

# Supporting information for “A multivariate spatial model for ordinal survey-based data”

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## Required packages

```
pacman::p_load(foreign, readxl, faraway, spdep, sp, ggplot2,
                 RColorBrewer, graphics, ggpubr, leaflet, nimble,
                 ggmcmc, extraDistr, parallel, MCMCvis, gridExtra,
                 corrplot, ggcorrplot, readr, lattice, install = FALSE)
```

## Data loading: GHQ-12 items

```
rm(list = ls())
HSRV2022 <- read.spss(file.path("../", "data", "ESCV2022_UV_Matem.sav"),
                       use.value.labels = TRUE, to.data.frame = TRUE)
# Sample size
NResp <- nrow(HSRV2022)

# P8_1 Concentrate
HSRV2022$P8_1[HSRV2022$P8_1 == "NS/NC"] <- NA
HSRV2022$P8_1 <- factor(HSRV2022$P8_1, levels = c("Más que lo habitual", "Igual que lo habitual",
                                                     "Menos que lo habitual", "Mucho menos que lo
                                                     ↪ habitual"))
levels(HSRV2022$P8_1) <- c("More", "Same", "Less", "Much less")
table(HSRV2022$P8_1)
```

```
##
##      More     Same     Less Much less
##      470     8195     919      194
```

```
P8_1 <- as.numeric(HSRV2022$P8_1)

# P8_2 Lose sleep over worries
HSRV2022$P8_2[HSRV2022$P8_2 == "NS/NC"] <- NA
HSRV2022$P8_2 <- factor(HSRV2022$P8_2, levels = c("Más que lo habitual", "Igual que lo habitual",
                                                     ↪
```

```

    "Menos que lo habitual", "Mucho menos que lo
    ↪ habitual"))
levels(HSRV2022$P8_2) <- c("Not at all", "No more", "Rather more", "Much more than usual")
table(HSRV2022$P8_2)

```

```

##                                     Not at all          No more      Rather more
##                               1706             6490            1094
## Much more than usual
##                               488

```

```

P8_2 <- as.numeric(HSRV2022$P8_2)

# P8_3 Play a useful role
HSRV2022$P8_3[HSRV2022$P8_3 == "NS/NC"] <- NA
HSRV2022$P8_3 <- factor(HSRV2022$P8_3, levels = c("Más que lo habitual", "Igual que lo habitual",
↪
    "Menos que lo habitual", "Mucho menos que lo
    ↪ habitual"))
levels(HSRV2022$P8_3) <- c("More", "Same", "Less", "Much less")
table(HSRV2022$P8_3)

```

```

##                                     More          Same        Less  Much less
##                               823            8329           483            137

```

```

P8_3 <- as.numeric(HSRV2022$P8_3)

# P8_4 Make decisions
HSRV2022$P8_4[HSRV2022$P8_4 == "NS/NC"] <- NA
HSRV2022$P8_4 <- factor(HSRV2022$P8_4, levels = c("Más que lo habitual", "Igual que lo habitual",
↪
    "Menos que lo habitual", "Mucho menos que lo
    ↪ habitual"))
levels(HSRV2022$P8_4) <- c("More", "Same", "Less", "Much less")
table(HSRV2022$P8_4)

```

```

##                                     More          Same        Less  Much less
##                               619            8572           446            140

```

```

P8_4 <- as.numeric(HSRV2022$P8_4)

# P8_5 Constantly under strain
HSRV2022$P8_5[HSRV2022$P8_5 == "NS/NC"] <- NA
HSRV2022$P8_5 <- factor(HSRV2022$P8_5, levels = c("Más que lo habitual", "Igual que lo habitual",
↪
    "Menos que lo habitual", "Mucho menos que lo
    ↪ habitual"))
levels(HSRV2022$P8_5) <- c("Not at all", "No more", "Rather more", "Much more than usual")
table(HSRV2022$P8_5)

```

```

##          Not at all           No more      Rather more
##                1621                  5385                 2175
## Much more than usual
##                593

```

```

P8_5 <- as.numeric(HSRV2022$P8_5)

# P8_6 Unable to overcome difficulties
HSRV2022$P8_6[HSRV2022$P8_6 == "NS/NC"] <- NA
HSRV2022$P8_6 <- factor(HSRV2022$P8_6, levels = c("Más que lo habitual", "Igual que lo habitual",
→
"Menos que lo habitual", "Mucho menos que lo
→
habitual"))
levels(HSRV2022$P8_6) <- c("Not at all", "No more", "Rather more", "Much more than usual")
table(HSRV2022$P8_6)

```

```

##          Not at all           No more      Rather more
##                1173                  5748                 2258
## Much more than usual
##                593

```

```

P8_6 <- as.numeric(HSRV2022$P8_6)

# P8_7 Enjoy activities
HSRV2022$P8_7[HSRV2022$P8_7 == "NS/NC"] <- NA
HSRV2022$P8_7 <- factor(HSRV2022$P8_7, levels = c("Más que lo habitual", "Igual que lo habitual",
→
"Menos que lo habitual", "Mucho menos que lo
→
habitual"))
levels(HSRV2022$P8_7) <- c("More", "Same", "Less", "Much less")
table(HSRV2022$P8_7)

```

```

##          More      Same     Less  Much less
##            624       8176      798        175

```

```

P8_7 <- as.numeric(HSRV2022$P8_7)

# P8_8 Face up to problems
HSRV2022$P8_8[HSRV2022$P8_8 == "NS/NC"] <- NA
HSRV2022$P8_8 <- factor(HSRV2022$P8_8, levels = c("Más que lo habitual", "Igual que lo habitual",
→
"Menos que lo habitual", "Mucho menos que lo
→
habitual"))
levels(HSRV2022$P8_8) <- c("More", "Same", "Less", "Much less")
table(HSRV2022$P8_8)

```

```

##          More      Same     Less  Much less
##            508       8459      624        185

```

```

P8_8 <- as.numeric(HSRV2022$P8_8)

# P8_9 Feel depressed
HSRV2022$P8_9[HSRV2022$P8_9 == "NS/NC"] <- NA
HSRV2022$P8_9 <- factor(HSRV2022$P8_9, levels = c("Más que lo habitual", "Igual que lo habitual",
  ↵
  "Menos que lo habitual", "Mucho menos que lo
  ↵
  habitual"))
levels(HSRV2022$P8_9) <- c("Not at all", "No more", "Rather more", "Much more than usual")
table(HSRV2022$P8_9)

```

```

## 
##          Not at all           No more           Rather more
##                1535                 4863                  2271
## Much more than usual
##                1102

```

```

P8_9 <- as.numeric(HSRV2022$P8_9)

# P8_10 Lose confidence
HSRV2022$P8_10[HSRV2022$P8_10 == "NS/NC"] <- NA
HSRV2022$P8_10 <- factor(HSRV2022$P8_10, levels = c("Más que lo habitual", "Igual que lo
  ↵
  habitual",
  "Menos que lo habitual", "Mucho menos que lo
  ↵
  habitual"))
levels(HSRV2022$P8_10) <- c("Not at all", "No more", "Rather more", "Much more than usual")
table(HSRV2022$P8_10)

```

```

## 
##          Not at all           No more           Rather more
##                1355                 4984                  2287
## Much more than usual
##                1145

```

```

P8_10 <- as.numeric(HSRV2022$P8_10)

# P8_11 Feel worthless
HSRV2022$P8_11[HSRV2022$P8_11 == "NS/NC"] <- NA
HSRV2022$P8_11 <- factor(HSRV2022$P8_11, levels = c("Más que lo habitual", "Igual que lo
  ↵
  habitual",
  "Menos que lo habitual", "Mucho menos que lo
  ↵
  habitual"))
levels(HSRV2022$P8_11) <- c("Not at all", "No more", "Rather more", "Much more than usual")
table(HSRV2022$P8_11)

```

```

## 
##          Not at all           No more           Rather more
##                1151                 5865                  1513
## Much more than usual
##                1238

```

```

P8_11 <- as.numeric(HSRV2022$P8_11)

# P8_12 Feel reasonably happy
HSRV2022$P8_12[HSRV2022$P8_12 == "NS/NC"] <- NA
HSRV2022$P8_12 <- factor(HSRV2022$P8_12, levels = c("Más que lo habitual", "Igual que lo
↪ habitual",
                           "Menos que lo habitual", "Mucho menos que lo
↪ habitual"))
levels(HSRV2022$P8_12) <- c("More", "Same", "Less", "Much less")
table(HSRV2022$P8_12)

```

```

##          More      Same      Less Much less
##        754     8347      566      101

```

```

P8_12 <- as.numeric(HSRV2022$P8_12)

y <- data.frame(P8_1, P8_2, P8_3, P8_4, P8_5, P8_6,
                 P8_7, P8_8, P8_9, P8_10, P8_11, P8_12)

# Number of response variables
NVars <- ncol(y)
# Number of levels
NCats <- unique(apply(y, 2, function(x) {length(table(x))}))

ones <- rep(1, NCats)

rm(list = c("P8_1", "P8_2", "P8_3", "P8_4", "P8_5", "P8_6",
           "P8_7", "P8_8", "P8_9", "P8_10", "P8_11", "P8_12"))

# Covariate sex: 1 = Male; 2 = Female
sexC <- HSRV2022$sexo
levels(sexC) <- c("Male", "Female")
sex <- as.numeric(sexC)

# Covariate age group: 1 = [15,25); 2 = [25,35); 3 = [35,45); 4 = [45,55); 5 = [55,65);
# 6 = [65,70); 7 = [70,75); 8 = [75,...)
ageC <- cut(HSRV2022$Edad, breaks = c(15, 25, 35, 45, 55, 65, 70, 75, 103),
             include.lowest = TRUE, right = FALSE)
levels(ageC)[length(table(ageC))] <- "[75,...)"
age <- as.numeric(ageC)

# Number of respondents by sex and age group
table(sexC, ageC)

```

```

##          ageC
## sexC      [15,25) [25,35) [35,45) [45,55) [55,65) [65,70) [70,75) [75,...)
##   Male      467     504     671     815     655     507     477     830
##   Female    458     524     683     771     702     437     414     882

```

```

# Number of levels of each (categorical) covariate
NSex <- length(table(sexC))
NAges <- length(table(ageC))

```

```

# Cartography of the Region of Valencia
load(file.path("../", "data", "CartoCV.Rdata"))
# Neighborhood structure by contiguity
cv.nb <- poly2nb(carto_muni)

# Some extra neighborhoods are added for Rincón de Ademuz comarca
cv.nb[[277]] <- as.integer(sort(c(cv.nb[[277]], 312, 317, 517, 523, 508)))
cv.nb[[363]] <- as.integer(sort(c(cv.nb[[363]], 312, 317, 517, 523, 508)))
cv.nb[[364]] <- as.integer(sort(c(cv.nb[[364]], 312, 317, 517, 523, 508)))
cv.nb[[477]] <- as.integer(sort(c(cv.nb[[477]], 312, 317, 517, 523, 508)))

cv.nb[[312]] <- as.integer(sort(c(cv.nb[[312]], 277, 363, 364, 477)))
cv.nb[[317]] <- as.integer(sort(c(cv.nb[[317]], 277, 363, 364, 477)))
cv.nb[[517]] <- as.integer(sort(c(cv.nb[[517]], 277, 363, 364, 477)))
cv.nb[[523]] <- as.integer(sort(c(cv.nb[[523]], 277, 363, 364, 477)))
cv.nb[[508]] <- as.integer(sort(c(cv.nb[[508]], 277, 363, 364, 477)))

# Municipality codes
INE_MUN <- as.numeric(as.character(carto_muni@data$INE_MUN))

# Municipality of each respondent
muni <- as.numeric(HSRV2022$LOCALIDAD)
# Number of (distinct) municipalities (542)
NMuni <- length(INE_MUN); rm(INE_MUN)

# Number of neighbors of each municipality
nadj <- card(cv.nb)
# Neighbors of each municipality
map <- unlist(cv.nb)
# Sum of all the neighbor numbers of all municipalities
nadj.tot <- length(map)
# Cumulative sums of the number of neighbors of each municipality
index <- c(0, cumsum(nadj))

# Diagonal matrix with the number of neighbors of each area
D <- diag(nadj)
# Adjacency matrix
W <- nb2mat(cv.nb, style = "B", zero.policy = TRUE)
# Eigenvalues of D-W
Lambda <- eigen(D - W)$values
# Identity matrix
I <- diag(rep(1, NMuni))

# All the neighborhoods  $j \sim i$  where  $i < j$ 
from.to <- cbind(rep(1:NMuni, times = nadj), map); colnames(from.to) <- c("from", "to")
from.to <- from.to[which(from.to[, 1] < from.to[, 2]), ]
NDist <- nrow(from.to)

dcar_leroux <- nimbleFunction(
  name = 'dcar_leroux',
  run = function(x = double(1),          # Spatial random effect (vector)
                rho = double(0),        # Amount of spatial dependence (scalar)
                sd.theta = double(0),   # Standard deviation (scalar)
                Lambda = double(1),    # Eigenvalues of matrix  $D - W$ 
                from.to = double(2),    # Matrix of distinct pairs of neighbors from.to[, 1] <
                           #> from.to[, 2]
                log = integer(0, default = 0)) {
  returnType(double(0))
}

```

```

# Number of small areas
NMuni <- dim(x)[1]
# Number of distinct pairs of neighbors
NDist <- dim(from.to)[1]
# Required vectors
x.from <- nimNumeric(NDist)
x.to <- nimNumeric(NDist)
for (Dist in 1:NDist) {
  x.from[Dist] <- x[from.to[Dist, 1]]
  x.to[Dist] <- x[from.to[Dist, 2]]
}

# Log-density
logDens <- sum(dnorm(x[1:NMuni], mean = 0, sd = sd.theta * pow(1 - rho, -1/2), log = TRUE)) -
  NMuni/2 * log(1 - rho) + 1/2 * sum(log(rho * (Lambda[1:NMuni] - 1) + 1)) -
  1/2 * pow(sd.theta, -2) * rho * sum(pow(x.from[1:NDist] - x.to[1:NDist], 2))
if(log) return(logDens)
else return(exp(logDens))
}
)

```

## Proposed methods

```

# n.chains <- 5
# this_cluster <- makeCluster(n.chains)

```

## Model-Indep

```

# Model code
modelCode <- nimbleCode(
{
  for(Var in 1:NVars) {
    # Likelihood
    for (Resp in 1:NResp) {
      y[Resp, Var] ~ dcat(prlevels[Resp, Var, 1:NCats])

      # Definition of the probabilities of each category as a function of the
      # cumulative probabilities
      prlevels[Resp, Var, 1] <- p.gamma[Resp, Var, 1]
      for (Cat in 2:(NCats-1)) {
        prlevels[Resp, Var, Cat] <- p.gamma[Resp, Var, Cat] - p.gamma[Resp, Var, Cat-1]
      }
      prlevels[Resp, Var, NCats] <- 1 - p.gamma[Resp, Var, NCats-1]

      # Linear predictor
      for (Cat in 1:(NCats-1)) {
        logit(p.gamma[Resp, Var, Cat]) <- kappa[sex[Resp], age[Resp], Cat, Var] +
          sd.theta[Var] * theta[muni[Resp], Var]
      }
    }
  }
}

```

```

# Prior distributions

# kappa[1:NSex, 1:NAges, 1:(NCats-1), 1:NVars] cut points
# Monotonic transformation
for (Var in 1:NVars) {
  for (SexGroup in 1:NSex) {
    for (AgeGroup in 1:NAges) {
      for (Cat in 1:(NCats-1)) {
        kappa[SexGroup, AgeGroup, Cat, Var] <- logit(sum(delta[SexGroup, AgeGroup, Var,
→ 1:Cat]))
      }
      # delta[1:NSex, 1:NAges, 1:NVars, 1:NCats] Dirichlet prior
      delta[SexGroup, AgeGroup, Var, 1:NCats] ~ ddirch(ones[1:NCats])
    }
  }
}

# theta[1:NMuni, 1:NVars] spatial random effects
for (Var in 1:NVars) {
  # theta[1:NMuni, 1:NVars] spatial random effects
  # LCAR distribution
  theta[1:NMuni, Var] ~ dcar_leroux(rho = rho[Var],
                                       sd.theta = 1,
                                       Lambda = Lambda[1:NMuni],
                                       from.to = from.to[1:NDist, 1:2])
}

# Hyperparameters of the spatial random effects
for (Var in 1:NVars) {
  rho[Var] ~ dunif(0, 1)
  sd.theta[Var] ~ dhalfflat()
}

# Stochastic restrictions
# Required vectors
for (Var in 1:NVars) {
  for (Resp in 1:NResp) {
    theta.Resp[Resp, Var] <- theta[muni[Resp], Var]
  }

  # Zero-mean constraint for theta.Resp
  zero.theta.resp[Var] ~ dnorm(mean.thetas.resp[Var], 10000)
  mean.thetas.resp[Var] <- mean(theta.Resp[1:NResp, Var])
}

# Data to be loaded

modelData <- list(y = as.matrix(y), zero.theta.resp = rep(0, NVars))

modelConstants <- list(NResp = NResp, NCats = NCats, NVars = NVars, sex = sex,
                       age = age, muni = muni, NSex = NSex, NAges = NAges,
                       NMuni = NMuni, ones = ones, NDist = NDist, Lambda = Lambda,
                       from.to = from.to)

# Parameters to be saved

