Classification of Breast Cancer Clinical Stage with Gene Expression Data

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This document presents analysis for the MAQC-II project, human breast cancer data set with boosting algorithms developed in Wang (2018a,b) and implemented in R package `bst`.

Dataset comes from the MicroArray Quality Control (MAQC) II project and includes 278 breast cancer samples with 164 estrogen receptor (ER) positive cases. The data files `GSE20194_series_matrix.txt.gz` and `GSE20194_MDACC_Sample_Info.xls` can be downloaded from http://www.ncbi.nlm.nih.gov/geo/query/acc.cgi?token=rhojvaiwkcsaihq&acc=GSE20194. After reading the data, some unused variables are removed. From 22283 genes, the dataset is pre-screened to obtain 3000 genes with the largest absolute values of the two-sample t-statistics. The 3000 genes are standardized.

```
# The data files below were downloaded on June 1, 2016
require("gdata")
bc <- t(read.delim("GSE20194_series_matrix.txt.gz", sep = "",
    header = FALSE, skip = 80))
colnames(bc) <- bc[1, ]
bc <- bc[-1, -c(1, 2)]
### The last column is empty with variable name
### !series_matrix_table_end, thus omitted
bc <- bc[, -22284]
mode(bc) <- "numeric"  ### convert character to numeric
dat1 <- read.xls("GSE20194_MDACC_Sample_Info.xls", sheet = 1,
    header = TRUE)
y <- dat1$characteristics..ER_status
y <- ifelse(y == "P", 1, -1)
table(y)
## y
##  -1   1
## 114 164
res <- rep(NA, dim(bc)[2])
for (i in 1:dim(bc)[2]) res[i] <- abs(t.test(bc[, i] ~ y)$statistic)
### find 3000 largest absolute value of t-statistic
tmp <- order(res, decreasing = TRUE)[1:3000]
```

```
dat <- bc[, tmp]
### standardize variables
dat <- scale(dat)
```

Set up configuration parameters.

```
nrun <- 100
per <- c(0, 0.05, 0.1, 0.15)
learntype <- c("tree", "ls")[2]
tuning <- "error"
n.cores <- 4
plot.it <- TRUE
### robust tuning parameters used in bst/rbst function
s <- c(0.9, 1.01, 0.5, -0.2, 0.8, -0.5, -0.2)
nu <- c(0.01, 0.1, 0.01, rep(0.1, 4))
m <- 100  ### boosting iteration number
### whether to truncate the predicted values in each boosting
### iteration?
ctr.trun <- c(TRUE, rep(FALSE, 6))
### used in bst function
bsttype <- c("closs", "gloss", "qloss", "binom", "binom", "hinge",
    "expo")
### and corresponding labels
bsttype1 <- c("ClossBoost", "GlossBoost", "QlossBoost", "LogitBoost",
    "LogitBoost", "HingeBoost", "AdaBoost")
### used in rbst function
rbsttype <- c("closs", "gloss", "qloss", "tbinom", "binomd",
    "thinge", "texpo")
### and corresponding labels
rbsttype1 <- c("ClossBoostQM", "GlossBoostQM", "QlossBoostQM",
    "TLogitBoost", "DlogitBoost", "THingeBoost", "TAdaBoost")
```

The training data contains randomly selected 50 samples with positive estrogen receptor status and 50 samples with negative estrogen receptor status, and the rest were designated as the test data. The training data is contaminated by randomly switching response variable labels at varying pre-specified proportions per=0, 0.05, 0.1, 0.15. This process is repeated nrun=100 times. The base learner is learntype=ls (with quotes). To select optimal boosting iteration from maximum value of m=100, we run five-fold cross-validation averaging classification errors. In cross-validation, we set the number of cores for parallel computing by n.cores=4. Selected results can be plotted if plot.it=TRUE. Gradient based boosting includes ClossBoost, GlossBoost, QlossBoost, LogitBoost, HingeBoost and AdaBoost. Robust boosting using rbst contains ClossBoostQM, GlossBoostQM, QlossBoostQM, TLogitBoost, DlogitBoost, THingeBoost and TAdaBoost.

```
summary7 <- function(x) c(summary(x), sd = sd(x))
ptm <- proc.time()
library("bst")
```

```
## Loading required package:  gbm
## Loaded gbm 2.1.4
```

```
for (k in 1:7) {
    ### k controls which family in bst, and rfamily in rbst
    err.m1 <- err.m2 <- nvar.m1 <- nvar.m2 <- errbest.m1 <- errbest.m2 <- matrix(NA,
        ncol = 4, nrow = nrun)
    mstopbest.m1 <- mstopbest.m2 <- mstopcv.m1 <- mstopcv.m2 <- matrix(NA,
        ncol = 4, nrow = nrun)
    colnames(err.m1) <- colnames(err.m2) <- c("cont-0%", "cont-5%",
        "cont-10%", "cont-15%")
    colnames(mstopcv.m1) <- colnames(mstopcv.m2) <- colnames(err.m1)
    colnames(nvar.m1) <- colnames(nvar.m2) <- colnames(err.m1)
    colnames(errbest.m1) <- colnames(errbest.m2) <- colnames(err.m1)
    colnames(mstopbest.m1) <- colnames(mstopbest.m2) <- colnames(err.m1)
    for (ii in 1:nrun) {
        set.seed(1000 + ii)
        trid <- c(sample(which(y == 1))[1:50], sample(which(y ==
            -1))[1:50])
        dtr <- dat[trid, ]
        dte <- dat[-trid, ]
        ytrold <- y[trid]
        yte <- y[-trid]
        ### number of patients/no. variables in training and test data
        dim(dtr)
        dim(dte)
        ### randomly contaminate data
        ntr <- length(trid)
        set.seed(1000 + ii)
        con <- sample(ntr)
        for (j in 1) {
            ### controls learntype i controls how many percentage of data
            ### contaminated
            for (i in 1:4) {
                ytr <- ytrold
                percon <- per[i]
                ### randomly flip labels of the samples in training set
                ### according to pre-defined contamination level
                if (percon > 0) {
                  ji <- con[1:(percon * ntr)]
                  ytr[ji] <- -ytrold[ji]
                }
                dat.m1 <- bst(x = dtr, y = ytr, ctrl = bst_control(mstop = m,
                  center = FALSE, trace = FALSE, nu = nu[k],
                  s = s[k], trun = ctr.trun[k]), family = bsttype[k],
                  learner = learntype[j])
                err1 <- predict(dat.m1, newdata = dte, newy = yte,
                  type = "error")
                err1tr <- predict(dat.m1, newdata = dtr, newy = ytr,
                  type = "loss")
                ### cross-validation to select best boosting iteration
                set.seed(1000 + ii)
                cvm1 <- cv.bst(x = dtr, y = ytr, K = 5, n.cores = n.cores,
                  ctrl = bst_control(mstop = m, center = FALSE,
                    trace = FALSE, nu = nu[k], s = s[k], trun = ctr.trun[k]),
                  family = bsttype[k], learner = learntype[j],
                  main = bsttype[k], type = tuning, plot.it = FALSE)
                optmstop <- max(10, which.min(cvm1$cv))
                err.m1[ii, i] <- err1[optmstop]
                nvar.m1[ii, i] <- nsel(dat.m1, optmstop)[optmstop]
                errbest.m1[ii, i] <- min(err1)
                mstopbest.m1[ii, i] <- which.min(err1)
                mstopcv.m1[ii, i] <- optmstop
                dat.m2 <- rbst(x = dtr, y = ytr, ctrl = bst_control(mstop = m,
                  iter = 100, nu = nu[k], s = s[k], trun = ctr.trun[k],
                  center = FALSE, trace = FALSE), rfamily = rbsttype[k],
                  learner = learntype[j])
                err2 <- predict(dat.m2, newdata = dte, newy = yte,
                  type = "error")
                err2tr <- predict(dat.m2, newdata = dtr, newy = ytr,
                  type = "loss")
                ### cross-validation to select best boosting iteration
                set.seed(1000 + ii)
                cvm2 <- cv.rbst(x = dtr, y = ytr, K = 5, n.cores = n.cores,
                  ctrl = bst_control(mstop = m, iter = 100, nu = nu[k],
                    s = s[k], trun = ctr.trun[k], center = FALSE,
                    trace = FALSE), rfamily = rbsttype[k], learner = learntype[j],
                  main = rbsttype[k], type = tuning, plot.it = FALSE)
                optmstop <- max(10, which.min(cvm2$cv))
                err.m2[ii, i] <- err2[optmstop]
                nvar.m2[ii, i] <- nsel(dat.m2, optmstop)[optmstop]
                errbest.m2[ii, i] <- min(err2)
                mstopbest.m2[ii, i] <- which.min(err2)
                mstopcv.m2[ii, i] <- optmstop
            }
        }
        if (ii%%nrun == 0) {
            if (bsttype[k] %in% c("closs", "gloss", "qloss"))
                cat(paste("\nbst family ", bsttype1[k], ", s=",
                  s[k], ", nu=", nu[k], sep = ""), "\n")
            if (bsttype[k] %in% c("binom", "hinge", "expo"))
                cat(paste("\nbst family ", bsttype1[k], ", nu=",
                  nu[k], sep = ""), "\n")
            cat("best misclassification error from bst\n")
            print(round(apply(errbest.m1, 2, summary7), 4))
            cat("CV based misclassification error from bst\n")
            print(round(apply(err.m1, 2, summary7), 4))
            cat("best mstop with best misclassification error from bst\n")
            print(round(apply(mstopbest.m1, 2, summary7), 0))
```

