

## MSGARCH-model strategy-test

```
rm(list = ls())
library("MSGARCH")
options(prompt = "R> ", continue = "+ ", width = 70,
       digits = 4, max.print = 80, useFancyQuotes = FALSE)
tmp <- sessionInfo()
nam <- paste0("PART_II_R", tmp$R.version$major, ".",
              tmp$R.version$minor, "_", tmp$R.version$os)
sink(file = paste0("sink_", nam, ".txt"), append = FALSE, split = TRUE) # output printed in txt
print(tmp)

## R version 4.2.2 (2022-10-31)
## Platform: aarch64-apple-darwin20 (64-bit)
## Running under: macOS Ventura 13.1
##
## Matrix products: default
## BLAS:    /Library/Frameworks/R.framework/Versions/4.2-arm64/Resources/lib/libRblas.0.dylib
## LAPACK:  /Library/Frameworks/R.framework/Versions/4.2-arm64/Resources/lib/libRlapack.dylib
##
## locale:
## [1] en_US.UTF-8/en_US.UTF-8/en_US.UTF-8/C/en_US.UTF-8/en_US.UTF-8
##
## attached base packages:
## [1] stats      graphics   grDevices  utils      datasets   methods
## [7] base
##
## other attached packages:
## [1] MSGARCH_2.51
##
## loaded via a namespace (and not attached):
## [1] Rcpp_1.0.9      rstudioapi_0.14  knitr_1.41
## [4] magrittr_2.0.3  fanplot_4.0.0   lattice_0.20-45
## [7] rlang_1.0.6     fastmap_1.1.0   stringr_1.5.0
## [10] tools_4.2.2    grid_4.2.2     xfun_0.36
## [13] cli_3.6.0      coda_0.19-4    htmltools_0.5.4
## [16] yaml_2.3.6     digest_0.6.31  lifecycle_1.0.3
## [19] Matrix_1.5-1   vctrs_0.5.1   codetools_0.2-18
## [22] glue_1.6.2     evaluate_0.19  rmarkdown_2.19
## [25] stringi_1.7.12 compiler_4.2.2  expm_0.999-7
## [28] zoo_1.8-11
```

load SMI

```
data("SMI", package = "MSGARCH")

## Create MS(2)-GJR-std specification (Ardia 2008 and Ardia et al. 2008)
ms2.gjr.s <- CreateSpec(variance.spec = list(model = "gjrGARCH"),
```

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        distribution.spec = list(distribution = "std"),
        switch.spec = list(K = 2),
        constraint.spec = list(regime.const = "nu"))

## ML estimation
fit.ml <- FitML(ms2.gjr.s, data = SMI)

## Summary
summary(fit.ml)

## Specification type: Markov-switching
## Specification name: gjrGARCH_std gjrGARCH_std
## Number of parameters in each variance model: 4 4
## Number of parameters in each distribution: 1 1
## -----
## Fixed parameters:
## None
## -----
## Across regime constrained parameters:
## nu
## -----
## Fitted parameters:
##           Estimate Std. Error t value Pr(>|t|)
## alpha0_1    0.2071    0.0488  4.2433 1.101e-05
## alpha1_1    0.0005    0.0088  0.0569 4.773e-01
## alpha2_1    0.2137    0.0619  3.4505 2.798e-04
## beta_1     0.5264    0.0995  5.2915 6.065e-08
## nu_1       9.2469    1.3292  6.9568 1.740e-12
## alpha0_2    0.0922    0.0349  2.6396 4.150e-03
## alpha1_2    0.0052    0.0169  0.3057 3.799e-01
## alpha2_2    0.1516    0.0381  3.9770 3.490e-05
## beta_2     0.8716    0.0354  24.6392 <1e-16
## P_1_1      0.9977    0.0014 701.8053 <1e-16
## P_2_1      0.0027    0.0017  1.6008 5.471e-02
## -----
## Transition matrix:
##          t+1|k=1 t+1|k=2
## t|k=1   0.9977  0.0023
## t|k=2   0.0027  0.9973
## -----
## Stable probabilities:
## State 1 State 2
## 0.5407  0.4593
## -----
## LL: -3350.8467
## AIC: 6723.6935
## BIC: 6787.758
## -----
## Unconditional vol
set.seed(1234)
sqrt(250) * sapply(ExtractStateFit(fit.ml), UncVol)

## [1] 11.87 22.04

```

```

## Smoothed probabilities in regime 2 and volatility
smoothed.prob <- State(fit.ml)$SmoothProb[, 1, 2, drop = TRUE]
vol <- sqrt(250) * Volatility(fit.ml)