```

```

modelParameters <- c("kappa", "theta", "sd.theta", "rho",
                     "delta")

# Create a function with all the needed code
run_MCMC_allcode <- function(X, code, constants, data, monitors) {

  pacman::p_load(nimble, extraDistr, install = FALSE)

  dcar_leroux <- nimbleFunction(
    name = 'dcar_leroux',
    run = function(x = double(1),           # Spatial random effect (vector)
                  rho = double(0),        # Amount of spatial dependence (scalar)
                  sd.theta = double(0),   # Standard deviation (scalar)
                  Lambda = double(1),    # Eigenvalues of matrix D - W
                  from.to = double(2),    # Matrix of distinct pairs of neighbors from.to[, 1] <
                                         #> from.to[, 2]
                  log = integer(0, default = 0)) {
      returnType(double(0))

      # Number of small areas
      NMuni <- dim(x)[1]
      # Number of distinct pairs of neighbors
      NDist <- dim(from.to)[1]
      # Required vectors
      x.from <- nimNumeric(NDist)
      x.to <- nimNumeric(NDist)
      for (Dist in 1:NDist) {
        x.from[Dist] <- x[from.to[Dist, 1]]
        x.to[Dist] <- x[from.to[Dist, 2]]
      }

      logDens <- sum(dnorm(x[1:NMuni], mean = 0, sd = sd.theta * pow(1 - rho, -1/2), log = TRUE))
    }
  )

  rcar_leroux <- nimbleFunction(
    name = 'rcar_leroux',
    run = function(n = integer(0),
                  rho = double(0),
                  sd.theta = double(0),
                  Lambda = double(1),
                  from.to = double(2)) {
      returnType(double(1))

      nimStop("user-defined distribution dcar_leroux provided without random generation
              <> function.")
      x <- nimNumeric(542)
      return(x)
    }
  )

  assign('dcar_leroux', dcar_leroux, envir = .GlobalEnv)
  assign('rcar_leroux', rcar_leroux, envir = .GlobalEnv)
}

```

```

NSex <- constants$NSex
NAges <- constants$NAges
NCats <- constants$NCats
ones <- constants$ones
NResp <- constants$NResp
NMuni <- constants$NMuni
NVars <- constants$NVars

# Let's create the Nimble model, creates the nodes (inits should be passed now)
model <- nimbleModel(code = code,
                      constants = constants,
                      data = data,
                      inits = list(delta = array(rdirichlet(NSex * NAgess * NVars, ones),
                                                 dim = c(NSex, NAgess, NVars, NCats)),
                                   rho = runif(NVars),
                                   theta = matrix(rnorm(NMuni * NVars, sd = 0.1), nrow = NMuni,
                                                 → ncol = NVars),
                                   sd.theta = runif(NVars)),
                      calculate = FALSE)

# Compile the model, which means generating C++ code, compiling that code, and loading it back
→ into R
Cmodel <- compileNimble(model)

# model$getParents(model$getNodeNames(dataOnly = TRUE), stochOnly = TRUE)

# Configuration
modelMCMCconfiguration <- configureMCMC(model, useConjugacy = FALSE,
                                             enableWAIC = TRUE)

# Remove desire samplers
modelMCMCconfiguration$removeSamplers(c("theta", "rho", "sd.theta"))

# Add slice/RW-MH theta[1:NMuni, 1:NVars] samplers
thetas <- matrix(nrow = NMuni, ncol = NVars)
for (Var in 1:NVars) {
  for (Muni in 1:NMuni) {
    thetas[Muni, Var] <- paste0("theta[", Muni, ",", Var, "]")
  }
}

smuni <- sort(unique(constants$muni))
for (Var in 1:NVars) {
  for (Muni in 1:NMuni) {
    ifelse(Muni %in% smuni,
           modelMCMCconfiguration$addSampler(target = thetas[Muni, Var], type = "RW"),
           modelMCMCconfiguration$addSampler(target = thetas[Muni, Var], type = "RW"))
  }
}

# Add slice rho sampler
rhos <- character(NVars)
for (Var in 1:NVars) {
  rhos[Var] <- paste0("rho[", Var, "]")
}

for (Var in 1:NVars) {
  modelMCMCconfiguration$addSampler(target = rhos[Var], type = "slice")
}

```

```

}

# Add slice sd.M.Muni sampler
sd.thetas <- character(NVars)
for (Var in 1:NVars) {
  sd.thetas[Var] <- paste0("sd.theta[",Var,"]")
}

for (Var in 1:NVars) {
  modelMCMCconfiguration$addSampler(target = sd.thetas[Var], type = "slice")
}

# Add new monitors
modelMCMCconfiguration$monitors <- c()
modelMCMCconfiguration$addMonitors(monitors)
# Build MCMC object
modelMCMC <- buildMCMC(modelMCMCconfiguration)
# Need to reset the nimbleFunctions in order to add the new MCMC
CmodelMCMC <- compileNimble(modelMCMC, project = model,
                                resetFunctions = TRUE)
# Results
results <- runMCMC(CmodelMCMC, niter = 8000, nburnin = 2000, thin = 30, setSeed = X)

return(results)
}

# system.time(salnimble <- parLapply(cl = this_cluster, X = 1:n.chains,
#                                     fun = run_MCMC_allcode,
#                                     code = modelCode,
#                                     constants = modelConstants,
#                                     data = modelData,
#                                     monitors = modelParameters))
#
## It's good practice to close the cluster when you're done with it.
# stopCluster(this_cluster)

# 1.84h on a server with: niter = 8000, nburnin = 2000, thin = 30
# saveRDS(salnimble, file = file.path("results", "multi-2022-nimble-MH-indep-8k-2k-30-WAIC.rds"))
salnimble1 <- readRDS(file = file.path("../", "results",
                                         "multi-2022-nimble-MH-indep-8k-2k-30-WAIC.rds"))

# WAIC for Model-Indep
# Let's create the Nimble model, creates the nodes
modelWAIC <- nimbleModel(code = modelCode,
                           constants = modelConstants,
                           data = modelData,
                           inits = list(delta = array(rdirichlet(NSex * NAge * NVars, ones),
                                         dim = c(NSex, NAge, NVars, NCats)),
                                         rho = runif(NVars),
                                         theta = matrix(rnorm(NMuni * NVars, sd = 0.1), nrow =
                                         NMuni, ncol = NVars),
                                         sd.theta = runif(NVars)),
                           calculate = FALSE)

## Defining model
## [Note] Registering 'dcar_leroux' as a distribution based on its use in BUGS code. If you make changes
## [Warning] Random generation function for dcar_leroux is not available. NIMBLE is generating a place

```

```

## Building model

## Setting data and initial values

## Checking model sizes and dimensions

## [Warning] Possible size/dimension mismatch amongst vectors and matrices in BUGS expression: 'theta'

## [Note] This model is not fully initialized. This is not an error.
## To see which variables are not initialized, use model$initializeInfo().
## For more information on model initialization, see help(modelInitialization).

```

```
CmodelWAIC <- compileNimble(modelWAIC)          # calculateWAIC needs compiled model to exist
```

```

## Compiling
## [Note] This may take a minute.
## [Note] Use 'showCompilerOutput = TRUE' to see C++ compilation details.

```

```
samples <- do.call(rbind, salnimble1)          # single matrix of samples
(waic <- calculateWAIC(samples, modelWAIC))
```

```

## Compiling
## [Note] This may take a minute.
## [Note] Use 'showCompilerOutput = TRUE' to see C++ compilation details.

```

```
## Calculating WAIC.
```

```

## nimbleList object of type waicNimbleList
## Field "WAIC":
## [1] 192525.4
## Field "lppd":
## [1] -94783.11
## Field "pWAIC":
## [1] 1479.595

```

## Model-Corr

```

# Model code

modelCode <- nimbleCode(
{
  for(Var in 1:NVars) {
    # Likelihood
    for (Resp in 1:NResp) {
      y[Resp, Var] ~ dcat(prlevels[Resp, Var, 1:NCats])

      # Definition of the probabilities of each category as a function of the
      # cumulative probabilities
    }
  }
}

```

```

prlevels[Resp, Var, 1] <- p.gamma[Resp, Var, 1]
for (Cat in 2:(NCats-1)) {
  prlevels[Resp, Var, Cat] <- p.gamma[Resp, Var, Cat] - p.gamma[Resp, Var, Cat-1]
}
prlevels[Resp, Var, NCats] <- 1 - p.gamma[Resp, Var, NCats-1]

# Linear predictor
for (Cat in 1:(NCats-1)) {
  logit(p.gamma[Resp, Var, Cat]) <- kappa[sex[Resp], age[Resp], Cat, Var] +
    theta[muni[Resp], Var]
}
}

# Prior distributions

# kappa[1:NSex, 1:NAges, 1:(NCats-1), 1:NVars] cut points
# Monotonic transformation
for (Var in 1:NVars) {
  for (SexGroup in 1:NSex) {
    for (AgeGroup in 1:NAges) {
      for (Cat in 1:(NCats-1)) {
        kappa[SexGroup, AgeGroup, Cat, Var] <- logit(sum(delta[SexGroup, AgeGroup, Var,
→ 1:Cat]))
      }
      # delta[1:NSex, 1:NAges, 1:NVars, 1:NCats] Dirichlet prior
      delta[SexGroup, AgeGroup, Var, 1:NCats] ~ ddirch(ones[1:NCats])
    }
  }
}

# theta[1:NMuni, 1:NVars] spatial random effects
for (Var in 1:NVars) {
  for (Muni in 1:NMuni) {
    theta[Muni, Var] <- inprod(sub.Muni[Muni, ], M.Muni[, Var])
  }
  # sub.Muni[1:NMuni, 1:NVars] underlying spatial REs
  # LCAR distribution
  sub.Muni[1:NMuni, Var] ~ dcar_leroux(rho = rho[Var],
                                         sd.theta = 1,
                                         Lambda = Lambda[1:NMuni],
                                         from.to = from.to[1:NDist, 1:2])
}

# Hyperparameter of the spatial random effects
for (Var in 1:NVars) {
  rho[Var] ~ dunif(0, 1)
}

# M.Resp[1:NVars, 1:NVars] and M.Muni[1:NVars, 1:NVars] M-matrices
for (Var1 in 1:NVars) {
  for (Var2 in 1:NVars) {
    M.Muni[Var1, Var2] ~ dnorm(0, tau.M.Muni)
  }
}

# Prior for precisions of M.Muni
tau.M.Muni <- pow(sd.M.Muni, -2)
sd.M.Muni ~ dhalfflat()

```

```

# Stochastic restrictions
# Required vectors
for (Var in 1:NVars) {
  for (Resp in 1:NResp) {
    sub.Muni.Resp[Resp, Var] <- sub.Muni[muni[Resp], Var]
  }

  # Zero-mean constraint for sub.Muni.Resp
  zero.sub.Muni.resp[Var] ~ dnorm(mean.sub.Munis.resp[Var], 10000)
  mean.sub.Munis.resp[Var] <- mean(sub.Muni.Resp[1:NResp, Var])
}

}

# Data to be loaded

modelData <- list(y = as.matrix(y), zero.sub.Muni.resp = rep(0, NVars))

modelConstants <- list(NResp = NResp, NCats = NCats, NVars = NVars, sex = sex,
                       age = age, muni = muni, NSex = NSex, NAges = NAges,
                       NMuni = NMuni, ones = ones, NDist = NDist, Lambda = Lambda,
                       from.to = from.to)

# Parameters to be saved

modelParameters <- c("kappa", "theta", "M.Muni", "sd.M.Muni", "rho",
                     "delta", "sub.Muni")

# Create a function with all the needed code
run_MCMC_allcode <- function(X, code, constants, data, monitors) {

  pacman::p_load(nimble, extraDistr, install = FALSE)

  dcar_leroux <- nimbleFunction(
    name = 'dcar_leroux',
    run = function(x = double(1),           # Spatial random effect (vector)
                  rho = double(0),        # Amount of spatial dependence (scalar)
                  sd.theta = double(0),   # Standard deviation (scalar)
                  Lambda = double(1),    # Eigenvalues of matrix D - W
                  from.to = double(2),    # Matrix of distinct pairs of neighbors from.to[, 1] <
                                         #> from.to[, 2]
                  log = integer(0, default = 0)) {
      returnType(double(0))

      # Number of small areas
      NMuni <- dim(x)[1]
      # Number of distinct pairs of neighbors
      NDist <- dim(from.to)[1]
      # Required vectors
      x.from <- nimNumeric(NDist)
      x.to <- nimNumeric(NDist)
      for (Dist in 1:NDist) {
        x.from[Dist] <- x[from.to[Dist, 1]]
        x.to[Dist] <- x[from.to[Dist, 2]]
      }

      logDens <- sum(dnorm(x[1:NMuni], mean = 0, sd = sd.theta * pow(1 - rho, -1/2), log = TRUE))
    }
  )
}

```

```

NMuni/2 * log(1 - rho) + 1/2 * sum(log(rho * (Lambda[1:NMuni] - 1) + 1)) -
1/2 * pow(sd.theta, -2) * rho * sum(pow(x.from[1:NDist] - x.to[1:NDist], 2))
if(log) return(logDens)
else return(exp(logDens))
}
)

rcar_leroux <- nimbleFunction(
  name = 'rcar_leroux',
  run = function(n = integer(0),
                 rho = double(0),
                 sd.theta = double(0),
                 Lambda = double(1),
                 from.to = double(2)) {
    returnType(double(1))

    nimStop("user-defined distribution dcar_leroux provided without random generation
    ↪   function.")
    x <- nimNumeric(542)
    return(x)
  }
)

assign('dcar_leroux', dcar_leroux, envir = .GlobalEnv)
assign('rcar_leroux', rcar_leroux, envir = .GlobalEnv)

NSex <- constants$NSex
NAges <- constants$NAges
NCats <- constants$NCats
ones <- constants$ones
NResp <- constants$NResp
NMuni <- constants$NMuni
NVars <- constants$NVars

# Let's create the Nimble model, creates the nodes (inits should be passed now)
model <- nimbleModel(code = code,
                      constants = constants,
                      data = data,
                      inits = list(delta = array(rdirichlet(NSex * NAges * NVars, ones),
                                                 dim = c(NSex, NAges, NVars, NCats)),
                                   rho = runif(NVars),
                                   sub.Muni = matrix(rnorm(NMuni * NVars, sd = 0.01), nrow =
                                     ↪   NMuni, ncol = NVars),
                                   M.Muni = matrix(rnorm(NVars * NVars, sd = 0.5), ncol = NVars,
                                     ↪   nrow = NVars),
                                   sd.M.Muni = runif(1, min = 0.2, max = 0.8)),
                      calculate = FALSE)

# Compile the model, which means generating C++ code, compiling that code, and loading it back
# into R
Cmodel <- compileNimble(model)

# model$getParents(model$getNodeNames(dataOnly = TRUE), stochOnly = TRUE)

# Configuration
modelMCMCconfiguration <- configureMCMC(model, useConjugacy = FALSE,
                                            enableWAIC = TRUE)

# Remove desire samplers

```

```

modelMCMCconfiguration$removeSamplers(c("sub.Muni", "rho", "sd.M.Muni"))

# Add slice/RW-MH sub.Muni[1:NMuni, 1:NVars] samplers
sub.Munis <- matrix(nrow = NMuni, ncol = NVars)
for (Var in 1:NVars) {
  for (Muni in 1:NMuni) {
    sub.Munis[Muni, Var] <- paste0("sub.Muni[,Muni, , , Var, ]")
  }
}

smuni <- sort(unique(constants$muni))
for (Var in 1:NVars) {
  for (Muni in 1:NMuni) {
    ifelse(Muni %in% smuni,
      modelMCMCconfiguration$addSampler(target = sub.Munis[Muni, Var], type = "RW"),
      modelMCMCconfiguration$addSampler(target = sub.Munis[Muni, Var], type = "RW"))
  }
}

# Add slice rho sampler
rhos <- character(NVars)
for (Var in 1:NVars) {
  rhos[Var] <- paste0("rho[,Var, ]")
}

for (Var in 1:NVars) {
  modelMCMCconfiguration$addSampler(target = rhos[Var], type = "slice")
}

# Add slice sd.M.Muni sampler
modelMCMCconfiguration$addSampler(target = "sd.M.Muni", type = "slice")

# Add new monitors
modelMCMCconfiguration$monitors <- c()
modelMCMCconfiguration$addMonitors(monitors)
# Build MCMC object
modelMCMC <- buildMCMC(modelMCMCconfiguration)
# Need to reset the nimbleFunctions in order to add the new MCMC
CmodelMCMC <- compileNimble(modelMCMC, project = model,
  resetFunctions = TRUE)
# Results
results <- runMCMC(CmodelMCMC, niter = 8000, nburnin = 2000, thin = 30, setSeed = X)

return(results)
}

# system.time(salnimble <- parLapply(cl = this_cluster, X = 1:n.chains,
#                                     fun = run_MCMC_allcode,
#                                     code = modelCode,
#                                     constants = modelConstants,
#                                     data = modelData,
#                                     monitors = modelParameters))
#
## It's good practice to close the cluster when you're done with it.
# stopCluster(this_cluster)

# 6.18h on a server with: niter = 8000, nburnin = 2000, thin = 30
# saveRDS(salnimble, file = file.path("results", "multi-2022-nimble-MH-corr-8k-2k-30-WAIC.rds"))
salnimble2 <- readRDS(file = file.path("../", "results",
  "multi-2022-nimble-MH-corr-8k-2k-30-WAIC.rds"))

```

```

# WAIC for Model-Corr
# Let's create the Nimble model, creates the nodes
modelWAIC <- nimbleModel(code = modelCode,
                           constants = modelConstants,
                           data = modelData,
                           inits = list(delta = array(rdirichlet(NSex * NAgés * NVars, ones),
                                         dim = c(NSex, NAgés, NVars, NCats)),
                                         rho = runif(NVars),
                                         sub.Muni = matrix(rnorm(NMuni * NVars, sd = 0.01), nrow =
                                         ↪ NMuni, ncol = NVars),
                                         M.Muni = matrix(rnorm(NVars * NVars, sd = 0.5), ncol =
                                         ↪ NVars, nrow = NVars),
                                         sd.M.Muni = runif(1, min = 0.2, max = 0.8)),
                           calculate = FALSE)

```

```

## Defining model

## Building model

## Setting data and initial values

## Checking model sizes and dimensions

## [Warning] Possible size/dimension mismatch amongst vectors and matrices in BUGS expression: 'sub.M

## [Note] This model is not fully initialized. This is not an error.
## To see which variables are not initialized, use model$initializeInfo().
## For more information on model initialization, see help(modelInitialization).