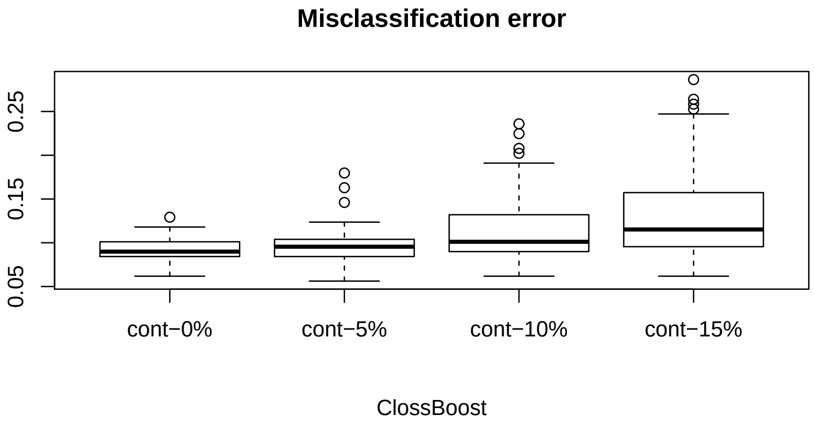
```
cat("best mstop with CV from bst\n")
print(round(apply(mstopcv.m1, 2, summary7), 0))
cat("nvar from bst\n")
print(round(apply(nvar.m1, 2, summary7), 1))

cat(paste("\nrbst family ", rbsttype1[k], ", s=",
    s[k], ", nu=", nu[k], sep = ""), "\n")
cat("\nbest misclassification error from rbst\n")
print(round(apply(errbest.m2, 2, summary7), 4))
cat("CV based misclassification error from rbst\n")
print(round(apply(err.m2, 2, summary7), 4))
cat("best mstop with best misclassification error from rbst\n")
print(round(apply(mstopbest.m2, 2, summary7), 0))
cat("best mstop with CV from rbst\n")
print(round(apply(mstopcv.m2, 2, summary7), 0))
cat("nvar from rbst\n")
print(round(apply(nvar.m2, 2, summary7), 1))
res <- list(err.m1 = err.m1, nvar.m1 = nvar.m1, errbest.m1 = errbest.m1,
    mstopbest.m1 = mstopbest.m1, mstopcv.m1 = mstopcv.m1,
    err.m2 = err.m2, nvar.m2 = nvar.m2, errbest.m2 = errbest.m2,
    mstopbest.m2 = mstopbest.m2, mstopcv.m2 = mstopcv.m2,
    s = s[k], nu = nu[k], trun = ctr.trun[k], family = bsttype[k],
    rfamily = rbsttype[k])
if (plot.it) {
    par(mfrow = c(2, 1))
    boxplot(err.m1, main = "Misclassification error",
      subset = "", sub = bsttype1[k])
    boxplot(err.m2, main = "Misclassification error",
      subset = "", sub = rbsttype1[k])
    boxplot(nvar.m1, main = "No. variables", subset = "",
      sub = bsttype1[k])
    boxplot(nvar.m2, main = "No. variables", subset = "",
      sub = rbsttype1[k])
}
check <- FALSE
if (check) {
    par(mfrow = c(3, 1))
    title <- paste("percentage of contamination ",
      percon, sep = "")
    plot(err2tr, main = title, ylab = "Loss value",
      xlab = "Iteration", type = "l", lty = "dashed",
      col = "red")
    points(err1tr, type = "l", lty = "solid", col = "black")
    legend("topright", c(bsttype1[k], rbsttype1[k]),
      lty = c("solid", "dashed"), col = c("black",
        "red"))
    plot(err2, main = title, ylab = "Misclassification error",
      xlab = "Iteration", type = "l", lty = "dashed",
      col = "red")
```