## MCMC estimation
nmcmc <- 12500
nburn <- 5000
nthin <- 5
ctr <- list(nmcmc = nmcmc, nburn = nburn,
            nthin = nthin, par0 = fit.ml$par)
fit.mcmc <- FitMCMC(ms2.gjr.s, data = SMI, ctr = ctr)
summary(fit.mcmc)

## Specification type: Markov-switching
## Specification name: gjrGARCH_std gjrGARCH_std
## Number of parameters in each variance model: 4 4
## Number of parameters in each distribution: 1 1
## -----
## Fixed parameters:
## None
## -----
## Across regime constrained parameters:
## nu
## -----
## Posterior sample (size: 2500)
##      Mean     SD     SE    TSSE    RNE
## alpha0_1 0.2095 0.0286 0.0006 0.0013 0.2047
## alpha1_1  0.0006 0.0004 0.0000 0.0000 0.2002
## alpha2_1  0.2301 0.0378 0.0008 0.0017 0.1913
## beta_1   0.5208 0.0433 0.0009 0.0019 0.2002
## nu_1     9.7887 1.5939 0.0319 0.0760 0.1761
## alpha0_2  0.1187 0.0435 0.0009 0.0020 0.1925
## alpha1_2  0.0056 0.0016 0.0000 0.0001 0.2159
## alpha2_2  0.1664 0.0406 0.0008 0.0017 0.2361
## beta_2   0.8502 0.0374 0.0007 0.0017 0.1923
## P_1_1    0.9972 0.0012 0.0000 0.0000 0.2354
## P_2_1    0.0027 0.0009 0.0000 0.0000 0.2054
## -----
## Posterior mean transition matrix:
##      t+1|k=1 t+1|k=2
## t|k=1  0.9972  0.0028
## t|k=2  0.0027  0.9973
## -----
## Posterior mean stable probabilities:
## State 1 State 2
## 0.4894  0.5106
## -----
## Acceptance rate MCMC sampler: 27.9%
## nmcmc: 12500
## nburn: 5000
## nthin: 5
## -----
## DIC: 6716.9449
## -----

```

## Convergence of the chain

```

#par(mfrow = c(3, 4))
#coda::traceplot(fit.MCMC$par)
#coda::heidel.diag(fit.MCMC$par)
#coda::acfplot(fit.MCMC$par)

## Posterior draws
draws <- as.matrix(fit.mcmc$par)

## This function computes the unconditional volatility
## for a GJR model with symmetric disturbances
f_ucvol <- function(par) {
  if (is.vector(par)) {
    par <- matrix(data = par, nrow = 1, dimnames = list(1, names(par)))
  }
  ucvol_1 <- sqrt(250) * par[, "alpha0_1"] / (1 - (par[, "alpha1_1"] + 0.5 * par[, "alpha2_1"] + par[, "beta1_1"]))
  ucvol_2 <- sqrt(250) * par[, "alpha0_2"] / (1 - (par[, "alpha1_2"] + 0.5 * par[, "alpha2_2"] + par[, "beta1_2"]))
  out <- list(ucvol_1 = ucvol_1, ucvol_2 = ucvol_2)
  return(out)
}

## Compute unconditional volatility
ucvol.draws <- f_ucvol(draws)
ucvol.bay <- lapply(ucvol.draws, mean)
ucvol.mle <- f_ucvol(fit.ml$par)

## Posterior mean
unlist(ucvol.bay)

## ucvol_1 ucvol_2
## 9.155 31.464

## Quantiles of unconditional volatility
sapply(ucvol.draws, quantile, probs = c(0.025, 0.975))

##      ucvol_1 ucvol_2
## 2.5%   8.014  23.91
## 97.5% 10.525  44.44

## Impact of parameter uncertainty in pred
nmesh <- 1000
x <- seq(from = -5, to = 0, length.out = nmesh)
pred.mle <- as.vector(PredPdf(fit.ml, x = x, nahead = 1))
pred.bay <- as.vector(PredPdf(fit.mcmc, x = x, nahead = 1))

pred.draws <- matrix(data = NA, nrow = nrow(draws), ncol = nmesh)
for (i in 1:nrow(draws)) {
  tmp <- PredPdf(ms2.gjr.s, par = draws[i,], x = x, data = SMI, nahead = 1)
  pred.draws[i,] <- as.vector(tmp)
}

```

## Backtesting