```

```
CmodelWAIC <- compileNimble(modelWAIC)          # calculateWAIC needs compiled model to exist
```

```

## Compiling
## [Note] This may take a minute.
## [Note] Use 'showCompilerOutput = TRUE' to see C++ compilation details.

```

```

samples <- do.call(rbind, salnimble2)           # single matrix of samples
(waic <- calculateWAIC(samples, modelWAIC))
```

```

## Compiling
## [Note] This may take a minute.
## [Note] Use 'showCompilerOutput = TRUE' to see C++ compilation details.

```

```
## Calculating WAIC.
```

```

## nimbleList object of type waicNimbleList
## Field "WAIC":
## [1] 190447.6
## Field "lppd":
## [1] -93940.28
## Field "pWAIC":
## [1] 1283.548

```

## Model-Corr&IRE

```

# Model code

modelCode <- nimbleCode(
{
  for(Var in 1:NVars) {
    # Likelihood
    for (Resp in 1:NResp) {
      y[Resp, Var] ~ dcat(prlevels[Resp, Var, 1:NCats])

      # Definition of the probabilities of each category as a function of the
      # cumulative probabilities
      prlevels[Resp, Var, 1] <- p.gamma[Resp, Var, 1]
      for (Cat in 2:(NCats-1)) {
        prlevels[Resp, Var, Cat] <- p.gamma[Resp, Var, Cat] - p.gamma[Resp, Var, Cat-1]
      }
      prlevels[Resp, Var, NCats] <- 1 - p.gamma[Resp, Var, NCats-1]

      # Linear predictor
      for (Cat in 1:(NCats-1)) {
        logit(p.gamma[Resp, Var, Cat]) <- kappa[sex[Resp], age[Resp], Cat, Var] +
          theta[muni[Resp], Var] + psi[Resp, Var]
      }
    }
  }

  # Prior distributions

  # kappa[1:NSex, 1:NAges, 1:(NCats-1), 1:NVars] cut points
  # Monotonic transformation
  for (Var in 1:NVars) {
    for (SexGroup in 1:NSex) {
      for (AgeGroup in 1:NAges) {
        for (Cat in 1:(NCats-1)) {
          kappa[SexGroup, AgeGroup, Cat, Var] <- logit(sum(delta[SexGroup, AgeGroup, Var,
→ 1:Cat]))
        }
      }
      # delta[1:NSex, 1:NAges, 1:NVars, 1:NCats] Dirichlet prior
      delta[SexGroup, AgeGroup, Var, 1:NCats] ~ ddirch(ones[1:NCats])
    }
  }

  # psi[1:NResp, 1:NVars] individual random effects
  for(Var in 1:NVars) {
    for (Resp in 1:NResp) {
      psi[Resp, Var] <- inprod(sub.Resp[Resp, ], M.Resp[, Var])
      # sub.Resp[1:NResp, 1:NVars] underlying individual REs
      sub.Resp[Resp, Var] ~ dnorm(0, 1)
    }
  }

  # theta[1:NMuni, 1:NVars] spatial random effects
  for (Var in 1:NVars) {
    for (Muni in 1:NMuni) {
      theta[Muni, Var] <- inprod(sub.Muni[Muni, ], M.Muni[, Var])
    }
  }
}

```

```

# sub.Muni[1:NMuni, 1:NVars] underlying spatial REs
# LCAR distribution
sub.Muni[1:NMuni, Var] ~ dcar_leroux(rho = rho[Var],
                                         sd.theta = 1,
                                         Lambda = Lambda[1:NMuni],
                                         from.to = from.to[1:NDist, 1:2])
}

# Hyperparameter of the spatial random effects
for (Var in 1:NVars) {
  rho[Var] ~ dunif(0, 1)
}

# M.Resp[1:NVars, 1:NVars] and M.Muni[1:NVars, 1:NVars] M-matrices
for (Var1 in 1:NVars) {
  for (Var2 in 1:NVars) {
    M.Resp[Var1, Var2] ~ dnorm(0, tau.M.Resp)
    M.Muni[Var1, Var2] ~ dnorm(0, tau.M.Muni)
  }
}

# Prior for precisions of M.Resp and M.Muni
tau.M.Resp <- pow(sd.M.Resp, -2)
sd.M.Resp ~ dhalfflat()

tau.M.Muni <- pow(sd.M.Muni, -2)
sd.M.Muni ~ dhalfflat()

# Stochastic restrictions
# Required vectors
for (Var in 1:NVars) {
  for (Resp in 1:NResp) {
    sub.Muni.Resp[Resp, Var] <- sub.Muni[muni[Resp], Var]
  }
}

# Zero-mean constraint for sub.Muni.Resp
zero.sub.Muni.resp[Var] ~ dnorm(mean.sub.Munis.resp[Var], 10000)
mean.sub.Munis.resp[Var] <- mean(sub.Muni.Resp[1:NResp, Var])
}

}

# Data to be loaded

modelData <- list(y = as.matrix(y), zero.sub.Muni.resp = rep(0, NVars))

modelConstants <- list(NResp = NResp, NCats = NCats, NVars = NVars, sex = sex,
                      age = age, muni = muni, NSex = NSex, NAges = NAges,
                      NMuni = NMuni, ones = ones, NDist = NDist, Lambda = Lambda,
                      from.to = from.to)

# Parameters to be saved

modelParameters <- c("kappa", "theta", "M.Muni", "rho",
                     "sd.M.Muni", "psi", "M.Resp", "sd.M.Resp",
                     "delta", "sub.Muni", "sub.Resp")

# Create a function with all the needed code

```

```

run_MCMC_allcode <- function(X, code, constants, data, monitors) {

  pacman::p_load(nimble, extraDistr, install = FALSE)

  dcar_leroux <- nimbleFunction(
    name = 'dcar_leroux',
    run = function(x = double(1),           # Spatial random effect (vector)
                  rho = double(0),        # Amount of spatial dependence (scalar)
                  sd.theta = double(0),   # Standard deviation (scalar)
                  Lambda = double(1),    # Eigenvalues of matrix D - W
                  from.to = double(2),    # Matrix of distinct pairs of neighbors from.to[, 1] <
                                         → from.to[, 2]
                  log = integer(0, default = 0)) {
      returnType(double(0))

      # Number of small areas
      NMuni <- dim(x)[1]
      # Number of distinct pairs of neighbors
      NDist <- dim(from.to)[1]
      # Required vectors
      x.from <- nimNumeric(NDist)
      x.to <- nimNumeric(NDist)
      for (Dist in 1:NDist) {
        x.from[Dist] <- x[from.to[Dist, 1]]
        x.to[Dist] <- x[from.to[Dist, 2]]
      }

      logDens <- sum(dnorm(x[1:NMuni], mean = 0, sd = sd.theta * pow(1 - rho, -1/2), log = TRUE))
      ← -
      NMuni/2 * log(1 - rho) + 1/2 * sum(log(rho * (Lambda[1:NMuni] - 1) + 1)) -
      1/2 * pow(sd.theta, -2) * rho * sum(pow(x.from[1:NDist] - x.to[1:NDist], 2))
      if(log) return(logDens)
      else return(exp(logDens))
    }
  )

  rcar_leroux <- nimbleFunction(
    name = 'rcar_leroux',
    run = function(n = integer(0),
                  rho = double(0),
                  sd.theta = double(0),
                  Lambda = double(1),
                  from.to = double(2)) {
      returnType(double(1))

      nimStop("user-defined distribution dcar_leroux provided without random generation
              → function.")
      x <- nimNumeric(542)
      return(x)
    }
  )

  assign('dcar_leroux', dcar_leroux, envir = .GlobalEnv)
  assign('rcar_leroux', rcar_leroux, envir = .GlobalEnv)

  NSex <- constants$NSex
  NAges <- constants$NAges
  NCats <- constants$NCats
  ones <- constants$ones
}

```

```

NResp <- constants$NResp
NMuni <- constants$NMuni
NVars <- constants$NVars

# Let's create the Nimble model, creates the nodes (inits should be passed now)
model <- nimbleModel(code = code,
                      constants = constants,
                      data = data,
                      inits = list(delta = array(rdirichlet(NSex * NAgés * NVars, ones),
                                                 dim = c(NSex, NAgés, NVars, NCats)),
                                   rho = runif(NVars),
                                   sub.Resp = matrix(rnorm(NResp * NVars, sd = 0.01), nrow =
                                     ↪ NResp, ncol = NVars),
                                   M.Resp = matrix(rnorm(NVars * NVars, sd = 0.5), ncol = NVars,
                                     ↪ nrow = NVars),
                                   sd.M.Resp = runif(1, min = 0.2, max = 0.8),
                                   sub.Muni = matrix(rnorm(NMuni * NVars, sd = 0.01), nrow =
                                     ↪ NMuni, ncol = NVars),
                                   M.Muni = matrix(rnorm(NVars * NVars, sd = 0.5), ncol = NVars,
                                     ↪ nrow = NVars),
                                   sd.M.Muni = runif(1, min = 0.2, max = 0.8)),
                      calculate = FALSE)

# Compile the model, which means generating C++ code, compiling that code, and loading it back
↪ into R
Cmodel <- compileNimble(model)

# model$getParents(model$getNodeNames(dataOnly = TRUE), stochOnly = TRUE)

# Configuration
modelMCMCconfiguration <- configureMCMC(model, useConjugacy = FALSE,
                                             enableWAIC = TRUE)

# Remove desire samplers
modelMCMCconfiguration$removeSamplers(c("sub.Muni", "rho", "sd.M.Muni",
                                         "sd.M.Resp"))

# Add slice/RW-MH sub.Muni[1:NMuni, 1:NVars] samplers
sub.Munis <- matrix(nrow = NMuni, ncol = NVars)
for (Var in 1:NVars) {
  for (Muni in 1:NMuni) {
    sub.Munis[Muni, Var] <- paste0("sub.Muni[", Muni, ", ", Var, "]")
  }
}

smuni <- sort(unique(constants$muni))
for (Var in 1:NVars) {
  for (Muni in 1:NMuni) {
    ifelse(Muni %in% smuni,
           modelMCMCconfiguration$addSampler(target = sub.Munis[Muni, Var], type = "RW"),
           modelMCMCconfiguration$addSampler(target = sub.Munis[Muni, Var], type = "RW"))
  }
}

# Add slice rho sampler
rhos <- character(NVars)
for (Var in 1:NVars) {
  rhos[Var] <- paste0("rho[", Var, "]")
}

```

```

for (Var in 1:NVars) {
  modelMCMCconfiguration$addSampler(target = rhos[Var], type = "slice")
}

# Add slice sd.M.Muni and sd.M.Resp samplers
modelMCMCconfiguration$addSampler(target = "sd.M.Resp", type = "slice")
modelMCMCconfiguration$addSampler(target = "sd.M.Muni", type = "slice")

# Add new monitors
modelMCMCconfiguration$monitors <- c()
modelMCMCconfiguration$addMonitors(monitors)
# Build MCMC object
modelMCMC <- buildMCMC(modelMCMCconfiguration)
# Need to reset the nimbleFunctions in order to add the new MCMC
CmodelMCMC <- compileNimble(modelMCMC, project = model,
                               resetFunctions = TRUE)

# Results
results <- runMCMC(CmodelMCMC, niter = 8000, nburnin = 2000, thin = 30, setSeed = X)

return(results)
}

# system.time(salnimble <- parLapply(cl = this_cluster, X = 1:n.chains,
#                                     fun = run_MCMC_allcode,
#                                     code = modelCode,
#                                     constants = modelConstants,
#                                     data = modelData,
#                                     monitors = modelParameters))
#
# # It's good practice to close the cluster when you're done with it.
# stopCluster(this_cluster)

# 14.42h on a server with: niter = 8000, nburnin = 2000, thin = 30
# saveRDS(salnimble, file = file.path("results",
#                                     "multi-2022-nimble-MH-corr-ire-8k-2k-30-WAIC.rds"))
salnimble3 <- readRDS(file = file.path("../", "results",
                                         "multi-2022-nimble-MH-corr-ire-8k-2k-30-WAIC.rds"))

# WAIC for Model-Correlation
# Let's create the Nimble model, creates the nodes
modelWAIC <- nimbleModel(code = modelCode,
                           constants = modelConstants,
                           data = modelData,
                           inits = list(delta = array(rdirichlet(NSex * NAge * NVars, ones),
                                         dim = c(NSex, NAge, NVars, NCats)),
                                         rho = runif(NVars),
                                         sub.Resp = matrix(rnorm(NResp * NVars, sd = 0.01), nrow =
                                         NResp, ncol = NVars),
                                         M.Resp = matrix(rnorm(NVars * NVars, sd = 0.5), ncol =
                                         NVars, nrow = NVars),
                                         sd.M.Resp = runif(1, min = 0.2, max = 0.8),
                                         sub.Muni = matrix(rnorm(NMuni * NVars, sd = 0.01), nrow =
                                         NMuni, ncol = NVars),
                                         M.Muni = matrix(rnorm(NVars * NVars, sd = 0.5), ncol =
                                         NVars, nrow = NVars),
                                         sd.M.Muni = runif(1, min = 0.2, max = 0.8)),
                                         calculate = FALSE)

```

```

## Defining model

## Building model

## Setting data and initial values

## Checking model sizes and dimensions

## [Warning] Possible size/dimension mismatch amongst vectors and matrices in BUGS expression: 'sub.M...
```

## [Note] This model is not fully initialized. This is not an error.  
 ## To see which variables are not initialized, use model\$initializeInfo().  
 ## For more information on model initialization, see help(modelInitialization).

```
CmodelWAIC <- compileNimble(modelWAIC)           # calculateWAIC needs compiled model to exist
```

```

## Compiling
## [Note] This may take a minute.
## [Note] Use 'showCompilerOutput = TRUE' to see C++ compilation details.
```

```
samples <- do.call(rbind, salnimble3)           # single matrix of samples
(waic <- calculateWAIC(samples, modelWAIC))
```

```

## Compiling
## [Note] This may take a minute.
## [Note] Use 'showCompilerOutput = TRUE' to see C++ compilation details.
```

```
## Calculating WAIC.
```

```

## nimbleList object of type waicNimbleList
## Field "WAIC":
## [1] 103170.1
## Field "lppd":
## [1] -36079.51
## Field "pWAIC":
## [1] 15505.53
```

## Model results

```
n.chains <- 5
labels <- c("Q1", "Q2", "Q3", "Q4", "Q5", "Q6", "Q7", "Q8", "Q9", "Q10", "Q11", "Q12")
```