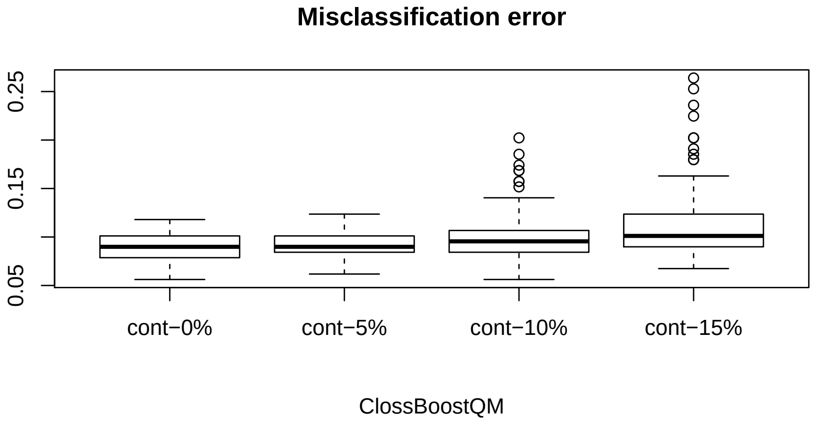
```
                points(err1, type = "l")
                legend("bottomright", c(bsttype1[k], rbsttype1[k]),
                  lty = c("solid", "dashed"), col = c("black",
                    "red"))
                plot(nsel(dat.m2, m), main = title, ylab = "No. variables",
                  xlab = "Iteration", lty = "dashed", col = "red",
                  type = "l")
                points(nsel(dat.m1, m), ylab = "No. variables",
                  xlab = "Iteration", lty = "solid", type = "l",
                  col = "black")
                legend("bottomright", c(bsttype1[k], rbsttype1[k]),
                  lty = c("solid", "dashed"), col = c("black",
                    "red"))
            }
        }
    }
}
##
## bst family ClossBoost, s=0.9, nu=0.01
## best misclassification error from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.     0.0506  0.0506   0.0449   0.0449
## 1st Qu.  0.0730  0.0730   0.0787   0.0787
## Median   0.0787  0.0843   0.0843   0.1011
## Mean     0.0804  0.0837   0.0971   0.1172
## 3rd Qu.  0.0843  0.0899   0.1081   0.1461
## Max.     0.1292  0.1404   0.2079   0.2528
## sd       0.0135  0.0154   0.0309   0.0480
## CV based misclassification error from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.     0.0618  0.0562   0.0618   0.0618
## 1st Qu.  0.0843  0.0843   0.0899   0.0955
## Median   0.0899  0.0955   0.1011   0.1152
## Mean     0.0909  0.0946   0.1138   0.1338
## 3rd Qu.  0.1011  0.1025   0.1306   0.1573
## Max.     0.1292  0.1798   0.2360   0.2865
## sd       0.0139  0.0190   0.0385   0.0530
## best mstop with best misclassification error from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.          1       1        1        1
## 1st Qu.      30      29       37       42
## Median       50      48       60       66
## Mean         49      47       56       61
## 3rd Qu.      72      66       80       89
## Max.        100     100      100      100
## sd           30      29       30       31
## best mstop with CV from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.         10      10       10       10
## 1st Qu.      10      18       33       52
## Median       39      46       50       68
## Mean         40      47       52       65
## 3rd Qu.      60      71       71       86
## Max.        100     100      100      100
## sd           29      30       27       24
## nvar from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.        1.0     1.0      1.0      1.0
## 1st Qu.     1.0     1.0      1.0      2.0
## Median      1.0     2.0      2.0      4.0
## Mean        2.4     3.1      3.2      3.8
## 3rd Qu.     3.0     4.2      5.0      5.0
## Max.       10.0    12.0     11.0     11.0
## sd          2.1     2.7      2.4      2.4
##
## rbst family ClossBoostQM, s=0.9, nu=0.01
##
## best misclassification error from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.     0.0506  0.0562   0.0449   0.0506
## 1st Qu.  0.0730  0.0730   0.0730   0.0772
## Median   0.0787  0.0787   0.0843   0.0843
## Mean     0.0792  0.0804   0.0870   0.0958
## 3rd Qu.  0.0843  0.0899   0.0955   0.1067
## Max.     0.1067  0.1180   0.1854   0.2303
## sd       0.0126  0.0125   0.0212   0.0330
## CV based misclassification error from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.     0.0562  0.0618   0.0562   0.0674
## 1st Qu.  0.0787  0.0843   0.0843   0.0899
## Median   0.0899  0.0899   0.0955   0.1011
## Mean     0.0903  0.0923   0.1024   0.1146
## 3rd Qu.  0.1011  0.1011   0.1067   0.1236
## Max.     0.1180  0.1236   0.2022   0.2640
## sd       0.0138  0.0140   0.0256   0.0401
## best mstop with best misclassification error from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.          1       1        1        1
## 1st Qu.      14       9        6        9
## Median       28      22       22       19
## Mean         31      26       27       31
## 3rd Qu.      48      38       37       52
## Max.         91     100       99      100
## sd           22      22       25       30
## best mstop with CV from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.         10      10       10       10
## 1st Qu.      10      10       10       10
## Median       19      16       19       14
## Mean         28      28       33       31
## 3rd Qu.      41      40       53       47
## Max.         99     100       95      100
## sd           22      24       27       28
## nvar from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.        1.0     1.0      1.0      1.0
## 1st Qu.     1.0     1.0      1.0      1.0
## Median      2.0     2.0      2.0      2.0
## Mean        3.1     3.3      4.0      4.3
## 3rd Qu.     4.0     4.0      6.0      6.0
## Max.       15.0    16.0     14.0     16.0
## sd          3.1     3.3      3.6      4.1
##
## bst family GlossBoost, s=1.01, nu=0.1
## best misclassification error from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.     0.0449  0.0506   0.0449   0.0562
## 1st Qu.  0.0730  0.0730   0.0787   0.0829
## Median   0.0787  0.0843   0.0843   0.1011
## Mean     0.0812  0.0837   0.0948   0.1126
## 3rd Qu.  0.0899  0.0899   0.1067   0.1348
## Max.     0.1292  0.1236   0.1910   0.2584
## sd       0.0138  0.0142   0.0280   0.0426
## CV based misclassification error from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.     0.0562  0.0562   0.0562   0.0618
## 1st Qu.  0.0787  0.0843   0.0899   0.0955
## Median   0.0899  0.0927   0.1011   0.1236
## Mean     0.0912  0.0947   0.1121   0.1319
## 3rd Qu.  0.1011  0.1011   0.1292   0.1573
## Max.     0.1798  0.1966   0.2360   0.3258
## sd       0.0166  0.0191   0.0370   0.0496
## best mstop with best misclassification error from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.          1       1        1        1
## 1st Qu.      19      16       22       23
## Median       45      36       40       48
## Mean         45      40       45       48
## 3rd Qu.      70      59       70       77
## Max.         99     100       99      100
## sd           30      28       31       32
## best mstop with CV from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.         10      10       10       10
## 1st Qu.      10      10       17       28
## Median       20      31       32       44
## Mean         30      39       39       48
## 3rd Qu.      45      55       54       72
## Max.         95     100      100       98
## sd           24      29       26       28
## nvar from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.        1.0     1.0      1.0      1.0
## 1st Qu.     1.0     1.0      1.0      2.0
## Median      1.0     2.0      2.0      4.0
## Mean        1.9     2.7      3.0      4.4
## 3rd Qu.     2.0     3.0      4.0      6.2
## Max.        9.0    12.0     10.0     13.0
## sd          1.6     2.3      2.2      3.2
##
## rbst family GlossBoostQM, s=1.01, nu=0.1
##
## best misclassification error from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.     0.0506  0.0562   0.0449   0.0562
## 1st Qu.  0.0730  0.0730   0.0730   0.0787
## Median   0.0787  0.0787   0.0843   0.0899
## Mean     0.0811  0.0826   0.0910   0.1037
## 3rd Qu.  0.0899  0.0899   0.1011   0.1250
## Max.     0.1292  0.1124   0.1910   0.2360
## sd       0.0137  0.0132   0.0264   0.0391
## CV based misclassification error from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.     0.0562  0.0618   0.0562   0.0618
## 1st Qu.  0.0829  0.0843   0.0899   0.0899
## Median   0.0899  0.0955   0.1011   0.1096
## Mean     0.0910  0.0940   0.1067   0.1238
## 3rd Qu.  0.1011  0.1011   0.1124   0.1517
## Max.     0.1461  0.1629   0.2135   0.2640
## sd       0.0148  0.0177   0.0315   0.0433
## best mstop with best misclassification error from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.          1       1        1        1
## 1st Qu.      22      10        8        8
## Median       46      37       29       20
## Mean         46      37       34       32
## 3rd Qu.      73      56       52       55
## Max.        100      97      100      100
## sd           30      29       29       30
## best mstop with CV from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.         10      10       10       10
## 1st Qu.      10      10       10       10
## Median       10      19       22       20
## Mean         31      33       35       32
## 3rd Qu.      50      48       54       47
## Max.        100      98       97       96
## sd           27      27       28       27
## nvar from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.        1.0     1.0      1.0      1.0
## 1st Qu.     1.0     1.0      1.0      1.0
## Median      1.0     2.0      2.0      2.0
## Mean        2.5     2.6      3.2      3.8
## 3rd Qu.     3.0     3.0      4.2      5.2
## Max.       11.0    11.0     11.0     13.0
## sd          2.4     2.4      2.6      3.4
##
## bst family QlossBoost, s=0.5, nu=0.01
## best misclassification error from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.     0.0449  0.0506   0.0449   0.0562
## 1st Qu.  0.0730  0.0730   0.0787   0.0829
## Median   0.0787  0.0843   0.0843   0.1011
## Mean     0.0812  0.0835   0.0948   0.1132
## 3rd Qu.  0.0899  0.0899   0.1067   0.1348
## Max.     0.1292  0.1180   0.1910   0.2584
## sd       0.0139  0.0140   0.0278   0.0434
## CV based misclassification error from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.     0.0562  0.0562   0.0562   0.0562
## 1st Qu.  0.0787  0.0843   0.0899   0.0955
## Median   0.0899  0.0955   0.1011   0.1292
## Mean     0.0908  0.0952   0.1120   0.1340
## 3rd Qu.  0.1011  0.1011   0.1306   0.1545
## Max.     0.1798  0.1966   0.2360   0.3258
## sd       0.0167  0.0192   0.0367   0.0511
## best mstop with best misclassification error from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.          1       1        1        1
## 1st Qu.      19      17       25       23
## Median       39      38       42       52
## Mean         42      40       47       49
## 3rd Qu.      64      60       72       78
## Max.         98     100       99      100
## sd           29      28       31       33
## best mstop with CV from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.         10      10       10       10
## 1st Qu.      10      10       18       28
## Median       24      32       39       45
## Mean         32      38       41       49
## 3rd Qu.      49      56       58       70
## Max.         99      98       97      100
## sd           24      27       27       28
## nvar from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.        1.0     1.0      1.0      1.0
## 1st Qu.     1.0     1.0      1.0      2.0
## Median      1.0     2.0      2.0      3.0
## Mean        2.0     2.6      3.2      4.1
## 3rd Qu.     2.0     3.0      5.0      6.2
## Max.       10.0    11.0     10.0     12.0
## sd          1.7     2.2      2.3      3.0
##
## rbst family QlossBoostQM, s=0.5, nu=0.01
##
## best misclassification error from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.     0.0506  0.0562   0.0449   0.0562
## 1st Qu.  0.0730  0.0730   0.0772   0.0787
## Median   0.0787  0.0787   0.0843   0.0899
## Mean     0.0811  0.0822   0.0908   0.1026
## 3rd Qu.  0.0899  0.0899   0.1011   0.1250
## Max.     0.1292  0.1124   0.1910   0.2360
## sd       0.0136  0.0131   0.0260   0.0386
## CV based misclassification error from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.     0.0562  0.0618   0.0562   0.0618
## 1st Qu.  0.0787  0.0843   0.0899   0.0899
## Median   0.0899  0.0927   0.1011   0.1067
## Mean     0.0909  0.0946   0.1064   0.1225
## 3rd Qu.  0.1011  0.1011   0.1124   0.1461
## Max.     0.1517  0.1573   0.2191   0.2640
## sd       0.0154  0.0170   0.0313   0.0428
## best mstop with best misclassification error from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.          1       1        1        1
## 1st Qu.      18      14        6        7
## Median       42      38       26       20
## Mean         43      38       33       33
## 3rd Qu.      69      58       50       54
## Max.        100      96       97       99
## sd           30      28       29       31
## best mstop with CV from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.         10      10       10       10
## 1st Qu.      10      10       10       10
## Median       10      24       23       26
## Mean         29      34       33       35
## 3rd Qu.      46      51       46       54
## Max.         93     100       99       96
## sd           24      28       27       28
## nvar from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.        1.0     1.0      1.0      1.0
## 1st Qu.     1.0     1.0      1.0      1.0
## Median      1.0     2.0      2.0      3.0
## Mean        2.4     2.8      3.1      4.1
## 3rd Qu.     3.0     3.0      4.0      7.0
## Max.       11.0    12.0     12.0     15.0
## sd          2.2     2.6      2.6      3.6
##
## bst family LogitBoost, nu=0.1
## best misclassification error from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.     0.0449  0.0562   0.0449   0.0506
## 1st Qu.  0.0730  0.0730   0.0787   0.1053
## Median   0.0843  0.0843   0.1124   0.1433
## Mean     0.0824  0.0896   0.1146   0.1487
## 3rd Qu.  0.0899  0.1067   0.1419   0.1798
## Max.     0.1461  0.1517   0.2303   0.3258
## sd       0.0152  0.0208   0.0419   0.0606
## CV based misclassification error from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.     0.0506  0.0562   0.0618   0.0562
## 1st Qu.  0.0843  0.0885   0.0997   0.1222
## Median   0.0899  0.1039   0.1348   0.1657
## Mean     0.0907  0.1027   0.1341   0.1735
## 3rd Qu.  0.1011  0.1180   0.1587   0.2107
## Max.     0.1573  0.1573   0.2697   0.3876
## sd       0.0145  0.0218   0.0444   0.0703
## best mstop with best misclassification error from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.          1       4        1        5
## 1st Qu.       3      14       26       33
## Median       44      37       48       69
## Mean         42      42       50       61
## 3rd Qu.      72      60       80       92
## Max.        100      99      100      100
## sd           34      28       30       31
## best mstop with CV from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.         10      15       16       10
## 1st Qu.      28      33       36       39
## Median       55      52       58       60
## Mean         53      53       58       60
## 3rd Qu.      74      70       76       84
## Max.        100      99       98      100
## sd           26      23       24       26
## nvar from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.        1.0     1.0      1.0      1.0
## 1st Qu.     1.0     2.0      3.0      4.0
## Median      2.0     3.0      5.0      7.0
## Mean        2.5     3.6      5.3      6.9
## 3rd Qu.     3.0     5.0      8.0      9.2
## Max.        9.0    10.0     13.0     15.0
## sd          1.8     2.2      2.9      3.6
##
## rbst family TLogitBoost, s=-0.2, nu=0.1
##
## best misclassification error from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.     0.0562  0.0506   0.0506   0.0449
## 1st Qu.  0.0730  0.0674   0.0787   0.0787
## Median   0.0843  0.0843   0.0899   0.1011
## Mean     0.0838  0.0825   0.1022   0.1156
## 3rd Qu.  0.0955  0.0955   0.1124   0.1404
## Max.     0.1180  0.1292   0.2360   0.2865
## sd       0.0136  0.0164   0.0395   0.0539
## CV based misclassification error from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.     0.0562  0.0562   0.0562   0.0562
## 1st Qu.  0.0787  0.0787   0.0843   0.0885
## Median   0.0899  0.0899   0.1011   0.1096
## Mean     0.0884  0.0920   0.1125   0.1326
## 3rd Qu.  0.0955  0.1067   0.1236   0.1699
## Max.     0.1180  0.1348   0.3146   0.3933
## sd       0.0131  0.0182   0.0453   0.0646
## best mstop with best misclassification error from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.          1       4        1        4
## 1st Qu.       1      12       20       26
## Median       11      31       50       50
## Mean         29      37       49       53
## 3rd Qu.      58      62       83       81
## Max.         99      99      100      100
## sd           32      29       34       30
## best mstop with CV from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.         10      13       10       11
## 1st Qu.      29      33       32       35
## Median       42      50       53       57
## Mean         48      53       53       57
## 3rd Qu.      68      74       75       81
## Max.         99     100       99      100
## sd           25      24       24       26
## nvar from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.        1.0     1.0      1.0      1.0
## 1st Qu.     1.0     1.0      1.0      1.0
## Median      2.0     2.0      2.0      2.0
## Mean        1.8     1.8      2.1      2.4
## 3rd Qu.     2.0     2.0      3.0      3.0
## Max.        7.0     5.0      7.0      8.0
## sd          1.1     1.0      1.3      1.5
##
## bst family LogitBoost, nu=0.1
## best misclassification error from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.     0.0449  0.0562   0.0449   0.0506
## 1st Qu.  0.0730  0.0730   0.0787   0.1053
## Median   0.0843  0.0843   0.1124   0.1433
## Mean     0.0824  0.0896   0.1146   0.1487
## 3rd Qu.  0.0899  0.1067   0.1419   0.1798
## Max.     0.1461  0.1517   0.2303   0.3258
## sd       0.0152  0.0208   0.0419   0.0606
## CV based misclassification error from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.     0.0506  0.0562   0.0618   0.0562
## 1st Qu.  0.0843  0.0885   0.0997   0.1222
## Median   0.0899  0.1039   0.1348   0.1657
## Mean     0.0907  0.1027   0.1341   0.1735
## 3rd Qu.  0.1011  0.1180   0.1587   0.2107
## Max.     0.1573  0.1573   0.2697   0.3876
## sd       0.0145  0.0218   0.0444   0.0703
## best mstop with best misclassification error from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.          1       4        1        5
## 1st Qu.       3      14       26       33
## Median       44      37       48       69
## Mean         42      42       50       61
## 3rd Qu.      72      60       80       92
## Max.        100      99      100      100
## sd           34      28       30       31
## best mstop with CV from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.         10      15       16       10
## 1st Qu.      28      33       36       39
## Median       55      52       58       60
## Mean         53      53       58       60
## 3rd Qu.      74      70       76       84
## Max.        100      99       98      100
## sd           26      23       24       26
## nvar from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.        1.0     1.0      1.0      1.0
## 1st Qu.     1.0     2.0      3.0      4.0
## Median      2.0     3.0      5.0      7.0
## Mean        2.5     3.6      5.3      6.9
## 3rd Qu.     3.0     5.0      8.0      9.2
## Max.        9.0    10.0     13.0     15.0
## sd          1.8     2.2      2.9      3.6
##
## rbst family DlogitBoost, s=0.8, nu=0.1
##
## best misclassification error from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.     0.0562  0.0506   0.0506   0.0562
## 1st Qu.  0.0787  0.0730   0.0843   0.1011
## Median   0.0899  0.0899   0.1124   0.1461
## Mean     0.0869  0.0907   0.1197   0.1556
## 3rd Qu.  0.0955  0.1067   0.1461   0.2079
## Max.     0.1685  0.1685   0.2978   0.3652
## sd       0.0162  0.0240   0.0503   0.0730
## CV based misclassification error from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.     0.0562  0.0562   0.0562   0.0618
## 1st Qu.  0.0787  0.0787   0.0899   0.1067
## Median   0.0899  0.0955   0.1124   0.1601
## Mean     0.0898  0.0997   0.1316   0.1708
## 3rd Qu.  0.1011  0.1180   0.1573   0.2317
## Max.     0.1798  0.1966   0.3202   0.3708
## sd       0.0163  0.0265   0.0562   0.0787
## best mstop with best misclassification error from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.          1       6        1        7
## 1st Qu.       1      19       34       41
## Median        1      52       62       70
## Mean         19      51       59       66
## 3rd Qu.      31      78       89       92
## Max.        100     100      100      100
## sd           31      31       32       28
## best mstop with CV from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.         10      18       15       11
## 1st Qu.      37      47       52       52
## Median       56      64       68       74
## Mean         56      63       68       70
## 3rd Qu.      74      78       84       90
## Max.         99     100      100      100
## sd           24      21       21       24
## nvar from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.        1.0     1.0      1.0      1.0
## 1st Qu.     1.0     1.0      1.0      2.0
## Median      1.0     1.0      2.0      3.0
## Mean        1.4     1.7      2.5      2.9
## 3rd Qu.     2.0     2.0      3.0      4.0
## Max.        5.0     5.0      8.0      8.0
## sd          0.8     0.9      1.5      1.4
##
## bst family HingeBoost, nu=0.1
## best misclassification error from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.     0.0449  0.0506   0.0449   0.0562
## 1st Qu.  0.0730  0.0730   0.0772   0.0787
## Median   0.0787  0.0843   0.0843   0.1011
## Mean     0.0788  0.0839   0.0954   0.1130
## 3rd Qu.  0.0843  0.0899   0.1081   0.1362
## Max.     0.1292  0.1348   0.2079   0.2528
## sd       0.0137  0.0177   0.0296   0.0414
## CV based misclassification error from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.     0.0562  0.0618   0.0562   0.0674
## 1st Qu.  0.0843  0.0843   0.0899   0.1011
## Median   0.0955  0.0955   0.1011   0.1264
## Mean     0.0931  0.0996   0.1165   0.1379
## 3rd Qu.  0.1011  0.1067   0.1348   0.1685
## Max.     0.1629  0.1910   0.3427   0.2809
## sd       0.0158  0.0230   0.0414   0.0492
## best mstop with best misclassification error from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.          1       1        1        1
## 1st Qu.      18      18       15       21
## Median       24      23       25       44
## Mean         27      28       36       48
## 3rd Qu.      32      30       56       76
## Max.         89     100      100       99
## sd           17      23       30       32
## best mstop with CV from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.         10      10       10       10
## 1st Qu.      10      16       19       27
## Median       23      26       30       42
## Mean         28      35       37       50
## 3rd Qu.      35      54       51       74
## Max.         99      95      100      100
## sd           20      25       23       28
## nvar from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.        1.0     1.0      1.0      1.0
## 1st Qu.     1.0     1.0      2.0      3.0
## Median      3.0     4.0      5.0     11.0
## Mean        6.6     8.9      8.8     12.4
## 3rd Qu.     9.0    15.0     14.2     20.0
## Max.       36.0    30.0     32.0     36.0
## sd          7.8     9.1      8.4      9.8
```