```
## Create GJR-std specification for comparison
gjr.s <- CreateSpec(variance.spec = list(model = "gjrGARCH"),
                      distribution.spec = list(distribution = "std"),
                      switch.spec = list(K = 1))

models <- list(gjr.s, ms2.gjr.s)

n.ots    <- 1000 # number of out-of-sample evaluation
n.its    <- 1500 # fit sample size
alpha     <- 0.05 # risk Level
k.update <- 100  # estimation frequency

## Initialization
VaR    <- matrix(NA, nrow = n.ots, ncol = length(models))
y.ots <- matrix(NA, nrow = n.ots, ncol = 1)
model.fit <- vector(mode = "list", length = length(models))

# iterate over out-of-sample time
for (i in 1:n.ots) {
  cat("Backtest - Iteration: ", i, "\n")
  y.its    <- SMI[i:(n.its + i - 1)] # in-sample data
  y.ots[i] <- SMI[n.its + i]           # out-of-sample data

  # iterate over models
  for (j in 1:length(models)) {

    # do we update the model estimation
    if (k.update == 1 || i %% k.update == 1) {
      cat("Model", j, "is reestimated\n")
      model.fit[[j]] <- FitML(spec = models[[j]], data = y.its,
                                ctr = list(do.se = FALSE))
    }

    # calculate VaR 1-step ahead
    VaR[i,j] <- Risk(model.fit[[j]]$spec, par = model.fit[[j]]$par,
                      data = y.its,
                      n.ahead = 1,
                      alpha   = alpha,
                      do.es   = FALSE,
                      do.its  = FALSE)$VaR
  }
}

## Backtest - Iteration: 1
## Model 1 is reestimated
## Model 2 is reestimated
## Backtest - Iteration: 2
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## Model 1 is reestimated
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## Model 1 is reestimated
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## Backtest - Iteration: 645
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## Backtest - Iteration: 701
## Model 1 is reestimated
## Model 2 is reestimated
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## Backtest - Iteration: 801
## Model 1 is reestimated
## Model 2 is reestimated
## Backtest - Iteration: 802
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## Backtest - Iteration: 803
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## Backtest - Iteration: 901
## Model 1 is reestimated
## Model 2 is reestimated
## Backtest - Iteration: 902
## Backtest - Iteration: 903
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## Backtest - Iteration: 1000

```

## Test the VaR

```

## Test the VaR
# install.packages("GAS")
library("GAS")

##
## Attaching package: 'GAS'

## The following object is masked from 'package:stats':
## 
##     residuals

CC.pval <- DQ.pval <- vector("double", length(models))
for (j in 1:length(models)) {
  test <- GAS::BacktestVaR(data = y.ots,

```

```

    VaR    = VaR[,j],
    alpha = alpha)

CC.pval[j] <- test$LRcc[2]
DQ.pval[j] <- test$DQ$pvalue
}
names(CC.pval) <- names(DQ.pval) <- c("GJR-std", "MS2-GJR-std")

print(CC.pval)