Convergence assessment for Model-Indep

```

# Function: salnimble to salwinbugs for Model-Indep

NimToWin <- function(salnimble) {

  n.chains <- length(salnimble)
  n.sims <- n.chains * nrow(salnimble[[1]])

  kappa <- array(dim = c(n.sims, NSex, NAge, NCats, NVars))
  theta <- array(dim = c(n.sims, NMuni, NVars))
  rho <- matrix(nrow = n.sims, ncol = NVars)
  sd.theta <- matrix(nrow = n.sims, ncol = NVars)

  for (Var in 1:NVars) {
    for (Cat in 1:(NCats - 1)) {
      for (Sex in 1:NSex) {
        for (Age in 1:NAge) {
          kappa[, Sex, Age, Cat, Var] <- c(salnimble[[1]][, paste0("kappa[", Sex, ", ", Age, ", ",
→ " , Cat, ", ", Var, "]")], salnimble[[2]][, paste0("kappa[", Sex, ", ", Age, ", ",
→ " , Cat, ", ", Var, "]")], salnimble[[3]][, paste0("kappa[", Sex, ", ", Age, ", ",
→ " , Cat, ", ", Var, "]")], salnimble[[4]][, paste0("kappa[", Sex, ", ", Age, ", ",
→ " , Cat, ", ", Var, "]")], salnimble[[5]][, paste0("kappa[", Sex, ", ", Age, ", ",
→ " , Cat, ", ", Var, "]")])
        }
      }
    }
  }

  for (Var in 1:NVars) {
    for (Muni in 1:NMuni) {
      theta[, Muni, Var] <- c(salnimble[[1]][, paste0("theta[", Muni, ", ", Var, "]")],
                                salnimble[[2]][, paste0("theta[", Muni, ", ", Var, "]")],
                                salnimble[[3]][, paste0("theta[", Muni, ", ", Var, "]")],
                                salnimble[[4]][, paste0("theta[", Muni, ", ", Var, "]")],
                                salnimble[[5]][, paste0("theta[", Muni, ", ", Var, "]")])
    }
  }

  for (Var in 1:NVars) {
    rho[, Var] <- c(salnimble[[1]][, paste0("rho[", Var, "]")], salnimble[[2]][, paste0("rho[", Var, "]")],
                      salnimble[[3]][, paste0("rho[", Var, "]")], salnimble[[4]][, paste0("rho[", Var, "]")],
                      salnimble[[5]][, paste0("rho[", Var, ")")])
  }

  for (Var in 1:NVars) {
    sd.theta[, Var] <- c(salnimble[[1]][, paste0("sd.theta[", Var, "]")], salnimble[[2]][, paste0("sd.theta[", Var, "]")],
                           salnimble[[3]][, paste0("sd.theta[", Var, "]")], salnimble[[4]][, paste0("sd.theta[", Var, "]")],
                           salnimble[[5]][, paste0("sd.theta[", Var, ")")])
  }

  summary <- MCMCsummary(object = salnimble, round = 4)
}

```

```

# summary <- "not available"
sims.list <- list("kappa" = kappa, "theta" = theta,
                  "sd.theta" = sd.theta, "rho" = rho)

salwinbugs <- list("summary" = summary, "sims.list" = sims.list,
                     "n.chains" = n.chains, "n.sims" = n.sims)

return(salwinbugs)
}

# salwinbugs1 <- NimToWin(salnimble = salnimble1)
# saveRDS(salwinbugs1, file = file.path("results", "salwinbugs1.rds"))
salwinbugs1 <- readRDS(file = file.path("../", "results", "salwinbugs1.rds"))

which((salwinbugs1$summary[startsWith(labels(salwinbugs1$summary)[[1]], "kappa"), 6] > 1.1) |
  → (salwinbugs1$summary[startsWith(labels(salwinbugs1$summary)[[1]], "kappa"), 7] < 100))

```

```
## integer(0)
```

```

which((salwinbugs1$summary[startsWith(labels(salwinbugs1$summary)[[1]], "theta"), 6] > 1.1) |
  → (salwinbugs1$summary[startsWith(labels(salwinbugs1$summary)[[1]], "theta"), 7] < 100))

```

```
## integer(0)
```

```

which((salwinbugs1$summary[startsWith(labels(salwinbugs1$summary)[[1]], "sd.theta"), 6] > 1.1) |
  → (salwinbugs1$summary[startsWith(labels(salwinbugs1$summary)[[1]], "sd.theta"), 7] < 100))

```

```
## integer(0)
```

```

which((salwinbugs1$summary[startsWith(labels(salwinbugs1$summary)[[1]], "rho"), 6] > 1.1) |
  → (salwinbugs1$summary[startsWith(labels(salwinbugs1$summary)[[1]], "rho"), 7] < 100))

```

```
## [1] 1 12
```

```

MCMCsummary(object = salnimble1, params = "kappa",
             # exact = TRUE,
             # ISB = FALSE,
             round = 4)[1:10, ]

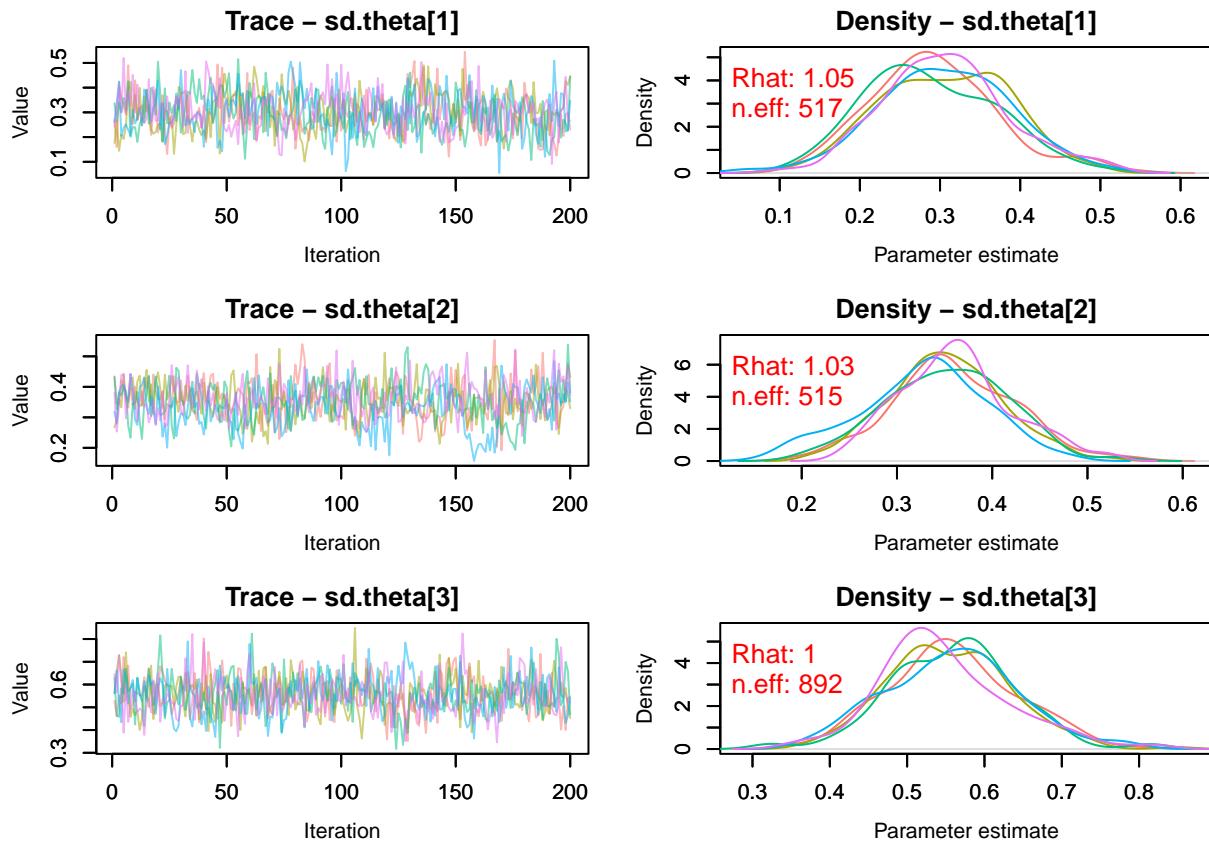
```

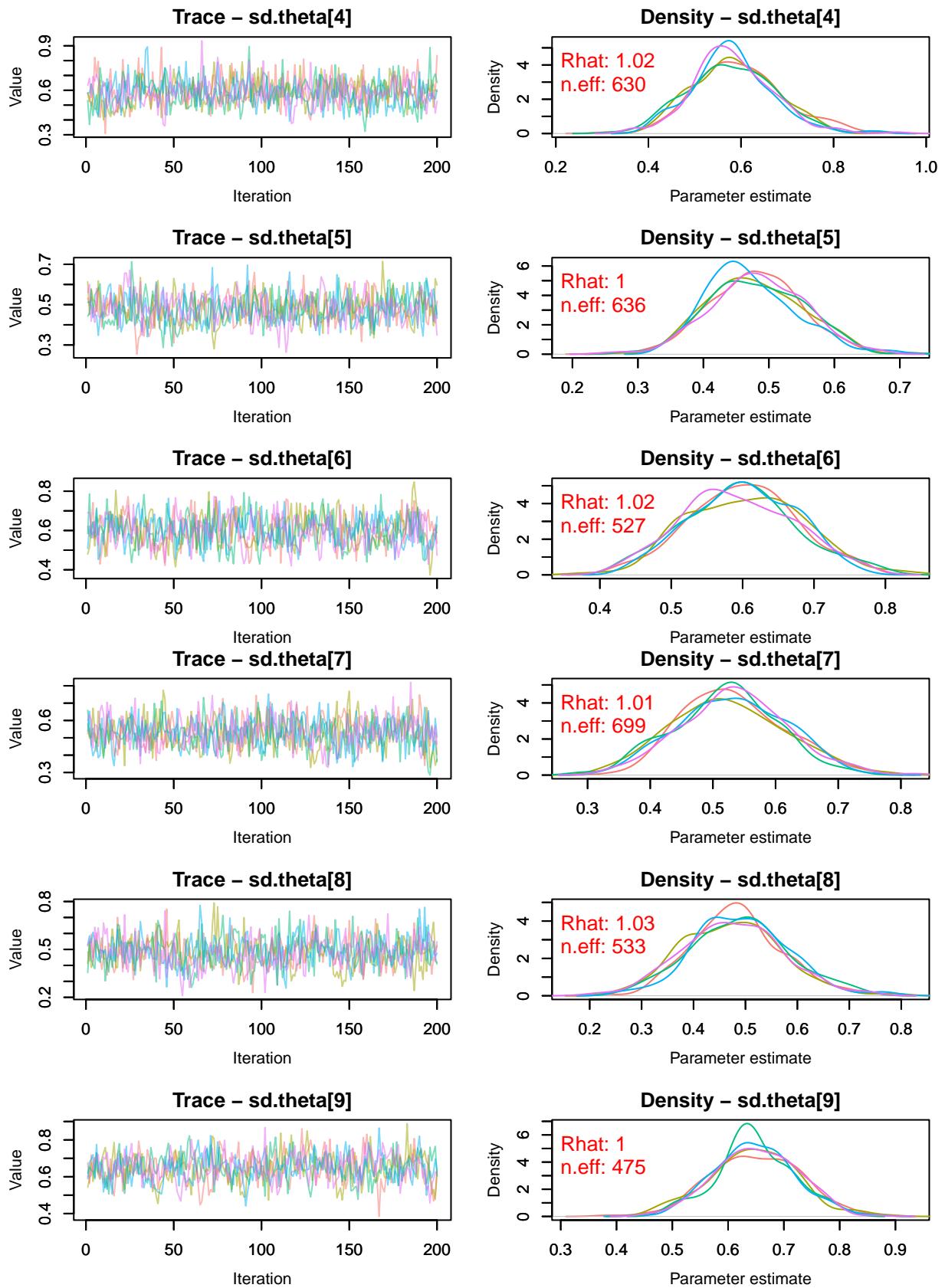
	mean	sd	2.5%	50%	97.5%	Rhat	n.eff
## kappa[1, 1, 1, 1]	-2.5754	0.1739	-2.9327	-2.5699	-2.2494	1.00	1174
## kappa[2, 1, 1, 1]	-2.3844	0.1686	-2.7289	-2.3794	-2.0781	1.00	1208
## kappa[1, 2, 1, 1]	-2.4628	0.1665	-2.7966	-2.4550	-2.1498	1.00	989
## kappa[2, 2, 1, 1]	-2.5266	0.1589	-2.8632	-2.5188	-2.2301	1.00	1000
## kappa[1, 3, 1, 1]	-2.7292	0.1533	-3.0197	-2.7199	-2.4244	1.01	1000
## kappa[2, 3, 1, 1]	-2.4652	0.1396	-2.7382	-2.4634	-2.1960	1.01	960
## kappa[1, 4, 1, 1]	-3.2979	0.1852	-3.6819	-3.2894	-2.9725	1.00	1000
## kappa[2, 4, 1, 1]	-2.8549	0.1541	-3.1922	-2.8493	-2.5666	1.00	780
## kappa[1, 5, 1, 1]	-3.1442	0.1983	-3.5294	-3.1397	-2.7843	1.01	892
## kappa[2, 5, 1, 1]	-3.1827	0.1937	-3.5774	-3.1806	-2.8277	1.01	2756

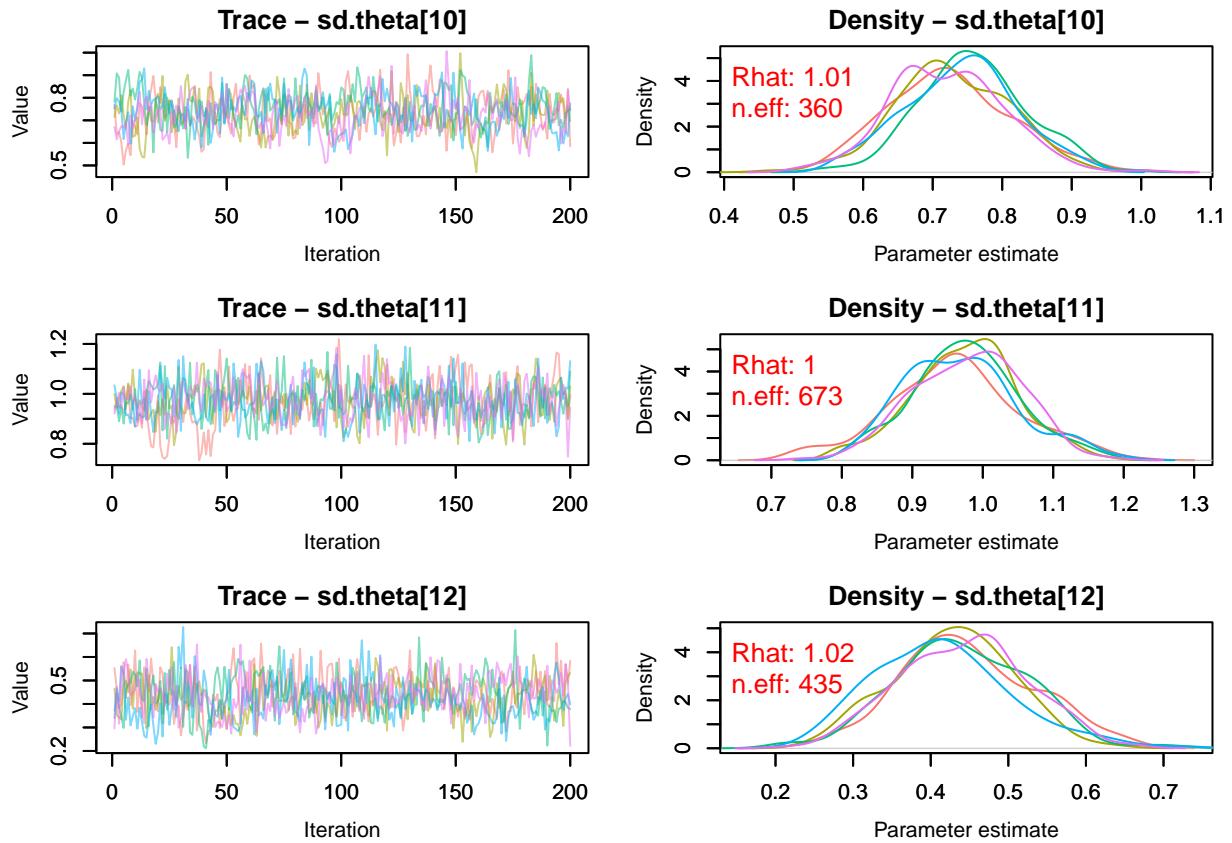
```
MCMCsummary(object = salnimble1, params = "theta",
            # exact = TRUE,
            # ISB = FALSE,
            round = 4)[1:10, ]
```

```
##               mean      sd  2.5%   50% 97.5% Rhat n.eff
## theta[1, 1] -0.0439 0.6895 -1.3864 -0.0467 1.3720 1.01 1075
## theta[2, 1]  0.0441 0.6638 -1.2400  0.0196 1.4005 1.00 1138
## theta[3, 1] -0.1012 0.6461 -1.2719 -0.1251 1.1998 1.01 1003
## theta[4, 1]  0.3868 0.6811 -1.0585  0.4176 1.5716 1.01  953
## theta[5, 1] -0.2265 0.5726 -1.3945 -0.2280 0.9430 1.02 1077
## theta[6, 1]  0.0715 0.5737 -1.0723  0.0555 1.1740 1.00 1000
## theta[7, 1] -0.0266 0.7226 -1.4569 -0.0339 1.3666 1.00  953
## theta[8, 1]  0.0445 0.7412 -1.4635  0.0331 1.5323 1.02 1055
## theta[9, 1]  0.3294 0.4231 -0.4975  0.3266 1.1545 1.02 1012
## theta[10, 1] -0.1043 0.7396 -1.5696 -0.1314 1.3917 1.00  956
```

```
MCMCtrace(object = salnimble1,
           pdf = FALSE, # no export to PDF
           ind = TRUE, # separate density lines per chain
           Rhat = TRUE,
           n.eff = TRUE,
           params = "sd.theta")
```