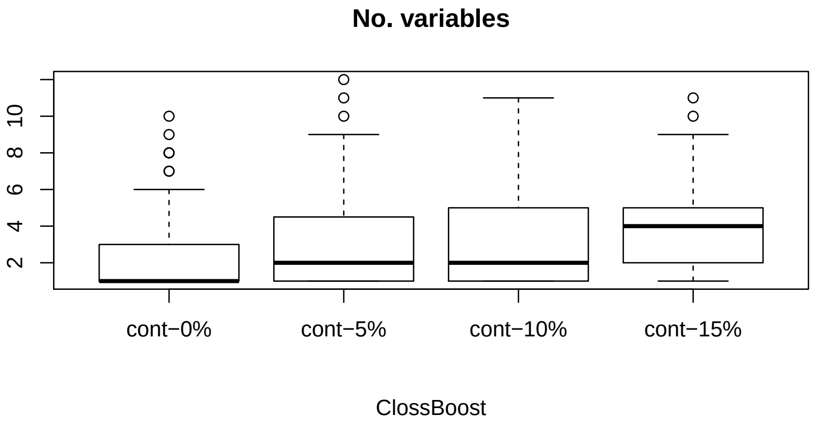
```
##
## rbst family THingeBoost, s=-0.5, nu=0.1
##
## best misclassification error from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.     0.0506  0.0506   0.0449   0.0506
## 1st Qu.  0.0730  0.0730   0.0772   0.0787
## Median   0.0787  0.0815   0.0843   0.0871
## Mean     0.0790  0.0817   0.0906   0.1007
## 3rd Qu.  0.0843  0.0899   0.1011   0.1236
## Max.     0.1348  0.1348   0.2022   0.1910
## sd       0.0135  0.0147   0.0253   0.0336
## CV based misclassification error from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.     0.0562  0.0618   0.0618   0.0618
## 1st Qu.  0.0843  0.0843   0.0899   0.0941
## Median   0.0955  0.0955   0.1011   0.1067
## Mean     0.0937  0.0957   0.1076   0.1197
## 3rd Qu.  0.1011  0.1011   0.1180   0.1362
## Max.     0.1461  0.1517   0.2022   0.2640
## sd       0.0149  0.0173   0.0295   0.0411
## best mstop with best misclassification error from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.          1       1        1        1
## 1st Qu.      17      17       16       20
## Median       23      23       24       29
## Mean         25      28       35       38
## 3rd Qu.      29      30       50       59
## Max.         93      99      100       99
## sd           18      22       30       27
## best mstop with CV from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.         10      10       10       10
## 1st Qu.      10      18       19       22
## Median       23      28       34       44
## Mean         33      38       41       48
## 3rd Qu.      45      56       59       68
## Max.         99     100       96       99
## sd           25      27       26       28
## nvar from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.        1.0     1.0      1.0      1.0
## 1st Qu.     1.0     1.8      2.0      2.0
## Median      4.0     4.0      7.5     11.0
## Mean        8.4     9.4      9.6     11.2
## 3rd Qu.    13.2    16.0     14.0     18.0
## Max.       33.0    34.0     30.0     33.0
## sd          9.0     9.5      8.7      9.0
##
```

```
## bst family AdaBoost, nu=0.1
## best misclassification error from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.     0.0449  0.0562   0.0449   0.0506
## 1st Qu.  0.0716  0.0730   0.0787   0.1011
## Median   0.0787  0.0843   0.1039   0.1264
## Mean     0.0797  0.0870   0.1073   0.1310
## 3rd Qu.  0.0857  0.0955   0.1292   0.1573
## Max.     0.1461  0.1461   0.2079   0.3034
## sd       0.0147  0.0198   0.0339   0.0443
## CV based misclassification error from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.     0.0618  0.0562   0.0618   0.0730
## 1st Qu.  0.0787  0.0899   0.1053   0.1222
## Median   0.0955  0.1067   0.1348   0.1517
## Mean     0.0923  0.1072   0.1333   0.1585
## 3rd Qu.  0.1011  0.1236   0.1573   0.1910
## Max.     0.1573  0.1573   0.2360   0.3146
## sd       0.0156  0.0237   0.0407   0.0473
## best mstop with best misclassification error from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.          1       1        1        2
## 1st Qu.       9       4        7        9
## Median       21      12       14       23
## Mean         25      17       25       39
## 3rd Qu.      35      26       32       72
## Max.         93      98      100      100
## sd           21      17       26       33
## best mstop with CV from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.         10      10       10       10
## 1st Qu.      13      12       14       15
## Median       21      18       24       34
## Mean         28      33       33       44
## 3rd Qu.      35      49       46       70
## Max.         92      99      100       99
## sd           20      28       26       30
## nvar from bst
##         cont-0% cont-5% cont-10% cont-15%
## Min.        1.0     1.0      1.0      1.0
## 1st Qu.     1.0     2.0      3.0      4.8
## Median      3.0     4.0      7.0     11.0
## Mean        4.1     6.6      8.6     11.7
## 3rd Qu.     6.0    10.2     12.0     17.0
## Max.       17.0    21.0     25.0     27.0
## sd          3.8     5.6      6.0      7.0
##
## rbst family TAdaBoost, s=-0.2, nu=0.1
##
```

```
## best misclassification error from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.     0.0562  0.0618   0.0562   0.0562
## 1st Qu.  0.0787  0.0787   0.0899   0.0955
## Median   0.0843  0.0899   0.1039   0.1236
## Mean     0.0856  0.0937   0.1059   0.1258
## 3rd Qu.  0.0955  0.1011   0.1180   0.1517
## Max.     0.1348  0.1573   0.1910   0.2360
## sd       0.0150  0.0195   0.0236   0.0380
## CV based misclassification error from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.     0.0562  0.0618   0.0730   0.0674
## 1st Qu.  0.0843  0.0955   0.1067   0.1236
## Median   0.0955  0.1067   0.1236   0.1461
## Mean     0.0978  0.1097   0.1289   0.1511
## 3rd Qu.  0.1067  0.1194   0.1419   0.1798
## Max.     0.1742  0.2472   0.2584   0.2921
## sd       0.0198  0.0269   0.0344   0.0425
## best mstop with best misclassification error from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.          1       2        1        1
## 1st Qu.      14      15       14       12
## Median       36      37       40       39
## Mean         42      39       44       42
## 3rd Qu.      70      60       70       69
## Max.         97      98      100       94
## sd           31      28       31       30
## best mstop with CV from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.         10      10       10       10
## 1st Qu.      14      15       19       13
## Median       28      36       38       30
## Mean         38      43       42       38
## 3rd Qu.      62      70       61       64
## Max.        100     100      100       98
## sd           28      28       26       28
## nvar from rbst
##         cont-0% cont-5% cont-10% cont-15%
## Min.        1.0     1.0      1.0      1.0
## 1st Qu.     2.0     3.0      4.0      3.0
## Median      3.0     6.0      8.0      8.0
## Mean        4.5     7.6      8.8      8.7
## 3rd Qu.     7.0    11.0     12.0     12.2
## Max.       18.0    22.0     26.0     28.0
## sd          3.7     5.4      5.7      6.2
print(proc.time() - ptm)
##      user    system   elapsed
## 49684.357  3190.518 53841.009
```