##      GJR-std MS2-GJR-std
##      0.02092     0.08402
print(DQ.pval)

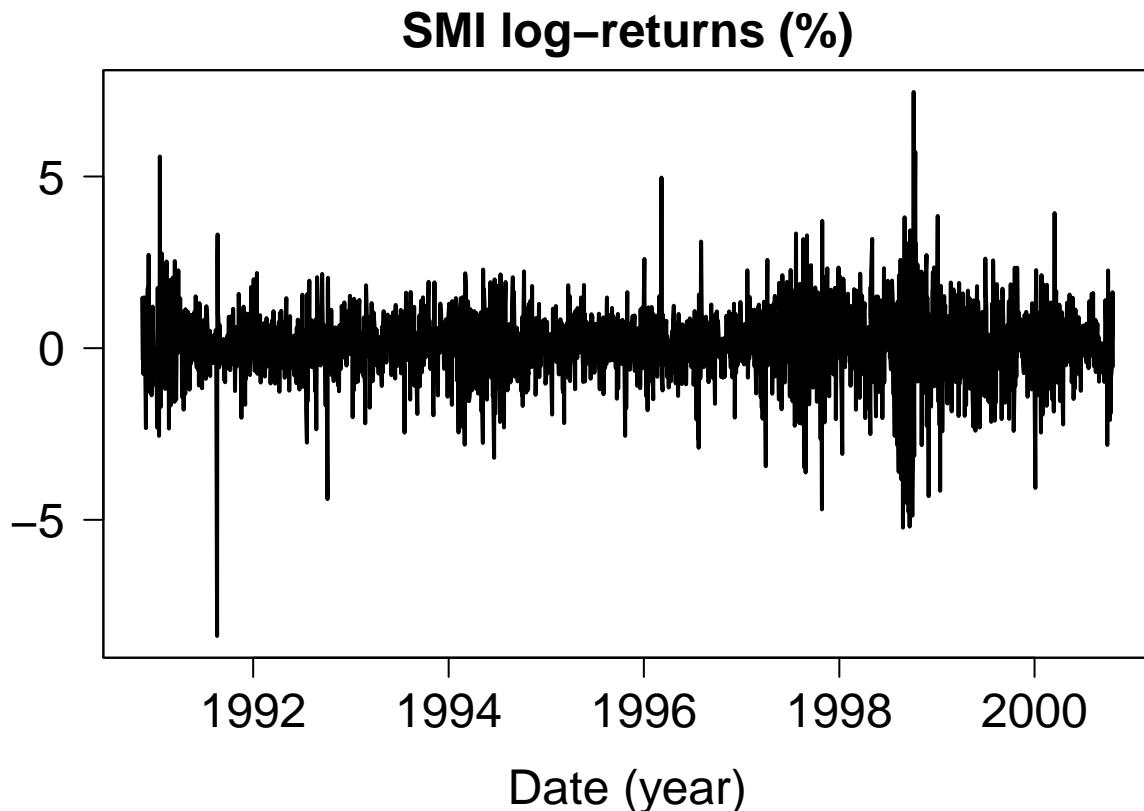
##      GJR-std MS2-GJR-std
##      0.03506     0.14453

sink()

#####
##      FIGURE 1      ##
#####

#pdf(file = "figure1.pdf", height = 13, width = 16, compress = TRUE)
par(mfrow = c(1, 1), mar = c(5,3,2,2) + 0.1)
plot(SMI, type = 'l', las = 1, lwd = 2, xlab = "Date (year)",
     ylab = "", col = "black", cex.axis = 1.5, cex.lab = 1.5)
title("SMI log-returns (%)", cex.main = 1.5)

```



```

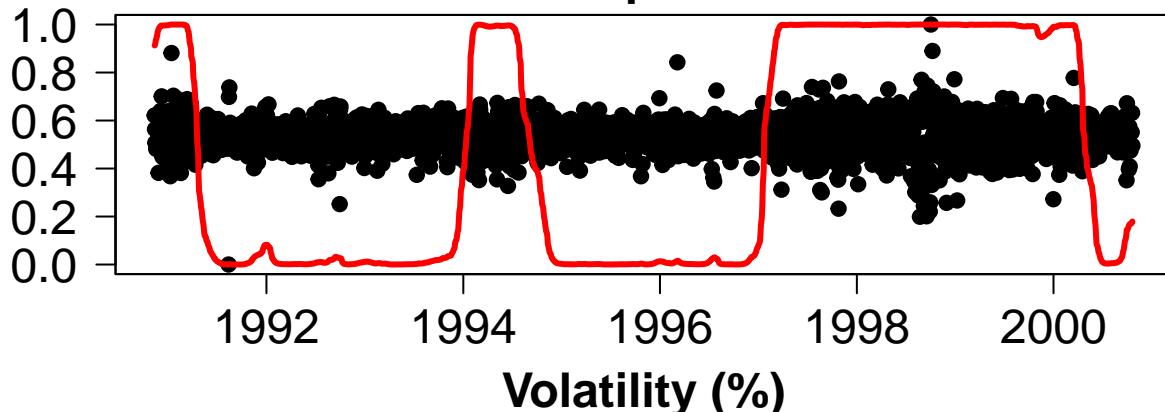
#dev.off()