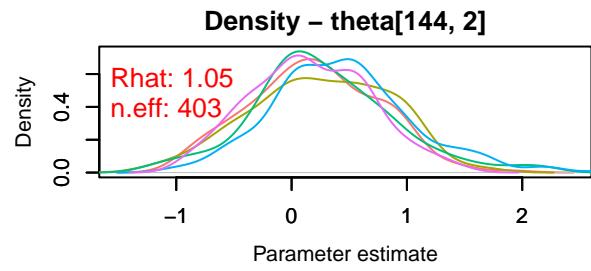
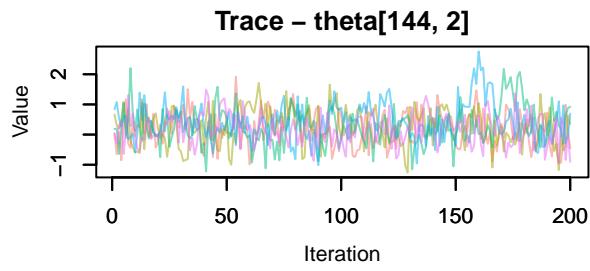
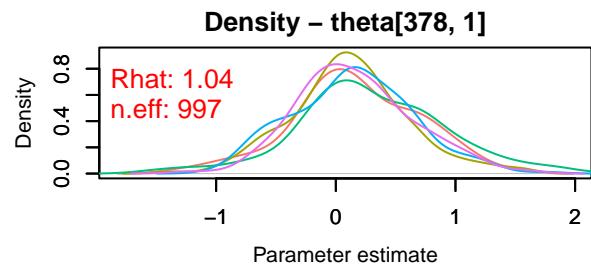
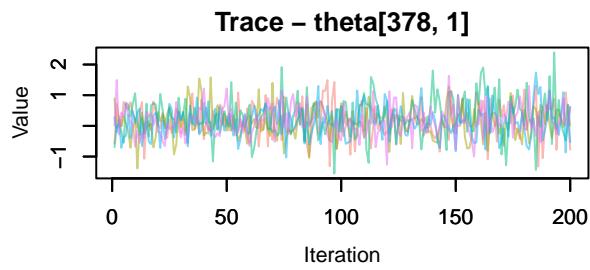
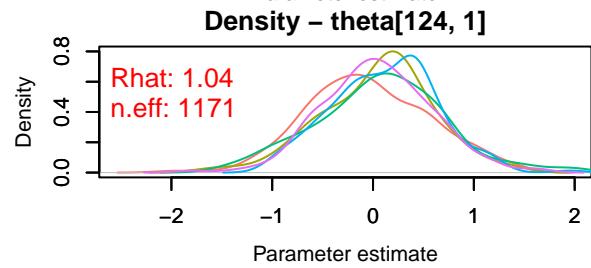
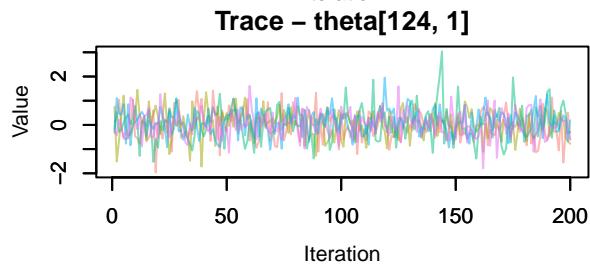
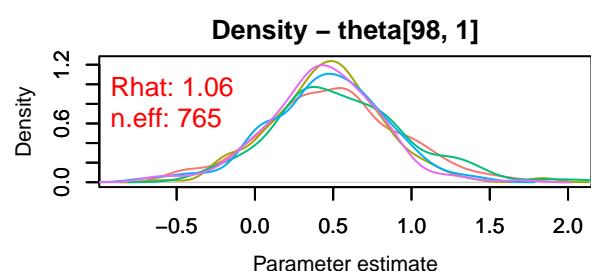
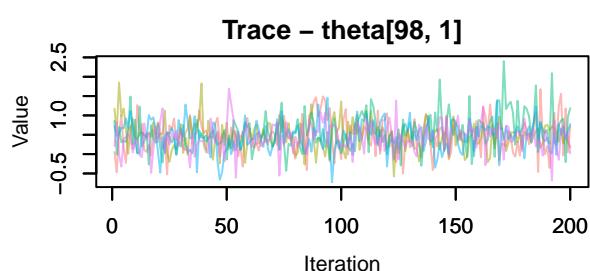
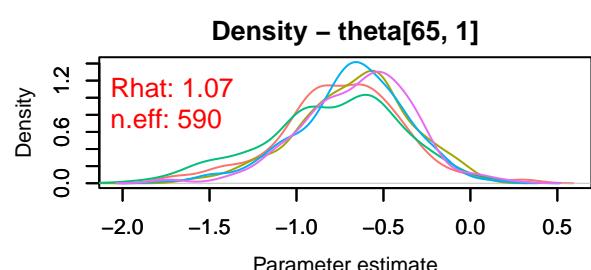
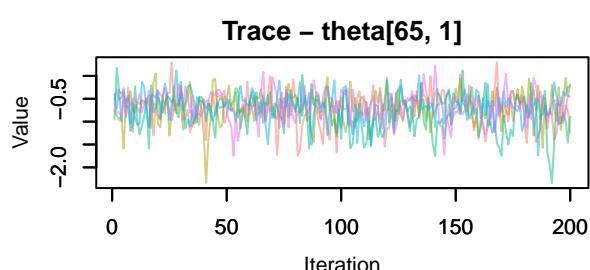
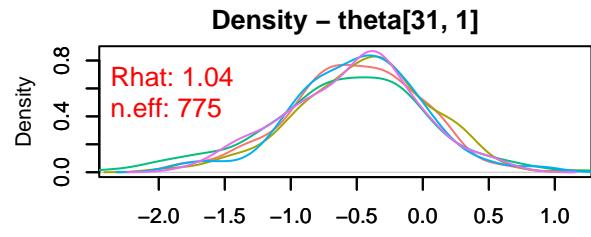
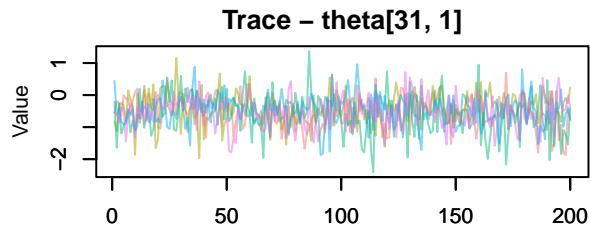


