sum(with(data, delta.K/K^2 * exp(R[idx]*T[idx])*delta))*2 / T[idx] -
            1/T[idx]*(F[idx]/K[idx]-1)^2

data      <- fm.spread
idx       <- 2
sig2      <- sum(with(data, delta.K/K^2 * exp(R[idx]*T[idx])*delta))*2 / T[idx] -
            1/T[idx]*(F[idx]/K[idx]-1)^2
```

Step 6 : Interpolate between near month and far month volatility to obtain VIX

```
sig      <- sqrt(T[1]*sig1*(NT2-N30)/(NT2-NT1) +
              T[2]*sig2*(N30-NT1)/(NT2-NT1))*sqrt(N365/N30)*100
```

Near Month σ	Far Month σ	Interpolated σ	quoted VIX
46.9643	31.8838	35.4859	35.83

The above table shows that the computed VIX, i.e. 35.4859 comes very close to the quoted VIX, i.e. 35.83. The difference could be arising from the near and far interest rates taken for computation or any synchronicity that would have happened while I had tried to capture the data.

6 Appendix

6.1 Option Data - Test Run

6.1.1 Near Month Option Prices

```
print(as.data.frame(nm.test),row.names=FALSE)
```

```
##     K      Cb      Ca     Pb     Pa
##  3800 1290.10 1314.25   0.40   0.50
##  3900 1192.95 1212.80   0.35   0.80
##  4000 1103.00 1107.95   0.70   0.85
##  4100 1005.00 1017.10   0.80   1.10
##  4200  894.95  913.90   1.00   1.20
##  4300  800.00  809.95   1.20   1.70
##  4400  696.15  709.50   1.90   2.00
##  4500  601.25  609.55   3.30   3.45
##  4600  500.70  520.00   4.45   4.50
##  4700  410.00  416.55   7.70   8.00
##  4800  316.00  321.05  13.20  13.40
##  4900  226.00  228.00  22.50  22.65
##  5000  144.50  145.00  40.40  40.50
##  5100   79.00   79.10  74.40  74.50
##  5200   34.75   35.00 129.00 129.95
##  5300   11.50   11.55 200.55 206.00
##  5400    3.60    3.65 286.00 307.00
##  5500    1.70    1.95 340.00 396.00
##  5600    1.00    1.35 481.00 507.35
##  5700    0.70    1.00 577.35 606.65
```

6.1.2 Near Month Option Prices

```
print(as.data.frame(fm.test),row.names=FALSE)

##     K      Cb      Ca     Pb     Pa
##  4000 1100.15 1110.00   5.90   6.50
##  4100 1006.25 1026.90   7.15   8.50
##  4200  905.15  931.15  10.00  10.70
##  4300  809.15  844.75  13.55  14.00
##  4400  713.10  732.85  18.00  18.75
##  4500  615.70  668.35  22.35  25.00
##  4600  526.80  572.05  32.00  33.30
##  4700  444.35  464.15  41.00  45.00
##  4800  366.60  408.60  61.50  62.00
##  4900  300.00  307.30  84.55  86.50
##  5000  231.00  232.00 116.00 117.00
##  5100  171.10  171.50 156.00 158.00
##  5200  120.05  121.80 203.00 209.35
##  5300   79.60   80.50 252.85 265.00
##  5400   48.10   48.50 322.45 345.65
##  5500   29.00   32.00 405.00 437.10
##  5600   15.90   19.85 477.85 509.00
##  5700    9.15    9.75 575.25 609.00
```

6.2 Option Data - May 12 , 2014 @ 12:21 PM

6.2.1 Near Month Option Prices

```
print(as.data.frame(nm.may12),row.names=FALSE)