#####
##      FIGURE 2      ##
#####

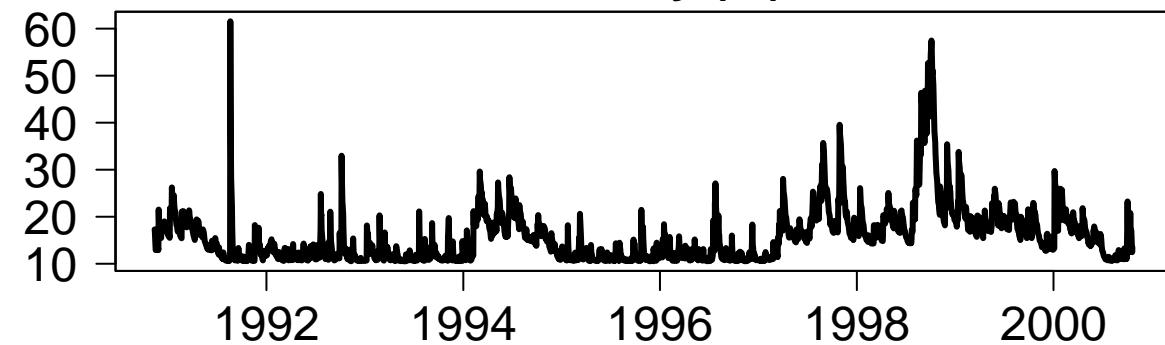
#pdf(file = "figure2.pdf", height = 13, width = 16, compress = TRUE)
op <- par(mfrow = c(2,1),
          oma = c(1,1,0,0) + 0.0,
          mar = c(2,2,2,2) + 0.0)
plot(as.vector(SMI), las = 1, type = 'p', pch = 20, col = 'black',
     cex = 1.5, axes = FALSE, ann = FALSE)
par(new = TRUE)
ylabel <- expression(paste("Pr(", s[t], " = 2 | ", hat(psi), ", ", I[t], ")"))
plot(zoo::zoo(smoothed.prob, order.by = zoo::index(SMI)), lty = 1, plot.type = "single",
     col = "red", las = 1, ylab = "", xlab = "Date", lwd = 3, cex.axis = 1.5, cex.lab = 1.5)
title(main = "Smoothed probabilities", cex.main = 1.5)
plot(zoo::zoo(vol, order.by = zoo::index(SMI)), lty = 1, plot.type = "single",
     col = "black", las = 1, ylab = "", xlab = "Date", lwd = 3, cex.axis = 1.5, cex.lab = 1.5)
title(main = "Volatility (%)", cex.main = 1.5)

```

**Smoothed probabilities**



**Volatility (%)**



```

par(op)
#dev.off()

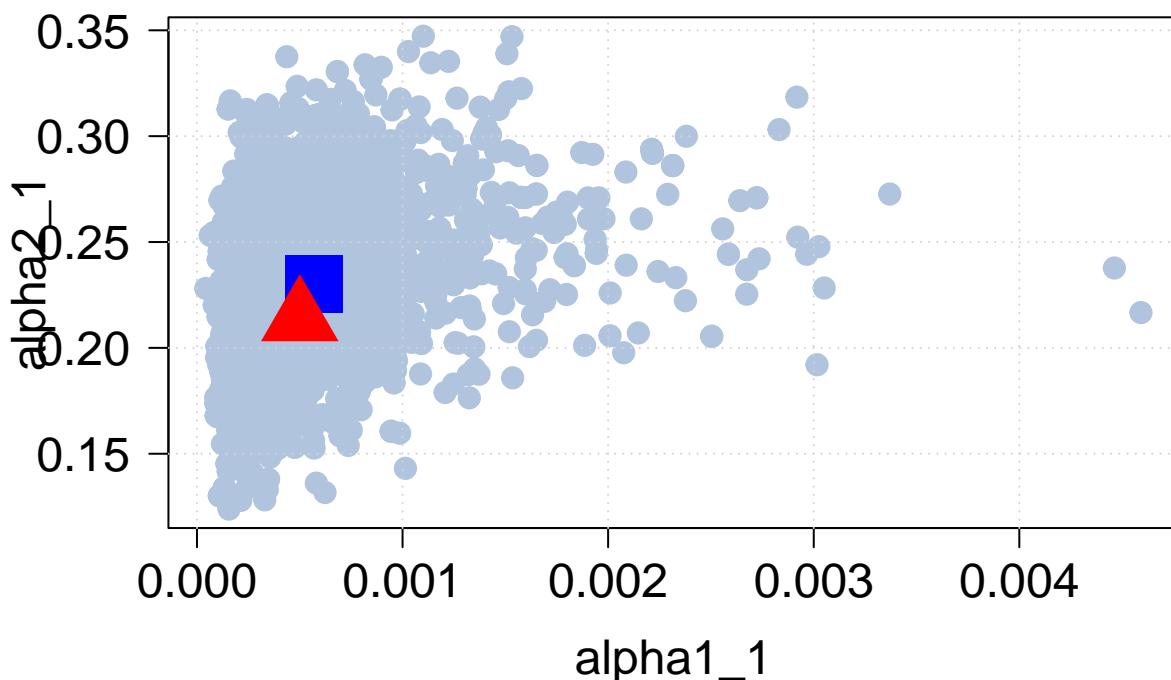
#####
##      FIGURE 3      ##
#####

```