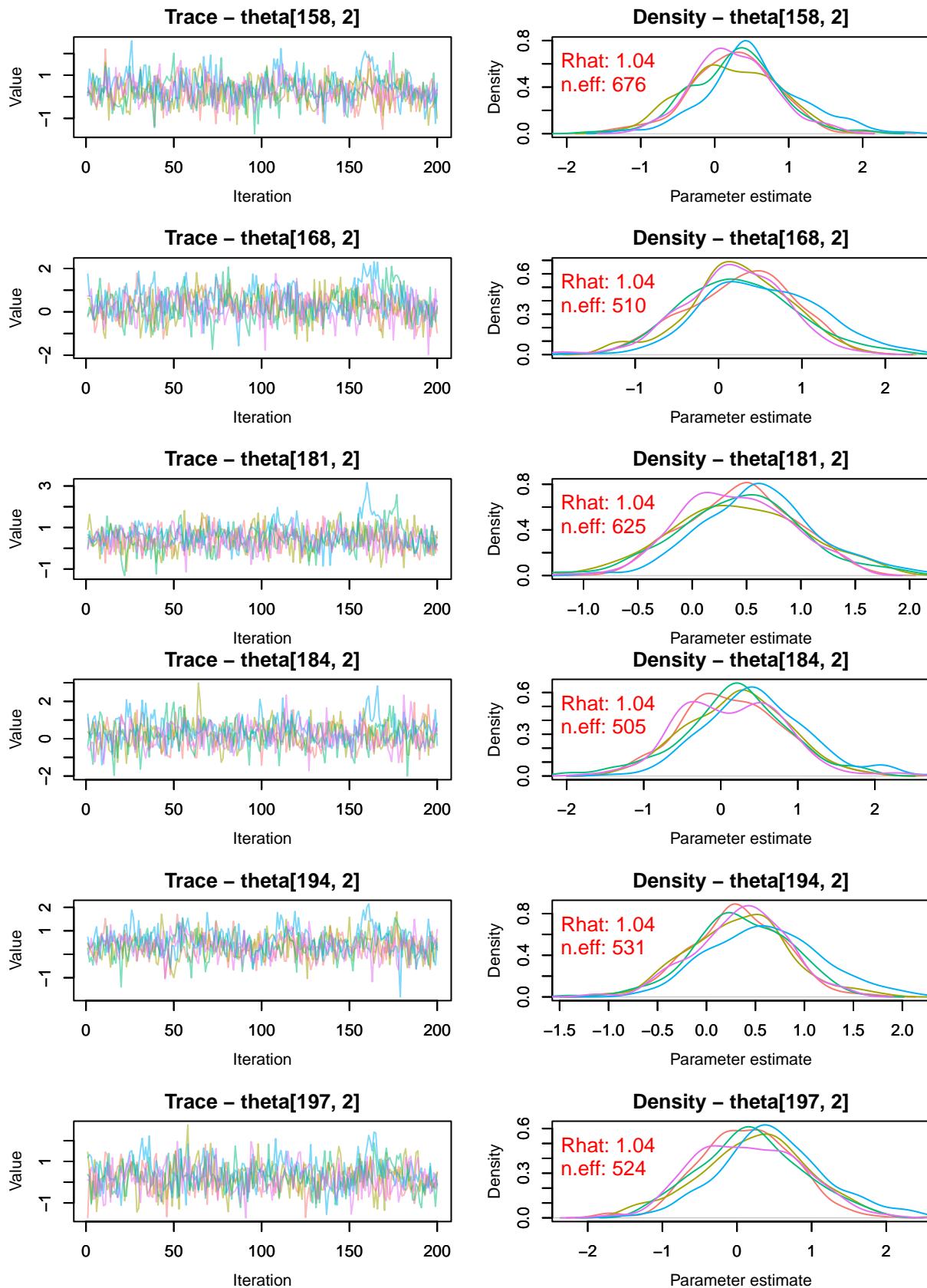


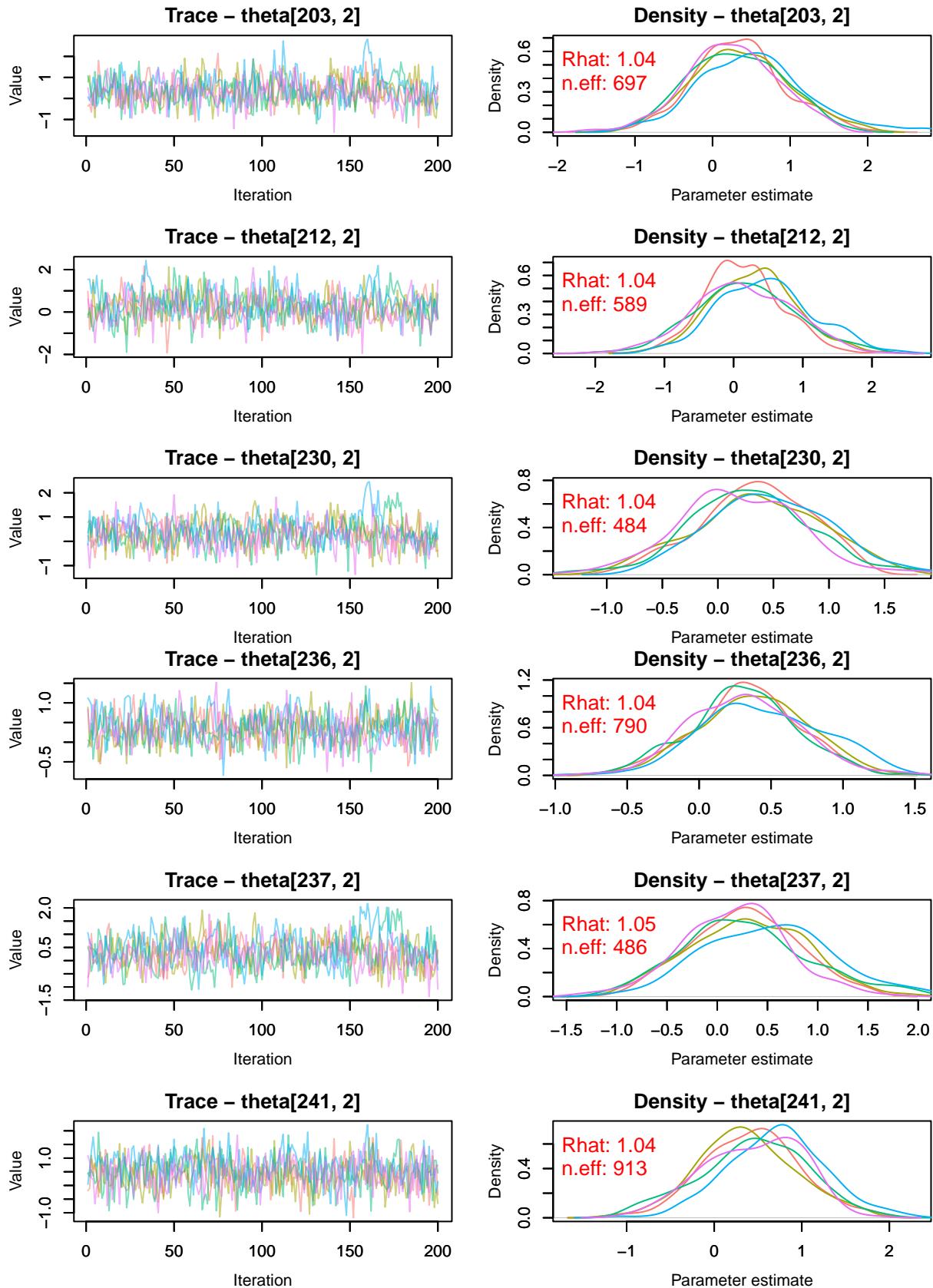


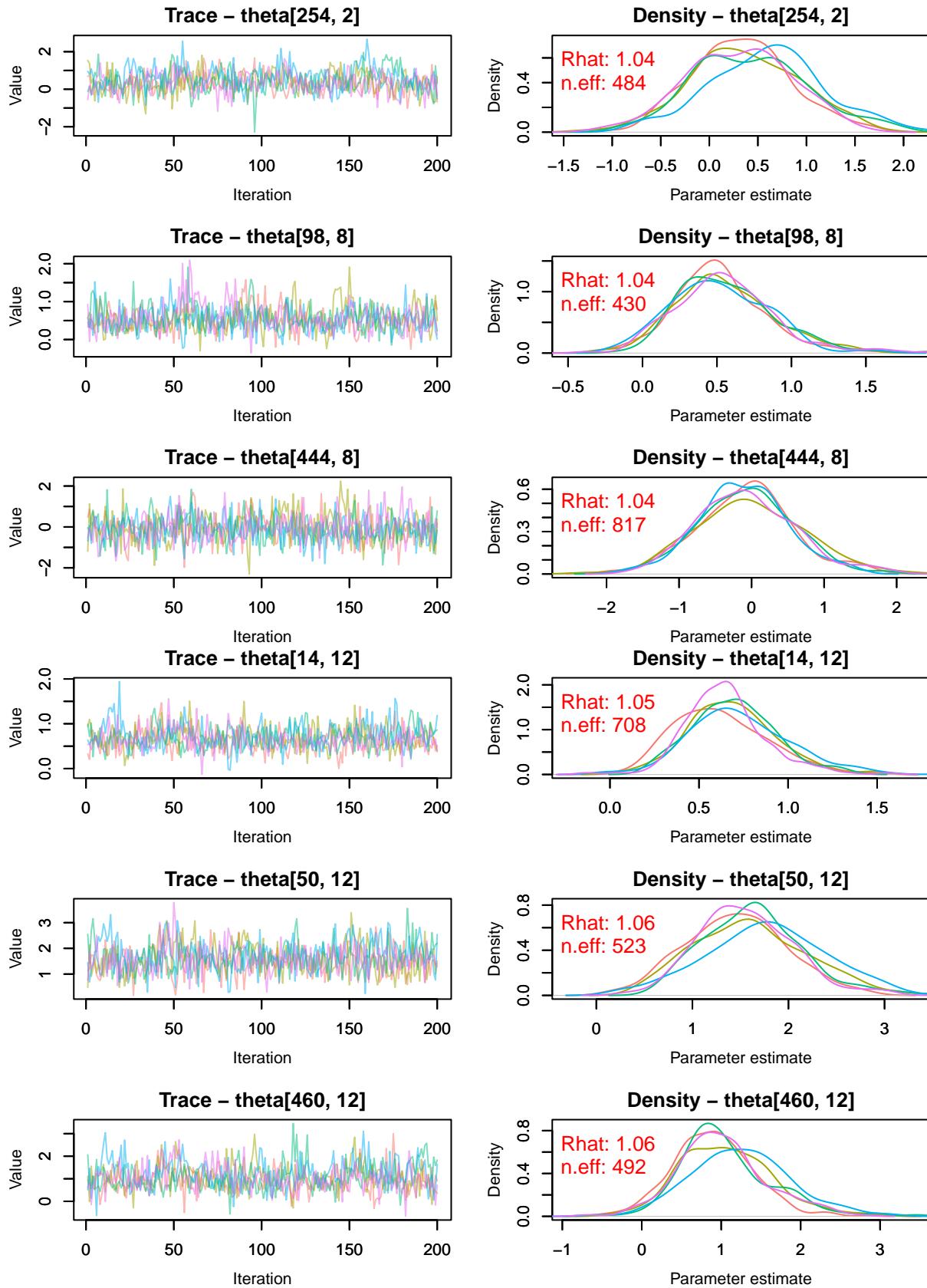
```
test <- "theta"

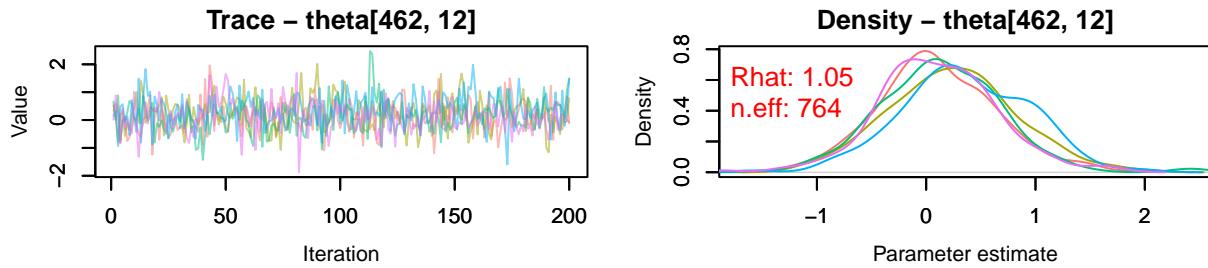
MCMCtrace(object = salnimble1,
            pdf = FALSE, # no export to PDF
            ind = TRUE, # separate density lines per chain
            Rhat = TRUE,
            n.eff = TRUE,
            exact = TRUE,
            ISB = FALSE,
            params = rownames(salwinbugs1$summary[startsWith(labels(salwinbugs1$summary)[[1]], 
            test), ])[(salwinbugs1$summary[startsWith(labels(salwinbugs1$summary)[[1]], test),
            6] > 1.03) | (salwinbugs1$summary[startsWith(labels(salwinbugs1$summary)[[1]], test),
            7] < 200])]
```











## Convergence assessment for Model-Corr

```
# Function: salnimble to salwinbugs for Model-Corr

NimToWin <- function(salnimble) {

  n.chains <- length(salnimble)
  n.sims <- n.chains * nrow(salnimble[[1]])

  kappa <- array(dim = c(n.sims, NSex, NAge, NCats, NVars))
  theta <- array(dim = c(n.sims, NMuni, NVars))
  sd.M.Muni <- numeric(length = n.sims)
  M.Muni <- array(dim = c(n.sims, NVars, NVars))
  rho <- matrix(nrow = n.sims, ncol = NVars)

  for (Var in 1:NVars) {
    for (Cat in 1:(NCats - 1)) {
      for (Sex in 1:NSex) {
        for (Age in 1:NAge) {
          kappa[, Sex, Age, Cat, Var] <- c(salnimble[[1]][, paste0("kappa[", Sex, ", ", Age, ", ",
          " , Cat, ", " , Var, "]")], salnimble[[2]][, paste0("kappa[", Sex, ", ", Age, ", ",
          " , Cat, ", " , Var, "]")], salnimble[[3]][, paste0("kappa[", Sex, ", ", Age, ", ",
          " , Cat, ", " , Var, "]")], salnimble[[4]][, paste0("kappa[", Sex, ", ", Age, ", ",
          " , Cat, ", " , Var, "]")], salnimble[[5]][, paste0("kappa[", Sex, ", ", Age, ", ",
          " , Cat, ", " , Var, "]")])
        }
      }
    }
  }

  for (Var in 1:NVars) {
    for (Muni in 1:NMuni) {
      theta[, Muni, Var] <- c(salnimble[[1]][, paste0("theta[", Muni, ", ", Var, "]")],
        salnimble[[2]][, paste0("theta[", Muni, ", ", Var, "]")], salnimble[[3]][, paste0("theta[",
        Muni, ", ", Var, "]")], salnimble[[4]][, paste0("theta[", Muni, ", ", Var, "]")],
        salnimble[[5]][, paste0("theta[", Muni, ", ", Var, "]")])
    }
  }

  sd.M.Muni <- c(salnimble[[1]][, "sd.M.Muni"], salnimble[[2]][, "sd.M.Muni"],
    salnimble[[3]][, "sd.M.Muni"], salnimble[[4]][, "sd.M.Muni"],
    salnimble[[5]][, "sd.M.Muni"])
}
```

```

for (Var1 in 1:NVars) {
  for (Var2 in 1:NVars) {
    M.Muni[, Var1, Var2] <- c(salnimble[[1]][, paste0("M.Muni[", Var1, ", ", Var2, "]\")],
                                salnimble[[2]][, paste0("M.Muni[", Var1, ", ", Var2, "]\")],
                                salnimble[[3]][, paste0("M.Muni[", Var1, ", ", Var2, "]\")],
                                salnimble[[4]][, paste0("M.Muni[", Var1, ", ", Var2, "]\")],
                                salnimble[[5]][, paste0("M.Muni[", Var1, ", ", Var2, "]\")])
  }
}

for (Var in 1:NVars) {
  rho[, Var] <- c(salnimble[[1]][, paste0("rho[", Var, "]\")],
                    salnimble[[2]][, paste0("rho[", Var, "]\")],
                    salnimble[[3]][, paste0("rho[", Var, "]\")],
                    salnimble[[4]][, paste0("rho[", Var, "]\")],
                    salnimble[[5]][, paste0("rho[", Var, "]\")])
}

summary <- MCMCsummary(object = salnimble, round = 4)
# summary <- "not available"
sims.list <- list("kappa" = kappa, "theta" = theta, "sd.M.Muni" = sd.M.Muni,
                  "M.Muni" = M.Muni, "rho" = rho)

salwinbugs <- list("summary" = summary, "sims.list" = sims.list,
                     "n.chains" = n.chains, "n.sims" = n.sims)

return(salwinbugs)
}

# salwinbugs2 <- NimToWin(salnimble = salnimble2)
# saveRDS(salwinbugs2, file = file.path("results", "salwinbugs2.rds"))
salwinbugs2 <- readRDS(file = file.path("../", "results", "salwinbugs2.rds"))

which((salwinbugs2$summary[startsWith(labels(salwinbugs2$summary)[[1]], "kappa"), 6] > 1.1) |
  → (salwinbugs2$summary[startsWith(labels(salwinbugs2$summary)[[1]], "kappa"), 7] < 100))

```

```
## integer(0)
```

```
which((salwinbugs2$summary[startsWith(labels(salwinbugs2$summary)[[1]], "sd.M.Muni"), 6] > 1.1)
  → | (salwinbugs2$summary[startsWith(labels(salwinbugs2$summary)[[1]], "sd.M.Muni"), 7] < 100))
```

```
## integer(0)
```

```
which((salwinbugs2$summary[startsWith(labels(salwinbugs2$summary)[[1]], "theta"), 6] > 1.1) |
  → (salwinbugs2$summary[startsWith(labels(salwinbugs2$summary)[[1]], "theta"), 7] < 100))
```

```
## integer(0)
```

```
MCMCsummary(object = salnimble2, params = "kappa",
             # exact = TRUE,
             # ISB = FALSE,
             round = 4)[1:10, ]
```

```

##               mean      sd    2.5%   50%  97.5% Rhat n.eff
## kappa[1, 1, 1, 1] -2.6112 0.1731 -2.9459 -2.6110 -2.2738 1.01 1058
## kappa[2, 1, 1, 1] -2.3826 0.1647 -2.7222 -2.3787 -2.0768 1.01 861
## kappa[1, 2, 1, 1] -2.4966 0.1690 -2.8469 -2.4918 -2.1651 1.00 982
## kappa[2, 2, 1, 1] -2.5389 0.1684 -2.8639 -2.5331 -2.2225 1.00 1046
## kappa[1, 3, 1, 1] -2.7670 0.1606 -3.0860 -2.7713 -2.4757 1.01 1020
## kappa[2, 3, 1, 1] -2.4918 0.1441 -2.7835 -2.4894 -2.2361 1.00 1000
## kappa[1, 4, 1, 1] -3.3326 0.1989 -3.7429 -3.3224 -2.9798 1.01 960
## kappa[2, 4, 1, 1] -2.9040 0.1578 -3.2336 -2.9044 -2.6051 1.01 1000
## kappa[1, 5, 1, 1] -3.1721 0.1934 -3.5596 -3.1598 -2.8165 1.01 926
## kappa[2, 5, 1, 1] -3.2198 0.1860 -3.5956 -3.2112 -2.8751 1.01 1046

```

```

MCMCsummary(object = salnimble2, params = "theta",
             # exact = TRUE,
             # ISB = FALSE,
             round = 4)[1:10, ]

```

```

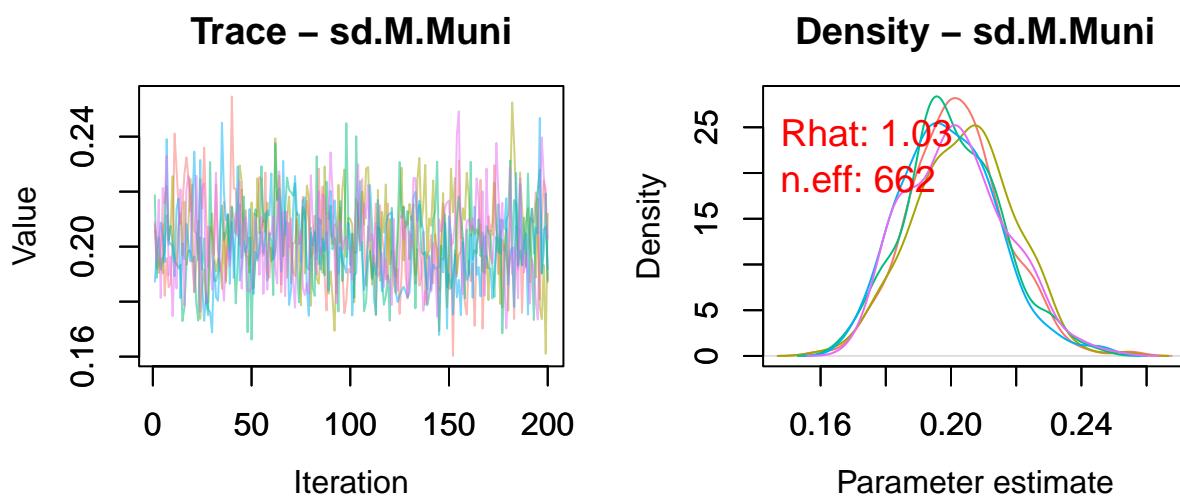
##               mean      sd    2.5%   50%  97.5% Rhat n.eff
## theta[1, 1]    0.0150 0.4553 -0.8817  0.0201 0.9334 1.01 1000
## theta[2, 1]   -0.3297 0.2982 -0.9045 -0.3354 0.2538 1.01 945
## theta[3, 1]   -0.0762 0.4359 -0.8942 -0.0900 0.7585 1.00 953
## theta[4, 1]   -0.1383 0.3822 -0.9428 -0.1223 0.5782 1.00 1000
## theta[5, 1]   -0.1882 0.1914 -0.5586 -0.1828 0.1905 1.00 1088
## theta[6, 1]    0.0630 0.3232 -0.5488  0.0655 0.6981 1.00 1011
## theta[7, 1]    0.0570 0.4576 -0.8418  0.0560 0.9570 1.00 1138
## theta[8, 1]   -0.0498 0.4168 -0.9187 -0.0486 0.7417 1.00  955
## theta[9, 1]    0.0888 0.1247 -0.1581  0.0906 0.3315 1.01 1123
## theta[10, 1]   -0.0414 0.4793 -0.9397 -0.0442 0.9253 1.00  962

```

```

MCMCtrace(object = salnimble2,
           pdf = FALSE, # no export to PDF
           ind = TRUE, # separate density lines per chain
           Rhat = TRUE,
           n.eff = TRUE,
           params = "sd.M.Muni")

```

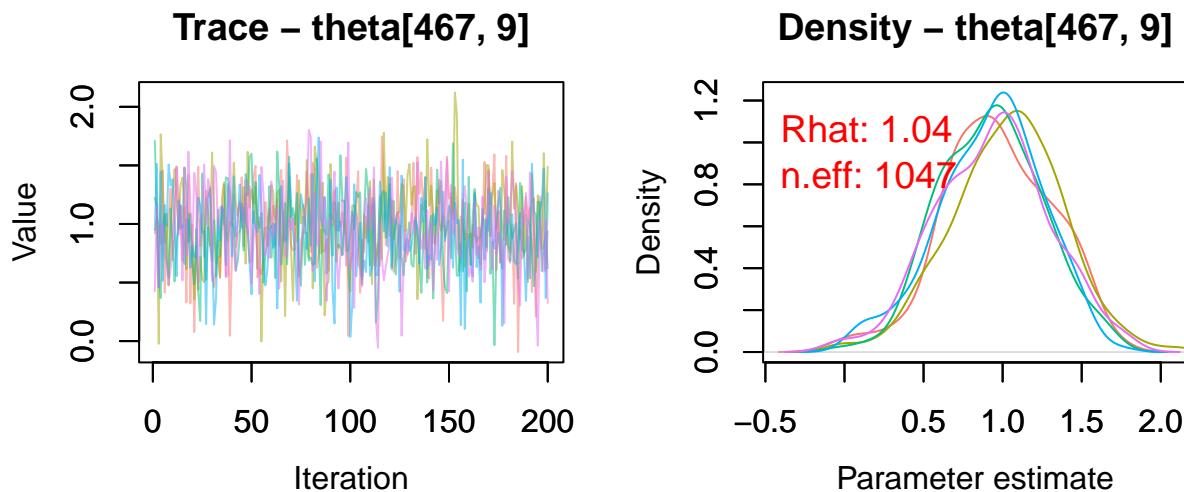


```

test <- "theta"

MCMCtrace(object = salnimble2,
            pdf = FALSE, # no export to PDF
            ind = TRUE, # separate density lines per chain
            Rhat = TRUE,
            n.eff = TRUE,
            exact = TRUE,
            ISB = FALSE,
            params = rownames(salwinbugs2$summary[startsWith(labels(salwinbugs2$summary)[[1]], test), ])[(salwinbugs2$summary[startsWith(labels(salwinbugs2$summary)[[1]], test), 6] > 1.03) | (salwinbugs2$summary[startsWith(labels(salwinbugs2$summary)[[1]], test), 7] < 200)])