Misclassification error
0.05
0.15
0.25
cont−0%
cont−5%
cont−10%
cont−15%
ClossBoost


Misclassification error
0.05
0.15
0.25
cont−0%
cont−5%
cont−10%
cont−15%
ClossBoostQM


No. variables
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4
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8
10
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cont−5%
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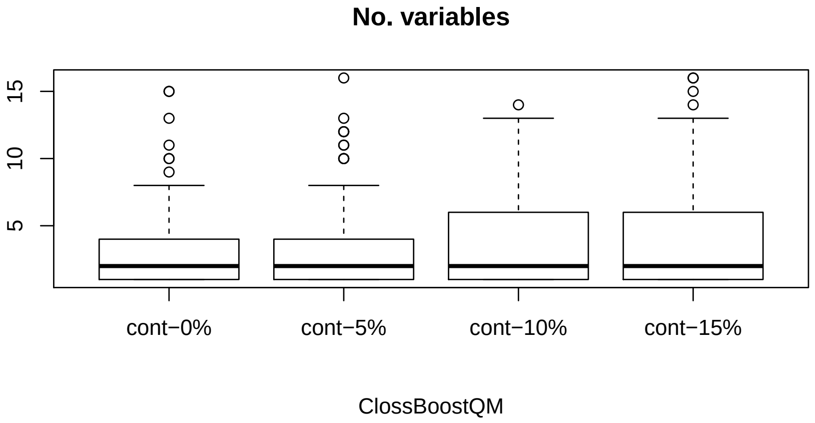
ClossBoost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cont−5%
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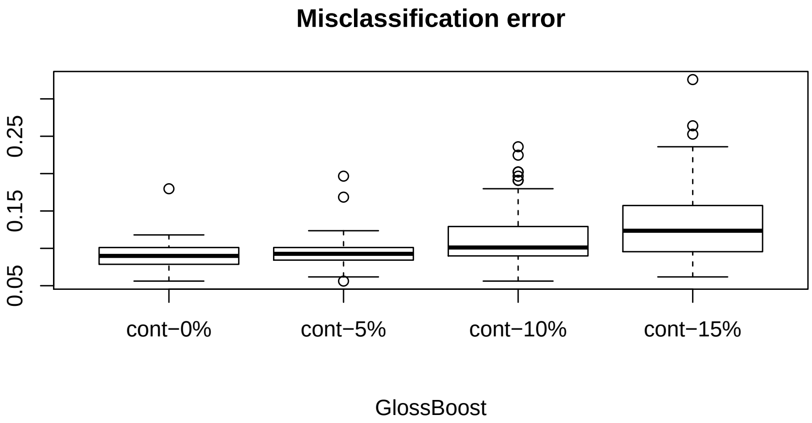
ClossBoostQM


Misclassification error
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0.15
0.25
cont−0%
cont−5%
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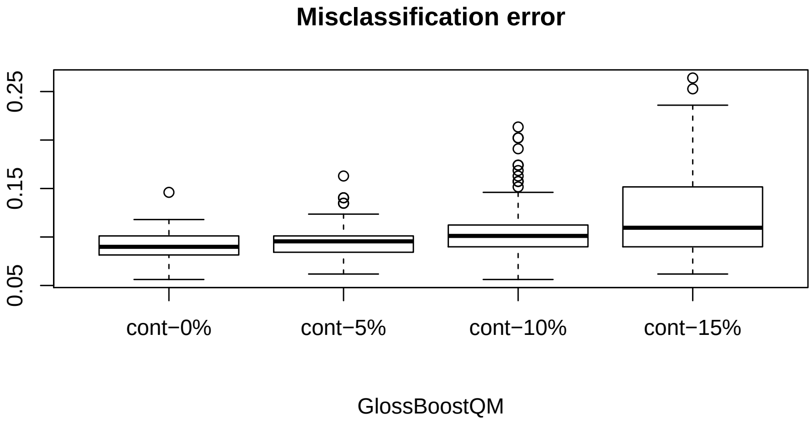
cont−15%
GlossBoost