```

sel <- c("alpha1_1", "alpha2_1")
tmp <- draws[, sel]
par.mle <- fit.ml$par[sel]
par.bay <- apply(tmp, 2, mean)
xlim <- range(c(tmp[,1], par.mle[1]))
ylim <- range(c(tmp[,2], par.mle[2]))
#pdf(file = "figure3.pdf", height = 13, width = 13, compress = TRUE)
par(mfrow = c(1, 1))
plot(tmp, pch = 20, las = 1, lwd = 2, cex = 2, xlim = xlim, ylim = ylim,
     col = "lightsteelblue", cex.axis = 1.5, cex.lab = 1.5)
grid()
par(new = TRUE)
points(par.bay[1], par.bay[2], cex = 4, lwd = 2,
       pch = 15, col = "blue", xlim = xlim, ylim = ylim)
points(par.mle[1], par.mle[2], cex = 4, lwd = 2,
       pch = 17, col = "red", xlim = xlim, ylim = ylim)

```



```

#dev.off()

#####
##      FIGURE 4      ##
#####

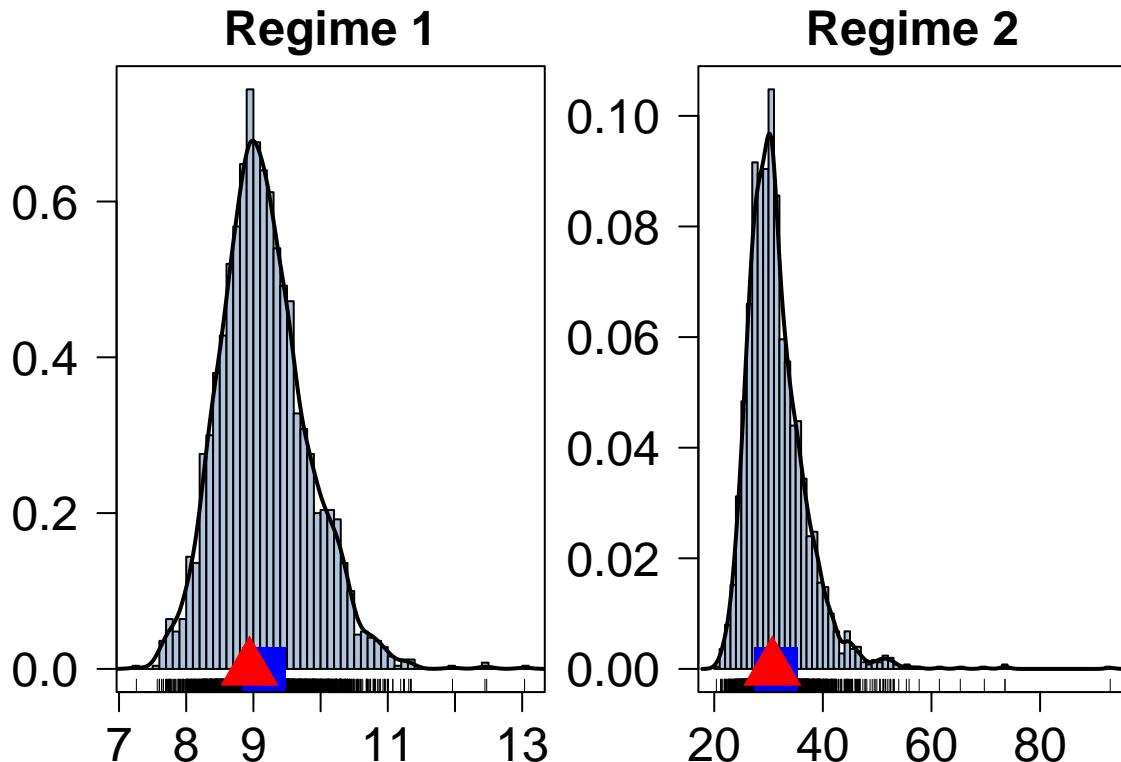
n <- length(ucvol.draws$ucvol_1)
#pdf(file = "figure4.pdf", height = 13, width = 16, compress = TRUE)
op <- par(mar = c(2, 2, 2, 2),
          mfrow = c(1, 2),
          oma = c(2, 2, 0.2, 0.2))
hist(ucvol.draws$ucvol_1, nclass = round(10 * log(n)), prob = TRUE,
     col = "lightsteelblue", las = 1, xlab = "Volatility (%)",
     ylab = "", cex.lab = 1.5, cex.axis = 1.5, main = "")
title(main = "Regime 1", cex.main = 1.5)

```