```



### Convergence assessment for Model-Corr&IRE

```

# Function: salnimble to salwinbugs for Model-Corr&IRE

NimToWin <- function(salnimble) {

  n.chains <- length(salnimble)
  n.sims <- n.chains * nrow(salnimble[[1]])

  kappa <- array(dim = c(n.sims, NSex, NAges, NCats, NVars))
  psi <- array(dim = c(n.sims, NResp, NVars))
  sd.M.Resp <- numeric(length = n.sims)
  M.Resp <- array(dim = c(n.sims, NVars, NVars))
  theta <- array(dim = c(n.sims, NMuni, NVars))
  sd.M.Muni <- numeric(length = n.sims)
  M.Muni <- array(dim = c(n.sims, NVars, NVars))
  rho <- matrix(nrow = n.sims, ncol = NVars)

  for (Var in 1:NVars) {
    for (Cat in 1:(NCats - 1)) {
      for (Sex in 1:NSex) {
        for (Age in 1:NAges) {
          kappa[, Sex, Age, Cat, Var] <- c(salnimble[[1]][, paste0("kappa[", Sex, ", ", Age, ", ", Cat, ", ", Var, "]")],
```

```

    salnimble[[2]][, paste0("kappa[", Sex, ", ", Age, ",
    salnimble[[3]][, paste0("kappa[", Sex, ", ", Age, ",
    salnimble[[4]][, paste0("kappa[", Sex, ", ", Age, ",
    salnimble[[5]][, paste0("kappa[", Sex, ", ", Age, ",

    ", Cat, ", ", Var, "])"],
    ", Cat, ", ", Var, "])],
    ", Cat, ", ", Var, "])],
    ", Cat, ", ", Var, "])])
    ", Cat, ", ", Var, "])])
  }
}

for (Var in 1:NVars) {
  for (Resp in 1:NResp) {
    psi[, Resp, Var] <- c(salnimble[[1]][, paste0("psi[", Resp, ", ", Var, "])],
    salnimble[[2]][, paste0("psi[", Resp, ", ", Var, "])],
    salnimble[[3]][, paste0("psi[", Resp, ", ", Var, "])],
    salnimble[[4]][, paste0("psi[", Resp, ", ", Var, "])],
    salnimble[[5]][, paste0("psi[", Resp, ", ", Var, ")])]
  }
}

sd.M.Resp <- c(salnimble[[1]][, "sd.M.Resp"], salnimble[[2]][, "sd.M.Resp"],
  salnimble[[3]][, "sd.M.Resp"], salnimble[[4]][, "sd.M.Resp"],
  salnimble[[5]][, "sd.M.Resp"])

for (Var1 in 1:NVars) {
  for (Var2 in 1:NVars) {
    M.Resp[, Var1, Var2] <- c(salnimble[[1]][, paste0("M.Resp[", Var1, ", ", Var2, "])],
      salnimble[[2]][, paste0("M.Resp[", Var1, ", ", Var2, "])],
      salnimble[[3]][, paste0("M.Resp[", Var1, ", ", Var2, "])],
      salnimble[[4]][, paste0("M.Resp[", Var1, ", ", Var2, "])],
      salnimble[[5]][, paste0("M.Resp[", Var1, ", ", Var2, ")])]
  }
}

for (Var in 1:NVars) {
  for (Muni in 1:NMuni) {
    theta[, Muni, Var] <- c(salnimble[[1]][, paste0("theta[", Muni, ", ", Var, "])],
      salnimble[[2]][, paste0("theta[", Muni, ", ", Var, "])],
      salnimble[[3]][, paste0("theta[", Muni, ", ", Var, "])],
      salnimble[[4]][, paste0("theta[", Muni, ", ", Var, "])],
      salnimble[[5]][, paste0("theta[", Muni, ", ", Var, ")])]
  }
}

sd.M.Muni <- c(salnimble[[1]][, "sd.M.Muni"], salnimble[[2]][, "sd.M.Muni"],
  salnimble[[3]][, "sd.M.Muni"], salnimble[[4]][, "sd.M.Muni"],
  salnimble[[5]][, "sd.M.Muni"])

for (Var1 in 1:NVars) {
  for (Var2 in 1:NVars) {
    M.Muni[, Var1, Var2] <- c(salnimble[[1]][, paste0("M.Muni[", Var1, ", ", Var2, "])],
      salnimble[[2]][, paste0("M.Muni[", Var1, ", ", Var2, "])],
      salnimble[[3]][, paste0("M.Muni[", Var1, ", ", Var2, "])],
      salnimble[[4]][, paste0("M.Muni[", Var1, ", ", Var2, "])],
      salnimble[[5]][, paste0("M.Muni[", Var1, ", ", Var2, ")])]
  }
}

```

```

}

for (Var in 1:NVars) {
  rho[, Var] <- c(salnimble[[1]][, paste0("rho[", Var, "]")],
    salnimble[[2]][, paste0("rho[", Var, "]")],
    salnimble[[3]][, paste0("rho[", Var, "]")],
    salnimble[[4]][, paste0("rho[", Var, "]")],
    salnimble[[5]][, paste0("rho[", Var, "]"))]
}

summary <- MCMCsummary(object = salnimble, round = 4)
# summary <- "not available"
sims.list <- list("kappa" = kappa, "theta" = theta, "M.Muni" = M.Muni,
  "rho" = rho, "sd.M.Muni" = sd.M.Muni, "psi" = psi,
  "sd.M.Resp" = sd.M.Resp, "M.Resp" = M.Resp)

salwinbugs <- list("summary" = summary, "sims.list" = sims.list,
  "n.chains" = n.chains, "n.sims" = n.sims)

return(salwinbugs)
}

# salwinbugs3 <- NimToWin(salnimble = salnimble3)
# saveRDS(salwinbugs3, file = file.path("results", "salwinbugs3.rds"))
salwinbugs3 <- readRDS(file = file.path("../", "results", "salwinbugs3.rds"))

which((salwinbugs3$summary[startsWith(labels(salwinbugs3$summary)[[1]], "kappa"), 6] > 1.1) |
  (salwinbugs3$summary[startsWith(labels(salwinbugs3$summary)[[1]], "kappa"), 7] < 100))

```

```
## integer(0)
```

```
which((salwinbugs3$summary[startsWith(labels(salwinbugs3$summary)[[1]], "sd.M.Muni"), 6] > 1.1)
  | (salwinbugs3$summary[startsWith(labels(salwinbugs3$summary)[[1]], "sd.M.Muni"), 7] < 100))
```

```
## integer(0)
```

```
which((salwinbugs3$summary[startsWith(labels(salwinbugs3$summary)[[1]], "theta"), 6] > 1.1) |
  (salwinbugs3$summary[startsWith(labels(salwinbugs3$summary)[[1]], "theta"), 7] < 100))
```

```
## integer(0)
```

```
which((salwinbugs3$summary[startsWith(labels(salwinbugs3$summary)[[1]], "sd.M.Resp"), 6] > 1.1)
  | (salwinbugs3$summary[startsWith(labels(salwinbugs3$summary)[[1]], "sd.M.Resp"), 7] < 100))
```

```
## integer(0)
```

```
which((salwinbugs3$summary[startsWith(labels(salwinbugs3$summary)[[1]], "psi"), 6] > 1.1) |
  (salwinbugs3$summary[startsWith(labels(salwinbugs3$summary)[[1]], "psi"), 7] < 100))
```

```
## integer(0)
```

```
MCMCsummary(object = salnimble3, params = "kappa",
            # exact = TRUE,
            # ISB = FALSE,
            round = 4)[1:10, ]
```

```
##               mean      sd    2.5%    50%   97.5% Rhat n.eff
## kappa[1, 1, 1, 1] -4.0030 0.2768 -4.5731 -4.0036 -3.4708 1.00 1003
## kappa[2, 1, 1, 1] -3.7967 0.2473 -4.2924 -3.7924 -3.3261 1.00  970
## kappa[1, 2, 1, 1] -3.9218 0.2430 -4.4046 -3.9187 -3.4581 1.01 1445
## kappa[2, 2, 1, 1] -3.8904 0.2363 -4.3534 -3.8956 -3.4216 1.00  988
## kappa[1, 3, 1, 1] -4.2577 0.2305 -4.6876 -4.2617 -3.8036 1.01 1111
## kappa[2, 3, 1, 1] -3.8801 0.2070 -4.2995 -3.8756 -3.4905 1.00  965
## kappa[1, 4, 1, 1] -4.9890 0.2604 -5.5495 -4.9876 -4.5058 1.00  944
## kappa[2, 4, 1, 1] -4.2869 0.2238 -4.7612 -4.2826 -3.8899 1.00  934
## kappa[1, 5, 1, 1] -4.7905 0.2562 -5.2968 -4.7829 -4.3253 1.00 1097
## kappa[2, 5, 1, 1] -4.7581 0.2590 -5.2821 -4.7522 -4.2430 1.00 1000
```

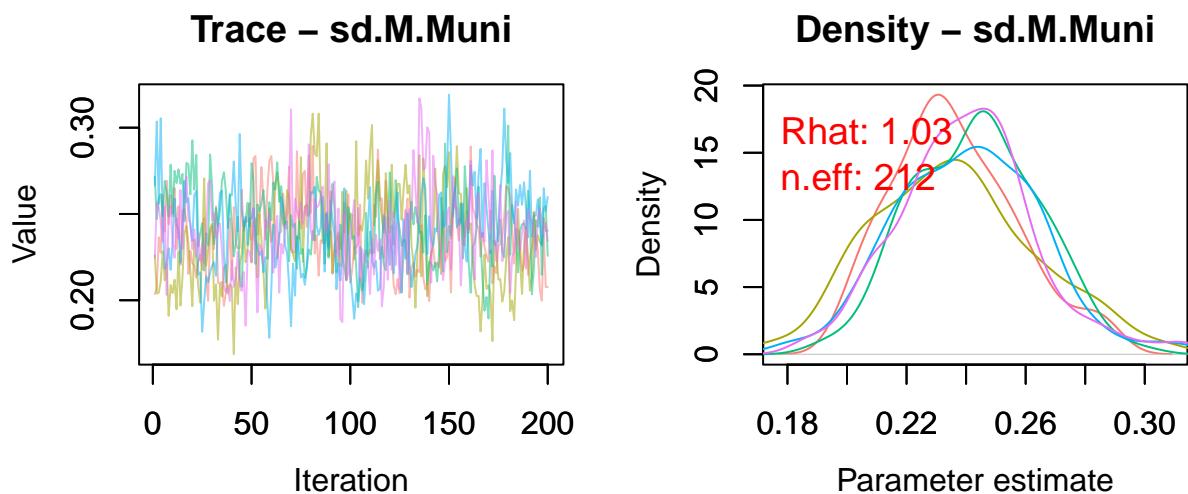
```
MCMCsummary(object = salnimble3, params = "theta",
            # exact = TRUE,
            # ISB = FALSE,
            round = 4)[1:10, ]
```

```
##               mean      sd    2.5%    50%   97.5% Rhat n.eff
## theta[1, 1]  -0.0448 0.2911 -0.6366 -0.0442 0.5428 1.00 1084
## theta[2, 1]  -0.0203 0.2791 -0.5612 -0.0281 0.5374 1.00 1443
## theta[3, 1]  -0.0414 0.2641 -0.5677 -0.0434 0.4668 1.00  900
## theta[4, 1]   0.2203 0.2884 -0.3022  0.2122 0.8244 1.01  934
## theta[5, 1]  -0.0733 0.2362 -0.5524 -0.0800 0.3920 1.00  936
## theta[6, 1]   0.0367 0.2505 -0.4401  0.0394 0.5253 1.01  921
## theta[7, 1]  -0.0124 0.3143 -0.6595 -0.0081 0.6258 1.00 1006
## theta[8, 1]   0.0285 0.3105 -0.5866  0.0309 0.6456 1.00 1047
## theta[9, 1]   0.0687 0.1959 -0.3015  0.0717 0.4520 1.00  941
## theta[10, 1]  -0.0266 0.3279 -0.6564 -0.0208 0.5887 1.01 1084
```

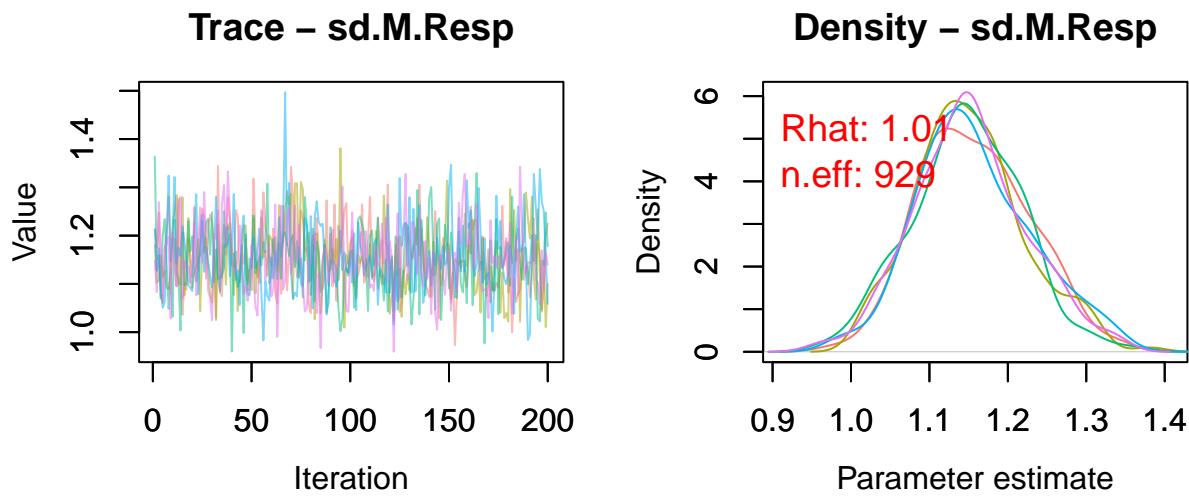
```
MCMCsummary(object = salnimble3, params = "psi",
            # exact = TRUE,
            # ISB = FALSE,
            round = 4)[1:10, ]
```

```
##               mean      sd    2.5%    50%   97.5% Rhat n.eff
## psi[1, 1]    4.2731 0.7922  2.8521  4.2324  5.9855 1.00 1000
## psi[2, 1]   -2.9513 0.7271 -4.1727 -2.9746 -1.4593 1.00 1121
## psi[3, 1]    0.2615 1.2542 -2.2734  0.2722  2.6930 1.00  878
## psi[4, 1]   -4.8959 0.6597 -6.1497 -4.9064 -3.4985 1.01  967
## psi[5, 1]    3.1538 0.8661  1.3123  3.1739  4.7894 1.01 1214
## psi[6, 1]   -1.7509 0.6943 -3.0997 -1.7370 -0.3800 1.00 1000
## psi[7, 1]   -0.1897 1.1725 -2.3539 -0.1894  2.0362 1.00 1046
## psi[8, 1]   -0.0807 1.2117 -2.4073 -0.0721  2.1425 1.00 1702
## psi[9, 1]    0.3816 1.1431 -1.8230  0.3410  2.6404 1.01 1253
## psi[10, 1]   1.2283 1.0045 -0.8305  1.2454  3.0538 1.00  956
```

```
MCMCtrace(object = salnimble3,
           pdf = FALSE, # no export to PDF
           ind = TRUE, # separate density lines per chain
           Rhat = TRUE,
           n.eff = TRUE,
           params = "sd.M.Muni")
```



```
MCMCtrace(object = salnimble3,
           pdf = FALSE, # no export to PDF
           ind = TRUE, # separate density lines per chain
           Rhat = TRUE,
           n.eff = TRUE,
           params = "sd.M.Resp")
```