Misclassification error
0.05
0.15
0.25
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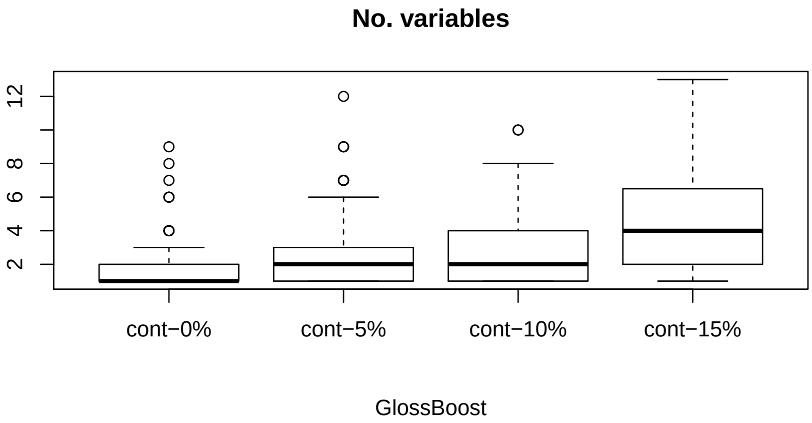
cont−5%
cont−10%
cont−15%
GlossBoostQM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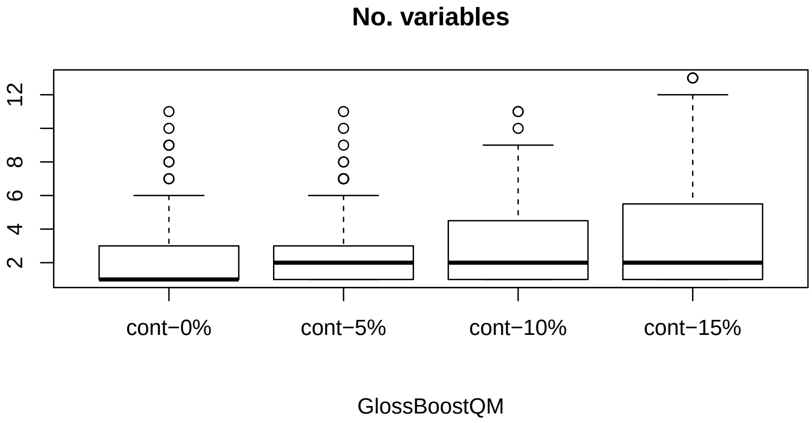
GlossBoost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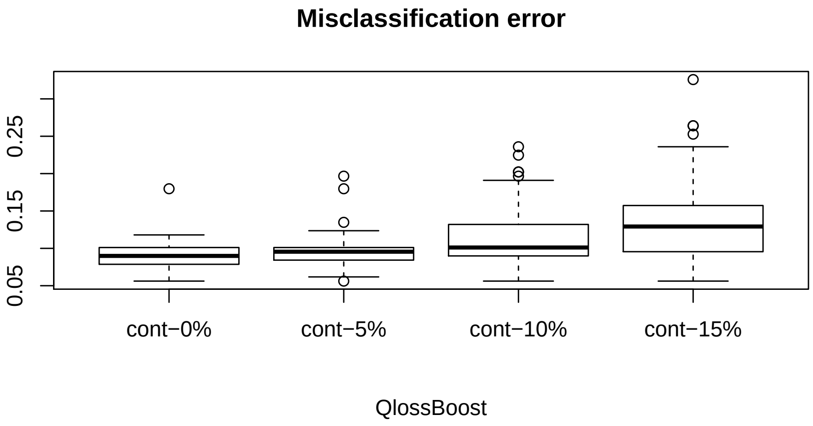
GlossBoostQM


Misclassification error
0.05
0.15
0.25
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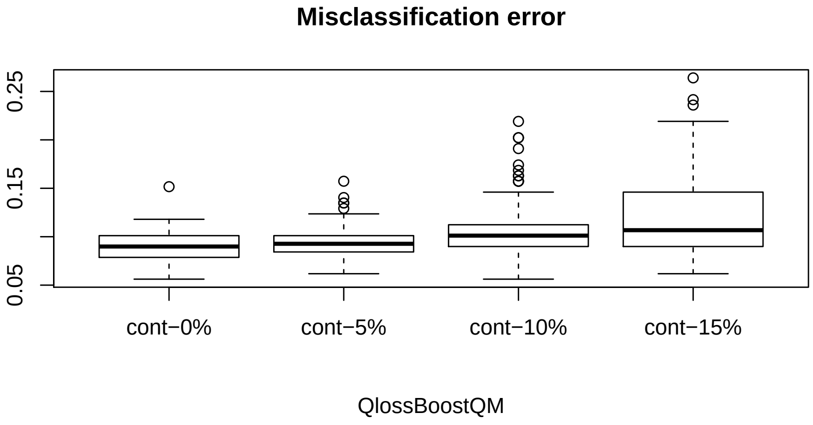
cont−5%
cont−10%
cont−15%
QlossBoost


Misclassification error
0.05
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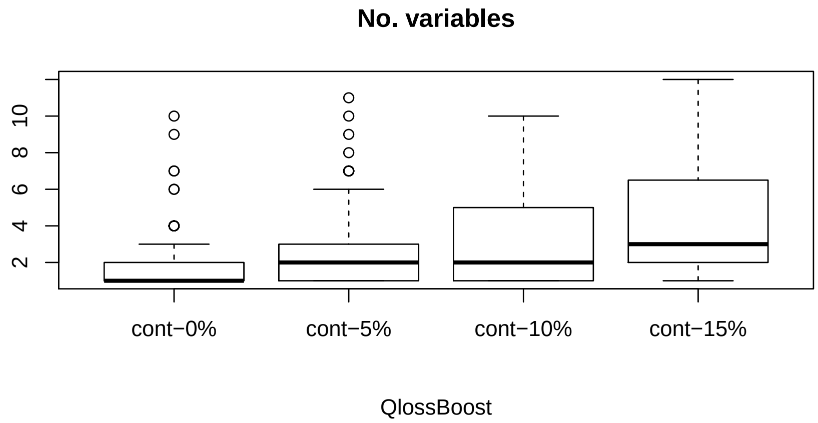
QlossBoostQM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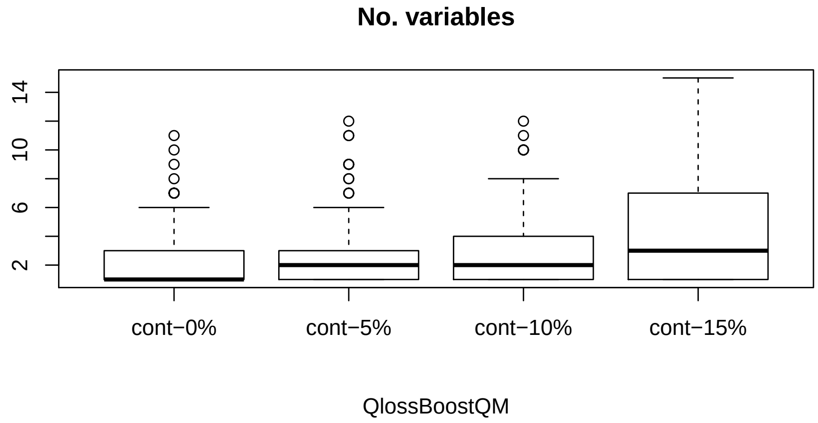
cont−15%
QlossBoost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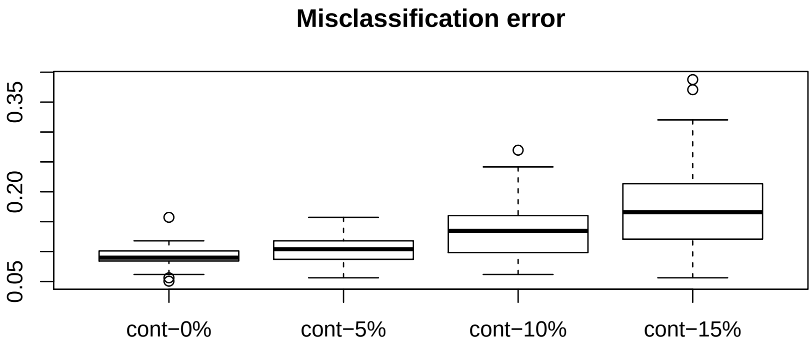
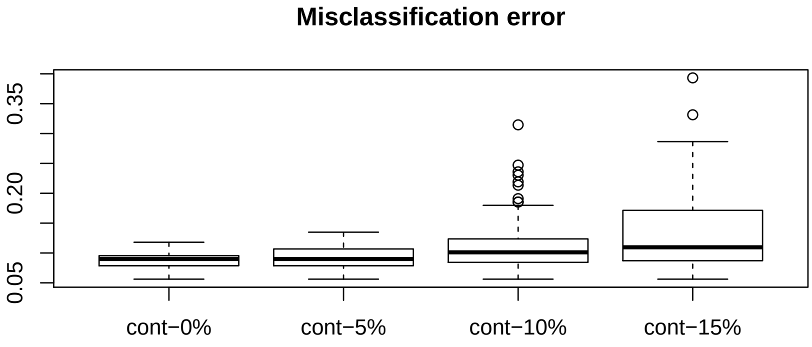
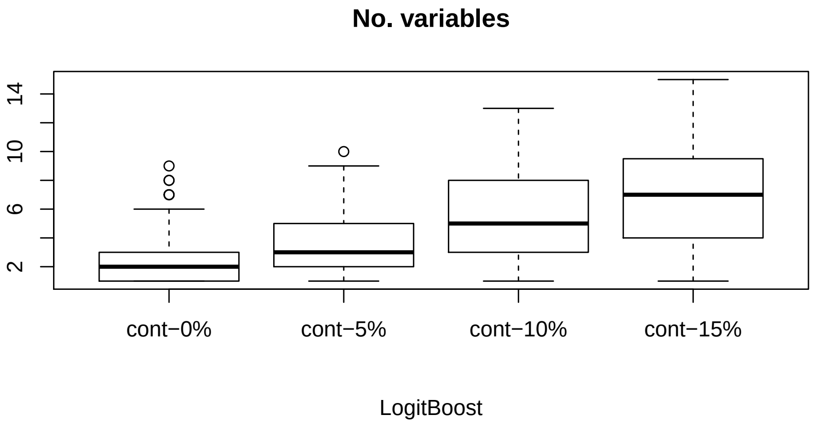
cont−5%
cont−10%
cont−15%
QlossBoostQM