```

lines(density(ucvol.draws$ucvol_1), col = "black", lwd = 2)
rug(ucvol.draws$ucvol_1); box()
points(ucvol.bay$ucvol_1, 0, pch = 15, col = "blue", lwd = 2, cex = 3)
points(ucvol.mle$ucvol_1, 0, pch = 17, col = "red", lwd = 2, cex = 3)
hist(ucvol.draws$ucvol_2, nclass = round(10 * log(n)), prob = TRUE,
      col = "lightsteelblue", las = 1, xlab = "Volatility (%)",
      ylab = "", cex.lab = 1.5, cex.axis = 1.5, main = "")
rug(ucvol.draws$ucvol_2); box()
points(ucvol.bay$ucvol_2, 0, pch = 15, col = "blue", lwd = 2, cex = 3)
points(ucvol.mle$ucvol_2, 0, pch = 17, col = "red", lwd = 2, cex = 3)
title(main = "Regime 2", cex.main = 1.5)
lines(density(ucvol.draws$ucvol_2), col = "black", lwd = 2)

```



```

par(op)
#dev.off()

#####
##      FIGURE 5      ##
#####

#pdf(file = "figure5.pdf", height = 13, width = 16, compress = TRUE)
#png(filename = "figure5.png", height = 13, width = 16, units = "in", res = 600)
xlim <- c(-4, -1.2)
ylim <- c(0, 0.1)
par(mfrow = c(1, 1))
matplot(x, t(pred.draws), xlim = xlim, ylim = ylim,
        type = "l", col = "lightsteelblue",
        xlab = "Return (%)", ylab = "Predictives",
        lty = 1.5, las = 1, cex.axis = 1.5, cex.lab = 1.5)
title(main = "Left-tail forecast of SMI index return", cex.main = 1.5)

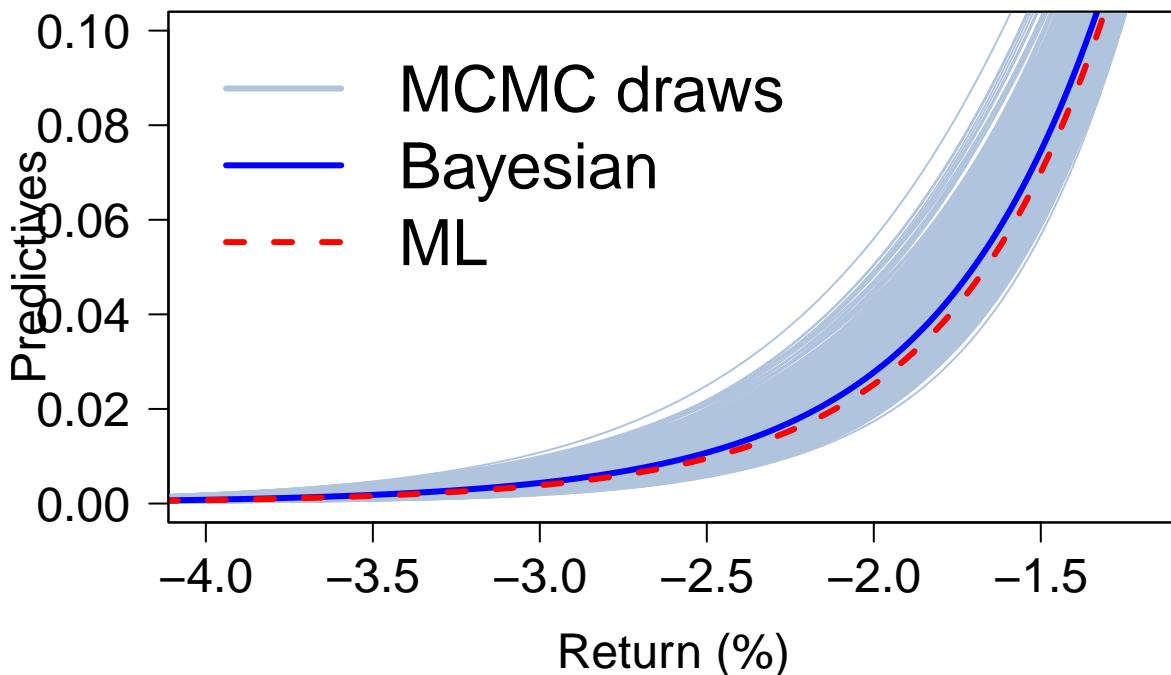
```

```

lines(x, pred.bay, xlim = xlim, ylim = ylim,
      type = "l", lty = "solid", col = "blue", lwd = 3)
lines(x, pred.mle, xlim = xlim, ylim = ylim,
      type = "l", pch = "o", lty = "dashed", col = "red", lwd = 3)
legend("topleft", c("MCMC draws", "Bayesian", "ML"),
       col = c("lightsteelblue", "blue", "red"), lwd = 3,
       lty = c(1, 1, 2), bty = "n", cex = 2)
box()

```

## Left-tail forecast of SMI index return