##     K      Cb      Ca     Pb     Pa
##  4700 2413.45 2420.45   1.45   1.55
##  4750 2178.00 2480.75   0.50   3.00
##  4800 2312.85 2318.30   1.90   2.10
##  4850 2078.00 2380.60   1.00     NA
##  4900 2213.75 2223.40   2.00   2.40
##  4950 1978.00 2280.45   0.15   3.05
##  5000 2115.10 2120.40   2.70   2.80
##  5050 1878.00 2180.50   0.20     NA
##  5100 2014.85 2020.95   3.05   3.15
##  5150 1781.00 2080.45   0.35     NA
##  5200 1915.75 1920.85   3.40   3.50
##  5250 1681.00 1980.55   0.35     NA
##  5300 1816.25 1821.70   4.05   4.20
##  5350 1581.00 1880.60   0.35     NA
##  5400 1717.00 1724.55   4.85   4.95
##  5450 1488.00 1834.10   1.50     NA
##  5500 1620.20 1625.70   5.65   5.80
##  5550 1408.50 1734.10   3.05     NA
##  5600 1520.95 1529.90   6.05   6.20
##  5650 1312.00 1587.70   3.05     NA
##  5700 1420.40 1427.95   6.90   7.00
##  5750 1218.50 1491.50   4.65   9.90
##  5800 1325.50 1330.20   8.20   8.30
##  5850 1112.90 1391.50   3.05     NA
##  5900 1229.00 1234.25  11.40  11.60
##  5950 1012.45 1295.00   3.05     NA
##  6000 1134.40 1138.75  15.10  15.20
##  6050  960.50 1198.50  14.80     NA
##  6100 1040.10 1045.70  20.20  20.40
##  6150  860.50 1102.00  21.00     NA
##  6200  946.70  951.70  25.65  25.85
##  6250  760.50 1002.00  25.00     NA
##  6300  857.65  862.90  34.10  34.40
##  6350  788.25  830.55  38.80  41.45
##  6400  769.70  774.50  45.55  45.85
##  6450  585.50  899.00  45.90     NA
##  6500  681.25  686.35  58.45  58.65
##  6550  625.00  666.50  65.15  67.45
```

```
## 6600 600.45 604.35   75.50   75.55
## 6650 551.20 469.45   86.20   86.70
## 6700 522.20 524.55   97.70   98.00
## 6750 481.60 496.00  110.55  112.00
## 6800 450.55 452.65  126.00  126.10
## 6850 414.80 420.00  139.90  143.25
## 6900 384.75 387.00  156.80  157.25
## 6950 349.15 353.05  172.55  176.10
## 7000 321.00 322.05  191.65  192.00
## 7050 291.45 295.55  212.05  216.25
## 7100 263.85 264.35  234.75  235.60
## 7150 239.60 240.85  257.55  261.15
## 7200 215.85 216.00  283.95  285.90
## 7250 194.05 196.40  305.90  314.85
## 7300 175.00 175.55  340.70  344.85
## 7350 156.25 159.45  362.75  385.35
## 7400 140.00 140.35  404.90  407.95
## 7450 121.70 122.80  416.05  452.65
## 7500 108.00 108.05  471.10  473.00
## 7550  93.70  94.90  483.25  524.75
## 7600  81.80  82.00  544.70  546.70
## 7650  69.15  70.10  402.50  684.00
## 7700  60.25  60.55  602.40  643.75
## 7750  51.50  52.90  482.50  769.00
## 7800  45.05  45.25  601.05  772.60
## 7850  36.25  40.50  570.00  864.50
## 7900  33.85  34.05  770.45  870.10
## 7950  26.20  32.00  658.50  948.90
## 8000  26.75  26.80  885.85  889.45
## 8050  15.55  26.95  737.50 1081.10
## 8100  21.15  21.35  800.50 1133.00
## 8150  18.00  20.50  830.00 1185.00
## 8200  16.75  16.85  893.00 1237.00
## 8250  13.55  14.90  939.00 1287.00
## 8300  13.10  13.15  986.50 1340.00
## 8350  10.85  10.95 1035.00 1390.00
## 8400  10.00  10.40 1084.00 1440.50
## 8450   8.50     NA 1129.00 1494.00
## 8500   8.35   8.65 1302.00 1399.00
## 8550   3.05     NA 1223.00 1594.00
## 8600   6.95   7.25 1274.00 1647.50
```

6.2.2 Near Month Option Prices

```
print(as.data.frame(fm.may12),row.names=FALSE)