LogitBoost



TLogitBoost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10
14
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cont−5%
cont−10%
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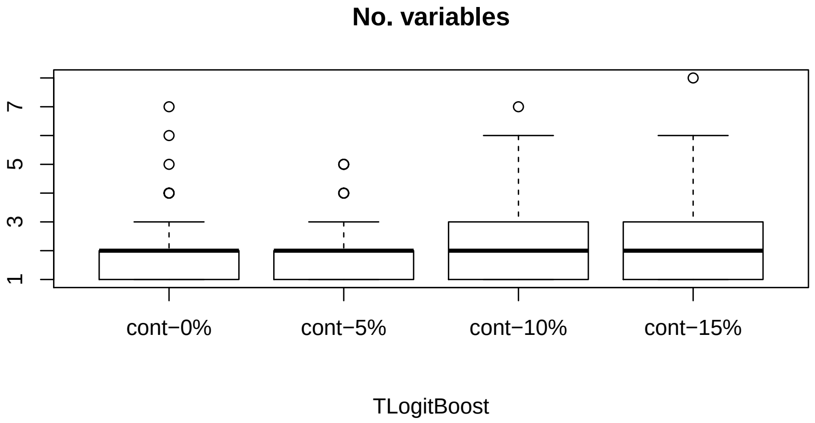
LogitBoost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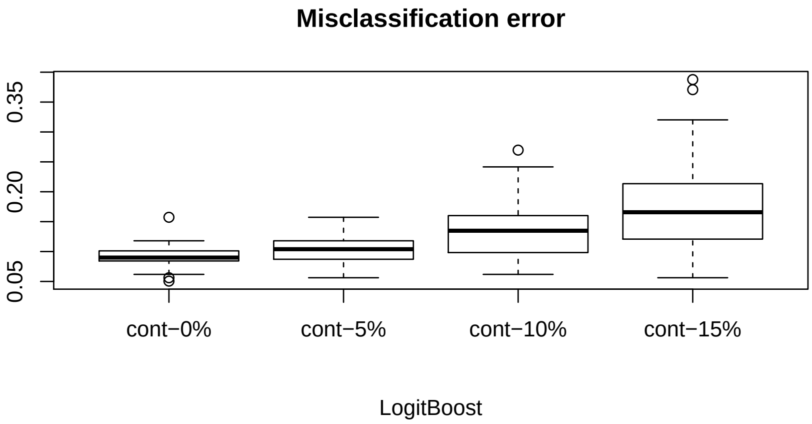
7
cont−0%
cont−5%
cont−10%
cont−15%
TLogitBoost


Misclassification error
0.05
0.20
0.35
cont−0%
cont−5%
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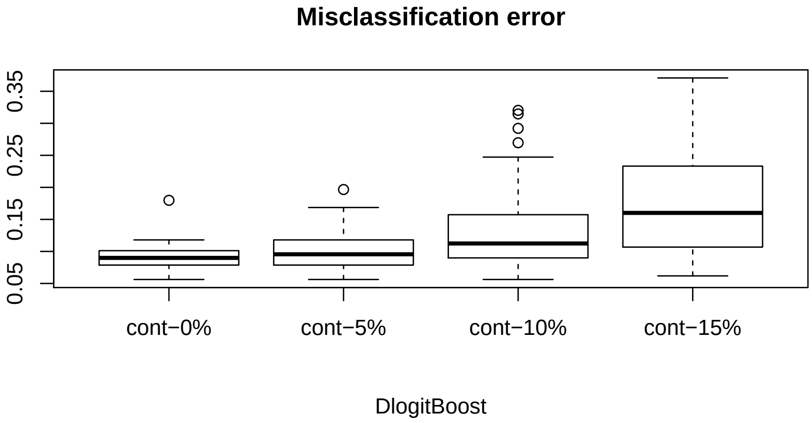
cont−15%
LogitBoost


Misclassification error
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0.15
0.25
0.35
cont−0%
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cont−10%
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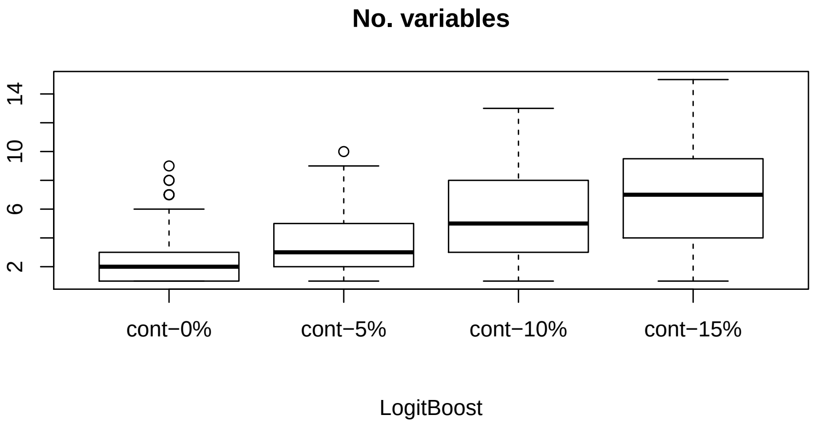
DlogitBoost


No. variables
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6
10
14
cont−0%
cont−5%
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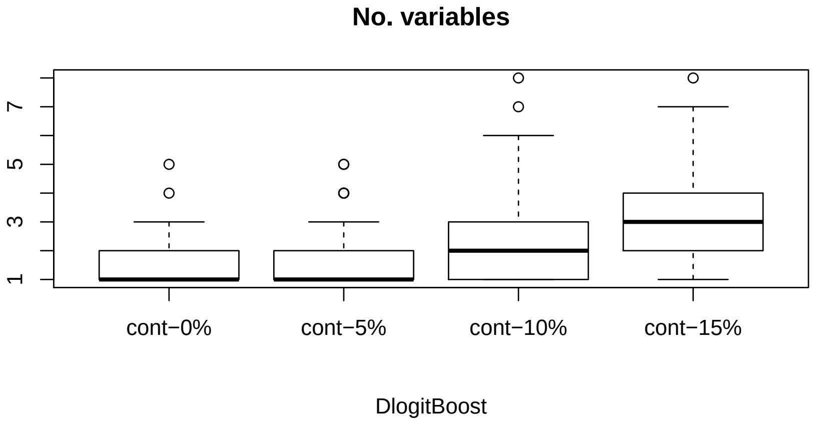
LogitBoost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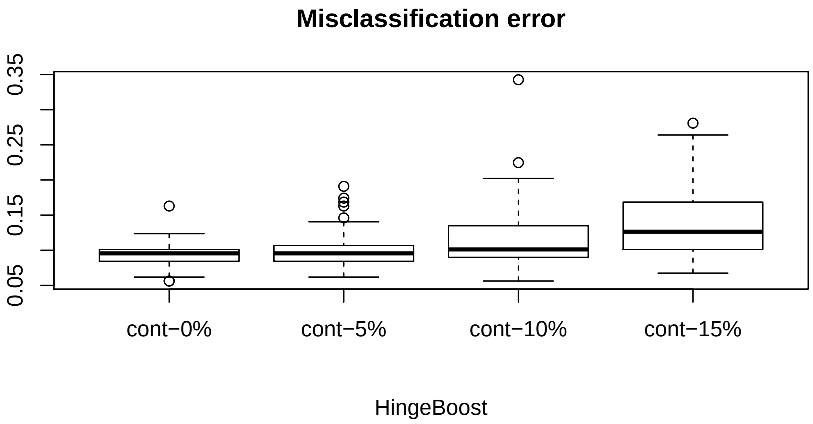
DlogitBoost


Misclassification error
0.05
0.15
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0.35
cont−0%
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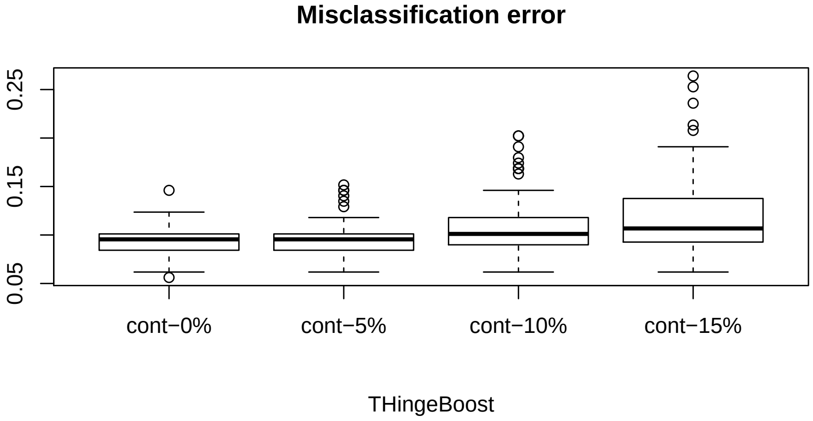
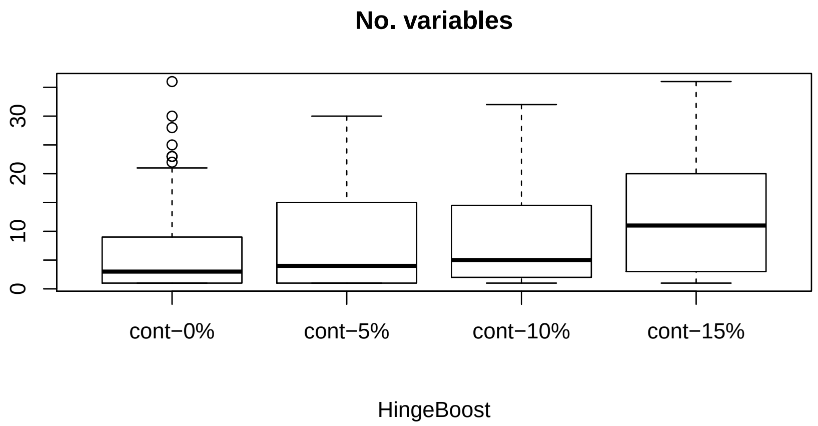
HingeBoost