```

#dev.off()

#####
##      FIGURE 6      ##
#####

library("zoo")

##
## Attaching package: 'zoo'

## The following objects are masked from 'package:base':
##
##     as.Date, as.Date.numeric

time.index <- zoo::index(SMI)[(n.its + 1):(n.ots + n.its)]
y_ots <- zoo::zoo(y.ots, order.by = time.index)
VaR   <- zoo::zoo(VaR, order.by = time.index)

## pdf(file = "figure6.pdf", height = 13, width = 16, compress = TRUE)
par(mfrow = c(1, 1))
plot(y_ots, type = 'p', las = 1, lwd = 1, xlab = "Date (year)",

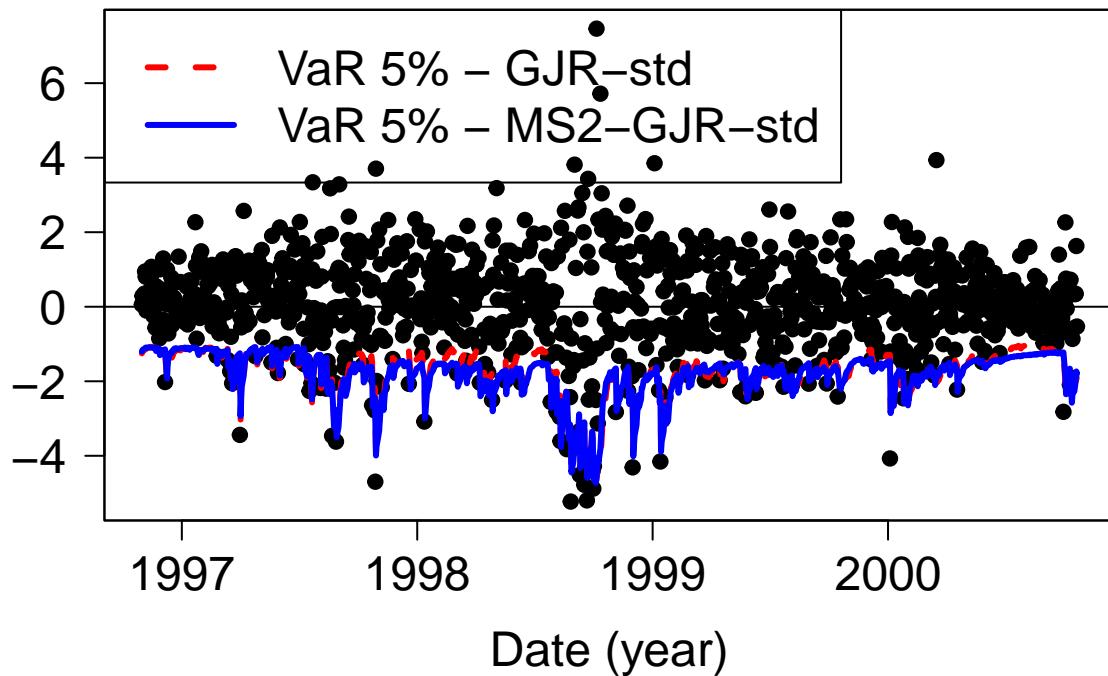
```

```

    ylab = "", col = "black", cex.axis = 1.5, cex.lab = 1.5, pch = 19)
lines(VaR[,1], type = 'l', col = "red", lwd = 3, lty = "dashed")
lines(VaR[,2], type = 'l', col = "blue", lwd = 3)
legend("topleft", legend = c("VaR 5% - GJR-std", "VaR 5% - MS2-GJR-std"),
       col = c("red", "blue"), lwd = 3, cex = 1.5, lty = c("dashed", "solid"))
abline(h = 0)
title("Backtesing VaR at 5% risk level", cex.main = 1.5)

```

## Backtesing VaR at 5% risk level



```
#dev.off()
```