##     K      Cb      Ca      Pb      Pa
##  2700 4390.90 4410.15    0.65    2.45
##  2800 4145.00 4449.00    0.65    2.90
##  2900 4045.00 4349.00    0.65    2.90
##  3000 4085.00 4110.65    0.65    2.90
##  3100 3845.00 4149.00    0.65    3.00
##  3200 3745.00 4049.00    0.50    3.00
##  3300 3645.00 3949.00    0.50    3.00
##  3400 3545.00 3849.00    0.50    3.00
##  3500 3458.95 3735.05    0.70    2.85
##  3600 3345.00 3649.00    0.70    3.00
##  3700 3245.00 3549.00    0.50    3.00
##  3800 3145.00 3449.00    0.65    3.00
##  3900 3045.00 3349.00    0.65    3.00
##  4000 3109.65 3120.55    2.30    2.50
##  4100 2845.00 3149.00      NA      NA
##  4200 2745.00 3049.00      NA      NA
##  4300 2645.00 2949.00      NA      NA
##  4400 2545.00 2849.00      NA      NA
##  4500 2615.00 2635.70    1.00      NA
##  4600 2345.00 2649.00    0.50      NA
##  4700 2245.00 2549.00    0.65      NA
##  4800 2145.00 2449.00    3.05      NA
##  4900 2047.00 2349.00    3.05      NA
##  5000 2131.00 2134.00    6.70    7.35
##  5100 1847.00 2149.00    3.05      NA
##  5150 1795.00 2099.00    3.05      NA
##  5200 1912.30 1962.45    6.80    7.80
##  5250 1698.00 1999.00    3.05      NA
##  5300 1757.90 1861.55    7.00    9.90
##  5350 1598.00 1899.00    3.05      NA
##  5400 1658.20 1762.55    8.75    9.95
##  5450 1505.00 1853.00    3.05      NA
##  5500 1558.25 1647.00   12.30   12.55
##  5550 1411.00 1753.00    3.05      NA
##  5600 1425.00 1656.50   13.20      NA
##  5650 1312.50 1606.00    3.05      NA
##  5700 1358.25 1522.75   16.00   20.00
##  5750 1219.50 1510.00    3.10      NA
##  5800 1342.85 1371.50   20.10   21.85
```

```
## 5850 1120.00 1410.00    3.20      NA
## 5900 1241.30 1305.65   22.55   26.90
## 5950 1027.50 1313.50    3.45      NA
## 6000 1162.55 1169.20   28.60   29.55
## 6050  934.00 1217.00    3.95      NA
## 6100 1044.50 1110.10   36.25   38.40
## 6150  836.00 1153.00    6.10      NA
## 6200  971.50  997.60   42.00   43.90
## 6250  825.00  960.00   11.15      NA
## 6300  880.05  906.25   52.05   53.40
## 6350  663.50  960.00   19.50      NA
## 6400  796.90  849.95   64.35   64.95
## 6450  583.50  935.00   32.35      NA
## 6500  715.75  720.95   79.05   79.90
## 6550  600.50  690.00   51.15      NA
## 6600  635.85  656.60   97.95   98.60
## 6650  453.50  745.00   98.00  113.75
## 6700  560.05  571.80  121.25  122.00
## 6750  424.00  678.00  115.00  149.05
## 6800  492.20  497.00  149.60  151.05
## 6850  415.05  507.00  141.40      NA
## 6900  424.35  431.90  182.20  183.20
## 6950  362.30  425.00  144.55  211.00
## 7000  372.00  374.80  221.05  222.05
## 7050  311.20  359.70  211.05  264.95
## 7100  311.40  315.85  263.05  264.40
## 7150  224.75  307.70  251.00  320.00
## 7200  262.55  264.05  309.85  314.20
## 7250  212.30  260.70  301.00  380.00
## 7300  216.45  218.40  358.20  368.50
## 7350  155.90  211.50  351.00      NA
## 7400  175.20  177.15  414.00  455.55
## 7450  118.50  168.60  381.00      NA
## 7500  139.25  140.45  482.70  483.50
## 7550  102.10  136.75  326.50  695.00
## 7600  110.25  110.50  460.20  606.00
## 7650   70.10  120.00  416.25  776.00
## 7700   84.50   85.25  566.90  679.80
## 7750   55.05   89.00  476.75  848.50
## 7800   65.30   66.50  616.75  724.75
## 7850   40.00   60.00  567.75  967.00
## 7900   50.00   50.35  724.75  864.90
## 7950   30.00      NA  630.00  999.00
```

```
## 8000   40.05   40.10  868.20  871.60
## 8050   26.00      NA  760.50 1102.50
## 8100   28.00   39.90  791.75 1152.50
## 8150   20.85      NA  817.75 1202.50
## 8200   17.00      NA  878.75 1256.00
## 8250   13.70      NA  913.75 1270.00
## 8300   11.00      NA  973.35 1320.00
## 8350    8.85      NA 1008.75 1374.00
## 8400    6.00      NA 1065.50 1424.00
## 8450    5.55      NA  888.40      NA
## 8500   13.20   14.75 1321.50 1339.00
```