Misclassification error
0.05
0.15
0.25
cont−0%
cont−5%
cont−10%
cont−15%
THingeBoost


No. variables
0
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20
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cont−5%
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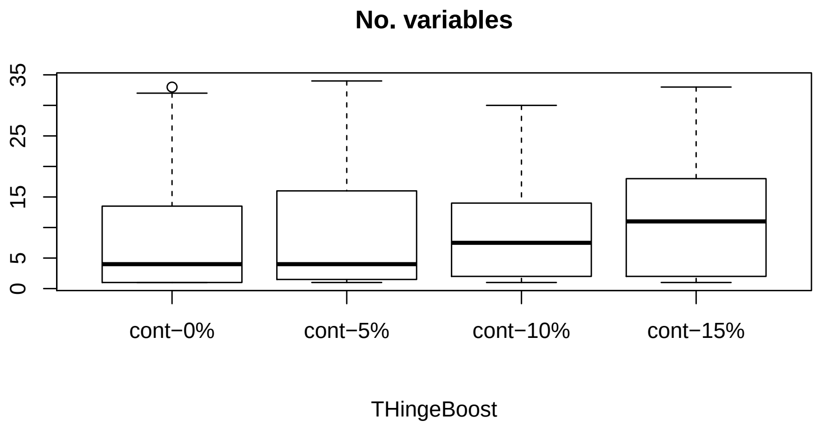
cont−15%
HingeBoost


No. variables
0
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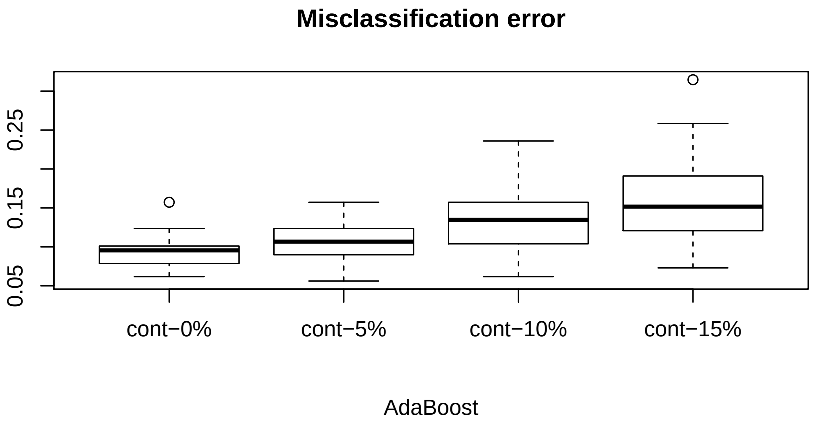
THingeBoost


Misclassification error
0.05
0.15
0.25
cont−0%
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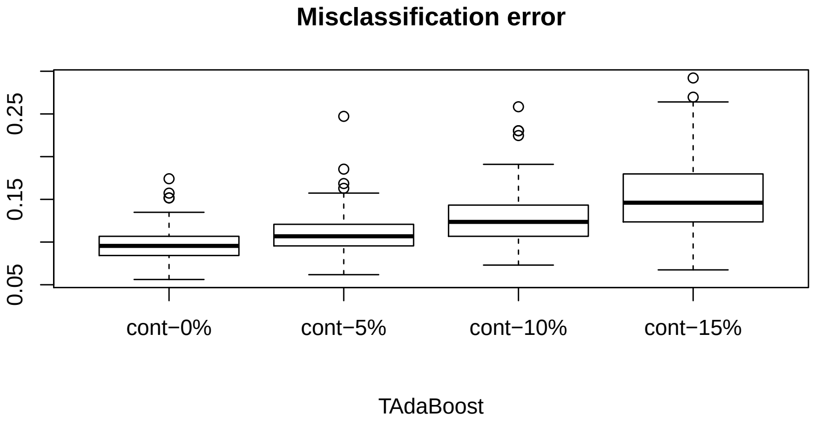
AdaBoost


Misclassification error
0.05
0.15
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cont−0%
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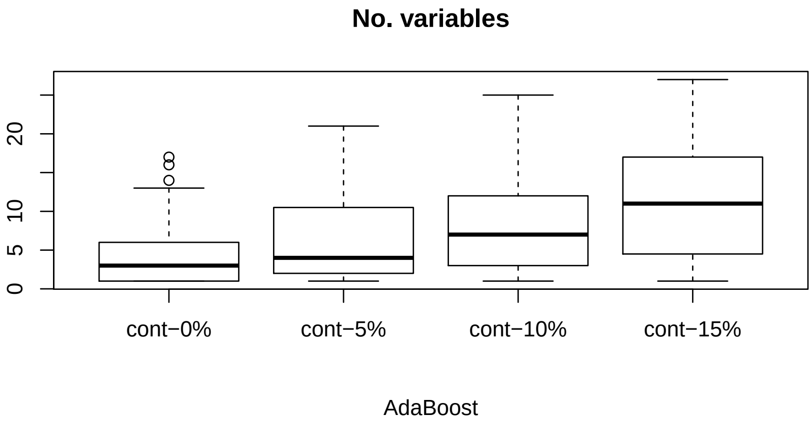
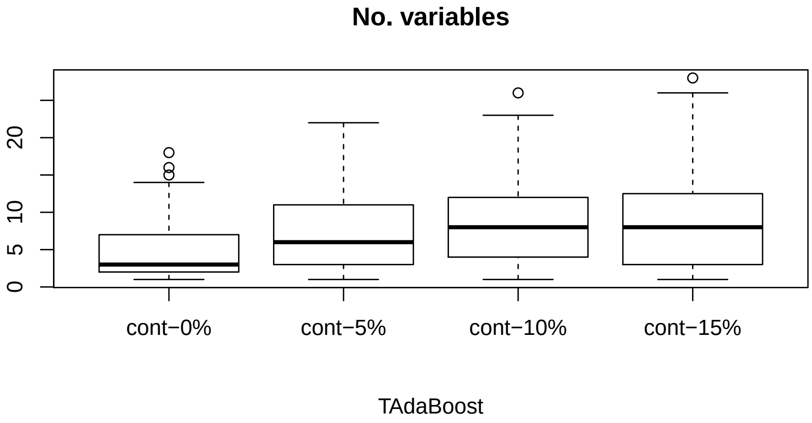
TAdaBoost





```
sessionInfo()
## R version 3.5.2 (2018-12-20)
## Platform: x86_64-pc-linux-gnu (64-bit)
## Running under: Ubuntu 18.04.1 LTS
##
## Matrix products: default
## BLAS: /usr/lib/x86_64-linux-gnu/blas/libblas.so.3.7.1
## LAPACK: /usr/lib/x86_64-linux-gnu/lapack/liblapack.so.3.7.1
##
## locale:
##  [1] LC_CTYPE=en_US.UTF-8       LC_NUMERIC=C
##  [3] LC_TIME=en_US.UTF-8        LC_COLLATE=en_US.UTF-8
##  [5] LC_MONETARY=en_US.UTF-8    LC_MESSAGES=en_US.UTF-8
##  [7] LC_PAPER=en_US.UTF-8       LC_NAME=C
##  [9] LC_ADDRESS=C               LC_TELEPHONE=C
## [11] LC_MEASUREMENT=en_US.UTF-8 LC_IDENTIFICATION=C
##
## attached base packages:
## [1] stats     graphics  grDevices utils     datasets
## [6] methods   base
```

```
##
## other attached packages:
## [1] bst_0.3-15   gbm_2.1.4    gdata_2.18.0 knitr_1.21
##
## loaded via a namespace (and not attached):
##  [1] codetools_0.2-16  lattice_0.20-38   gtools_3.8.1
##  [4] foreach_1.4.4     grid_3.5.2        gtable_0.2.0
##  [7] formatR_1.5       magrittr_1.5      evaluate_0.12
## [10] stringi_1.2.4     doParallel_1.0.14 rpart_4.1-13
## [13] Matrix_1.2-15     splines_3.5.2     iterators_1.0.10
## [16] tools_3.5.2       stringr_1.3.1     parallel_3.5.2
## [19] xfun_0.4          survival_2.43-3   compiler_3.5.2
## [22] gridExtra_2.3
```

References

Zhu Wang. Robust boosting with truncated loss functions. *Electronic Journal of Statistics*, 12(1):599–650, 2018a. doi: 10.1214/18-EJS1404.

Zhu Wang. Quadratic majorization for nonconvex loss with applications to the boosting algorithm. *Journal of Computational and Graphical Statistics*, 2018b. doi: 10.1080/10618600.2018.1424635.