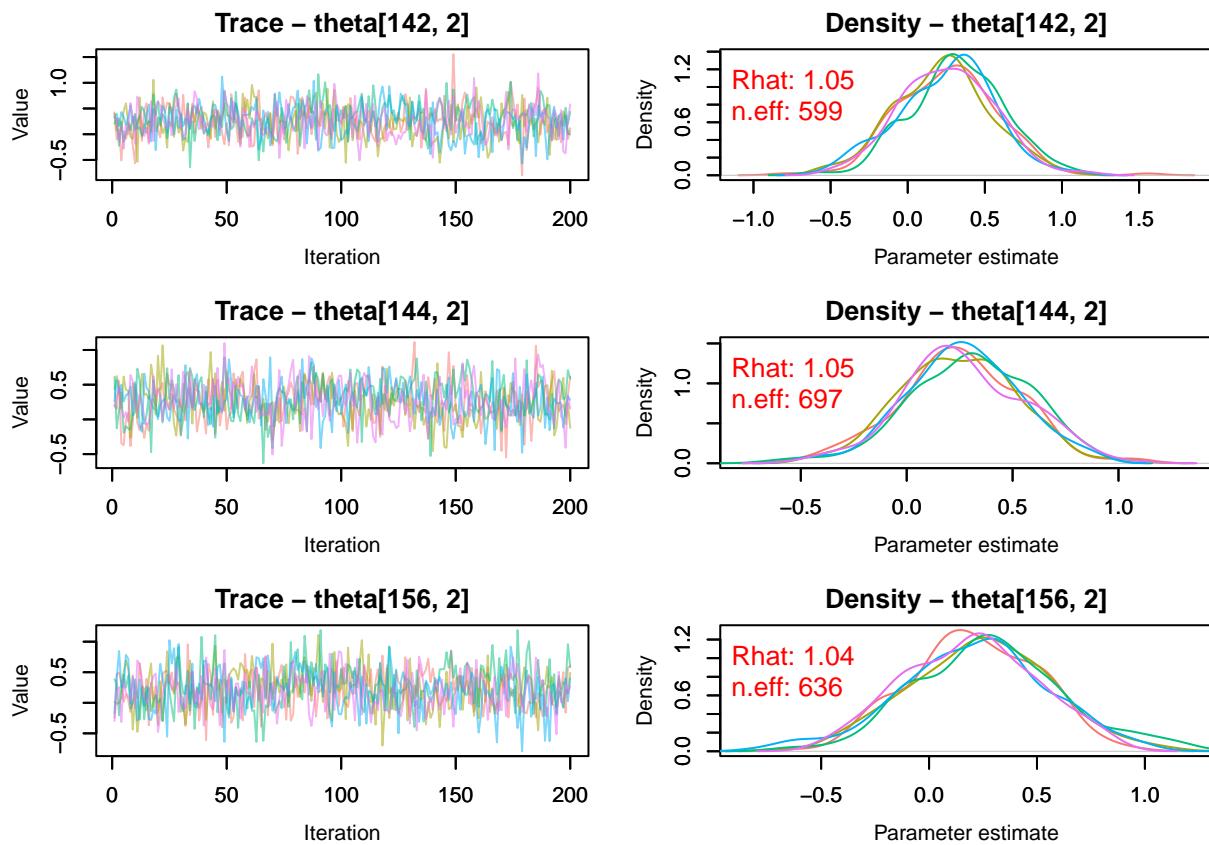
```
test <- "theta"

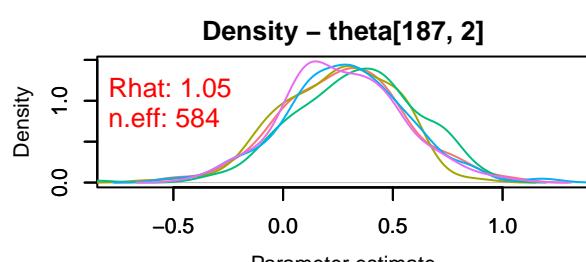
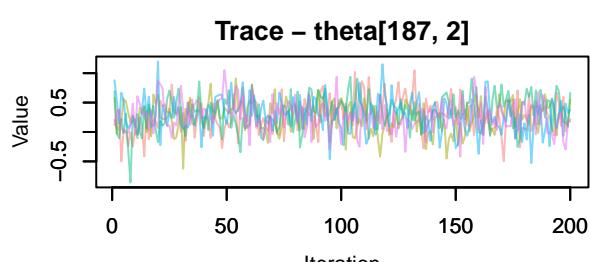
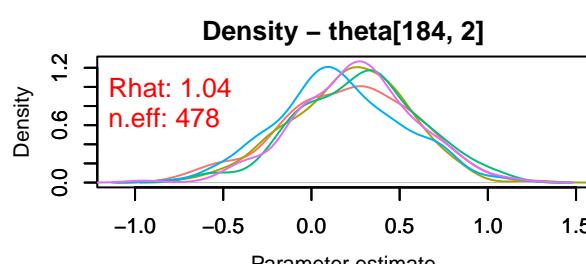
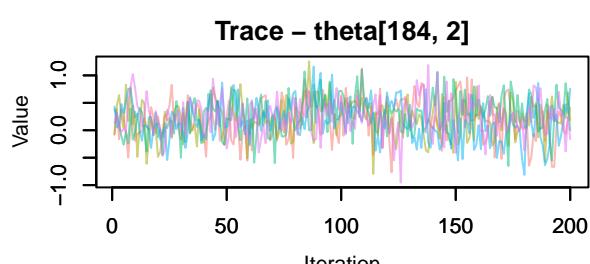
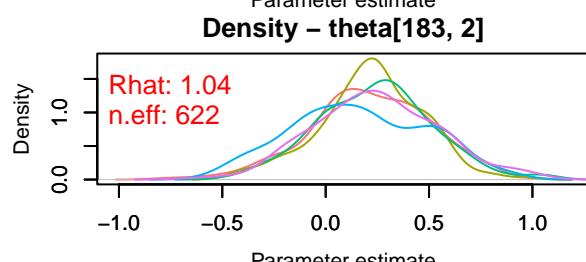
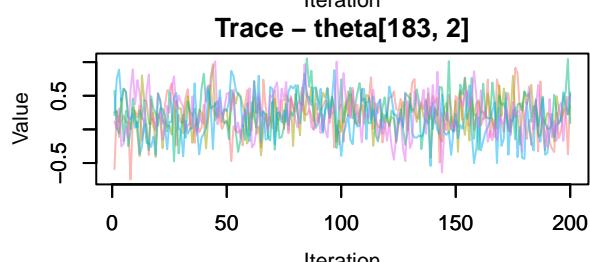
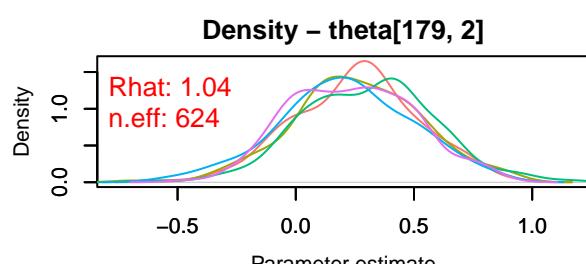
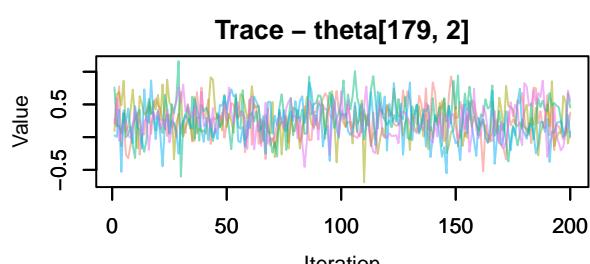
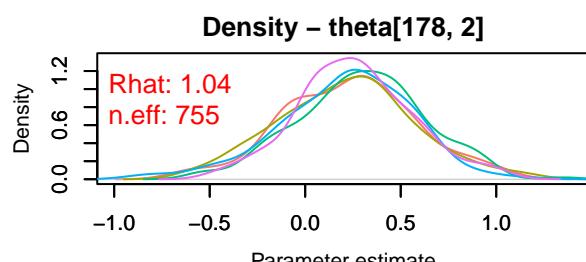
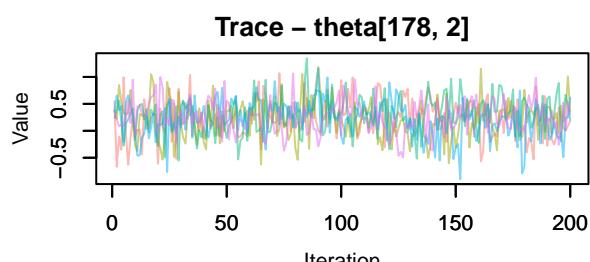
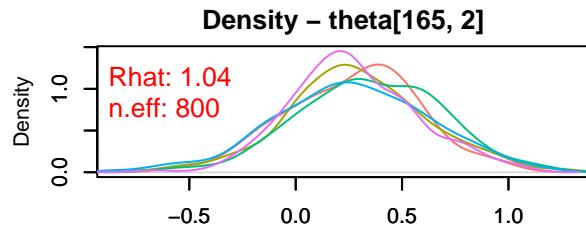
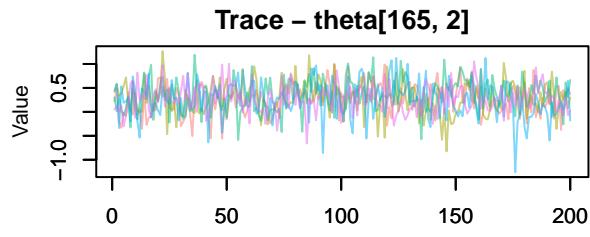
MCMCtrace(object = salnimble3,
           pdf = FALSE, # no export to PDF
           ind = TRUE, # separate density lines per chain
           Rhat = TRUE,
```

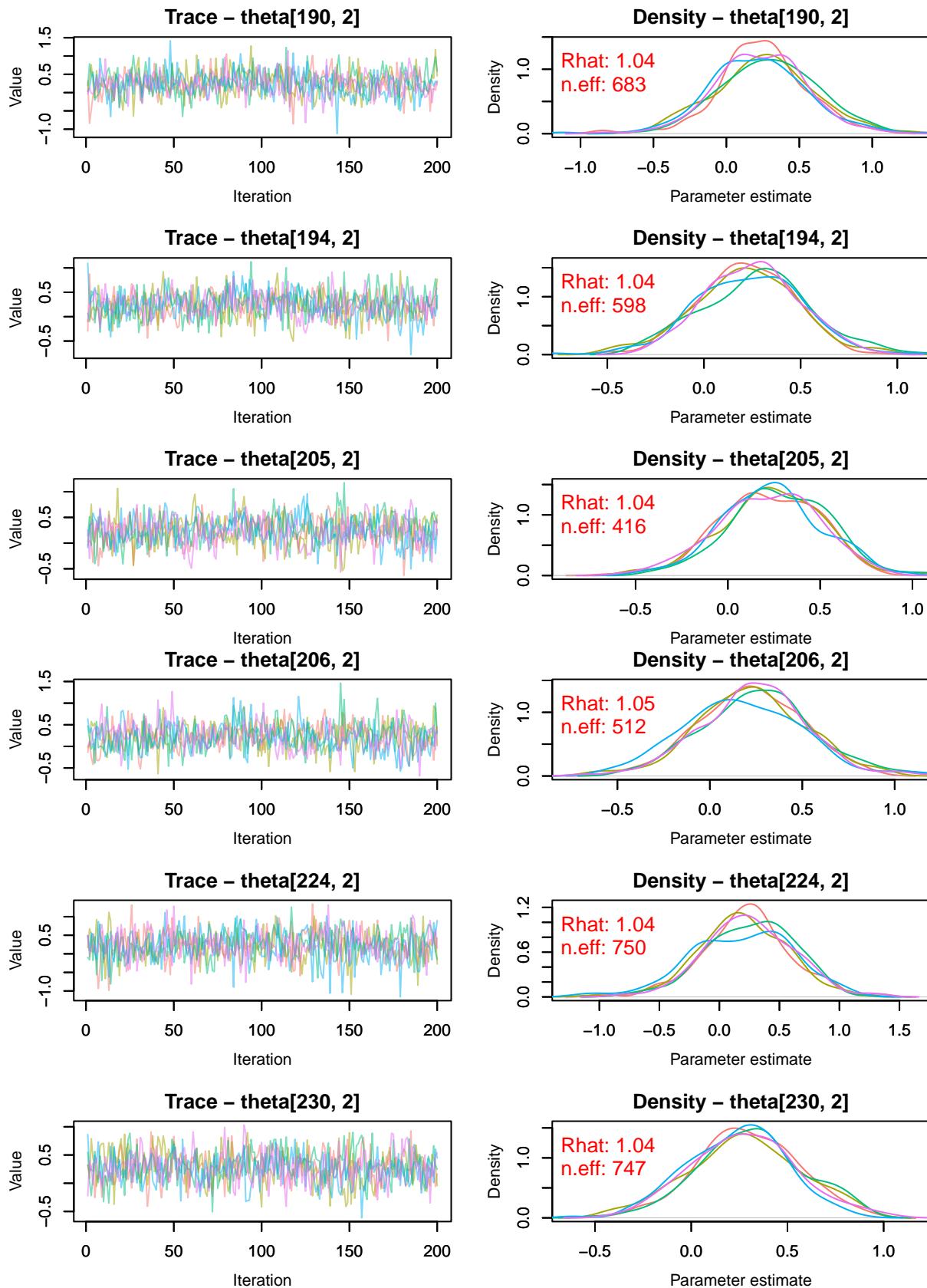
```

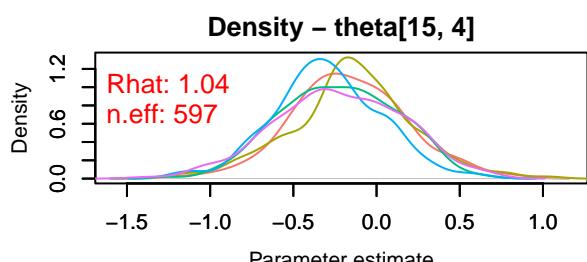
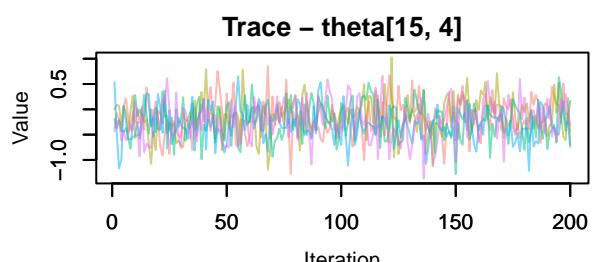
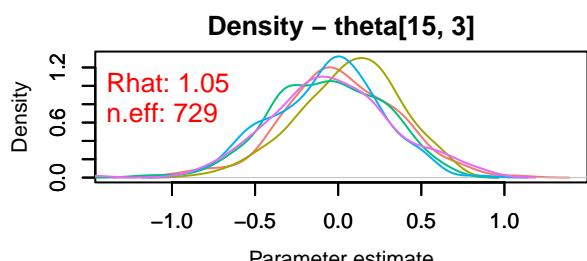
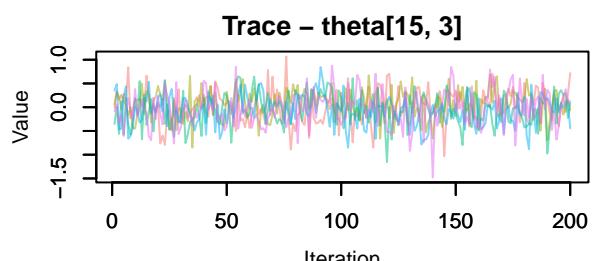
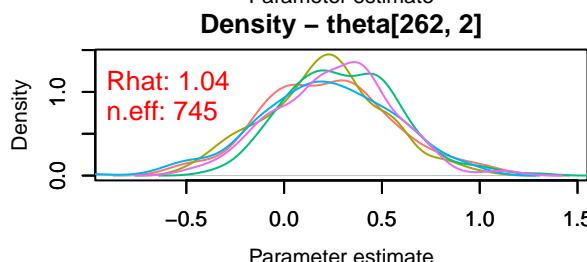
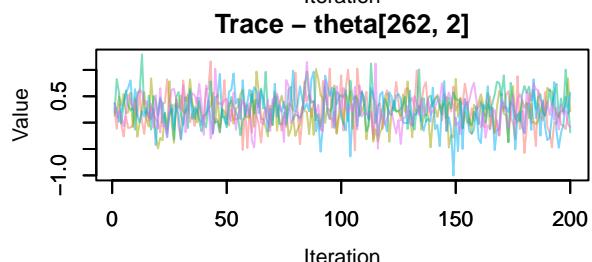
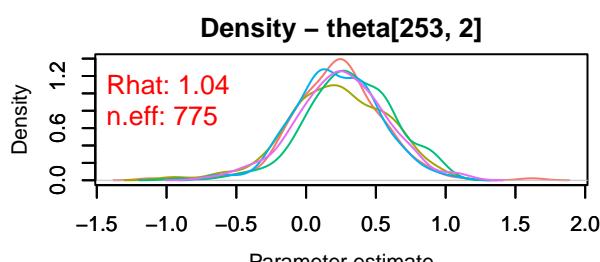
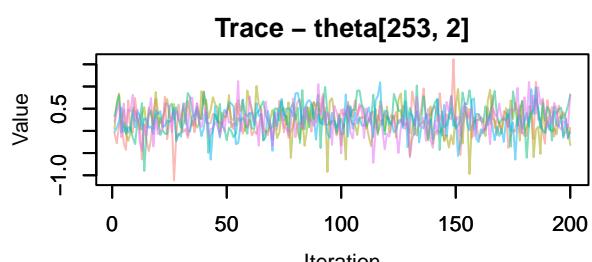
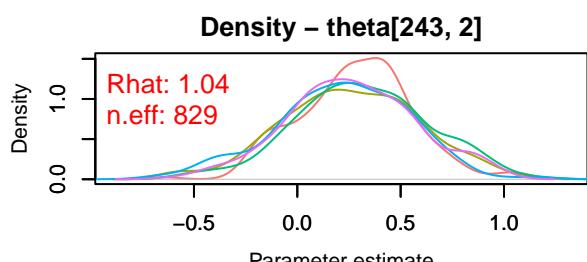
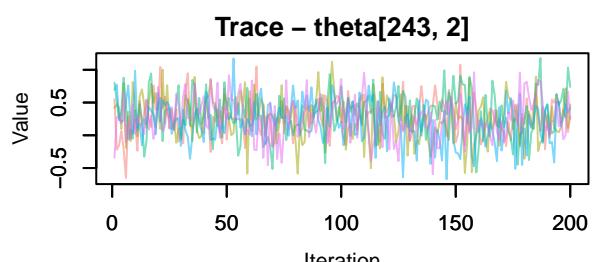
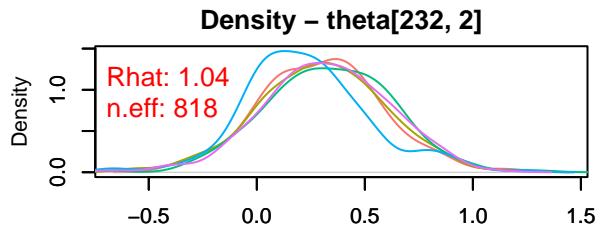
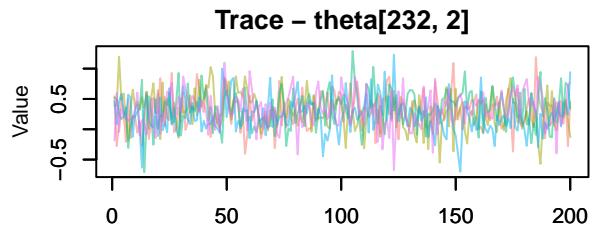
n.eff = TRUE,
exact = TRUE,
ISB = FALSE,
params = rownames(salwinbugs3$summary)[startsWith(labels(salwinbugs3$summary)[[1]],
→ test), ])[(salwinbugs3$summary[startsWith(labels(salwinbugs3$summary)[[1]], test),
→ 6] > 1.03) | (salwinbugs3$summary[startsWith(labels(salwinbugs3$summary)[[1]], test),
→ 7] < 200)])

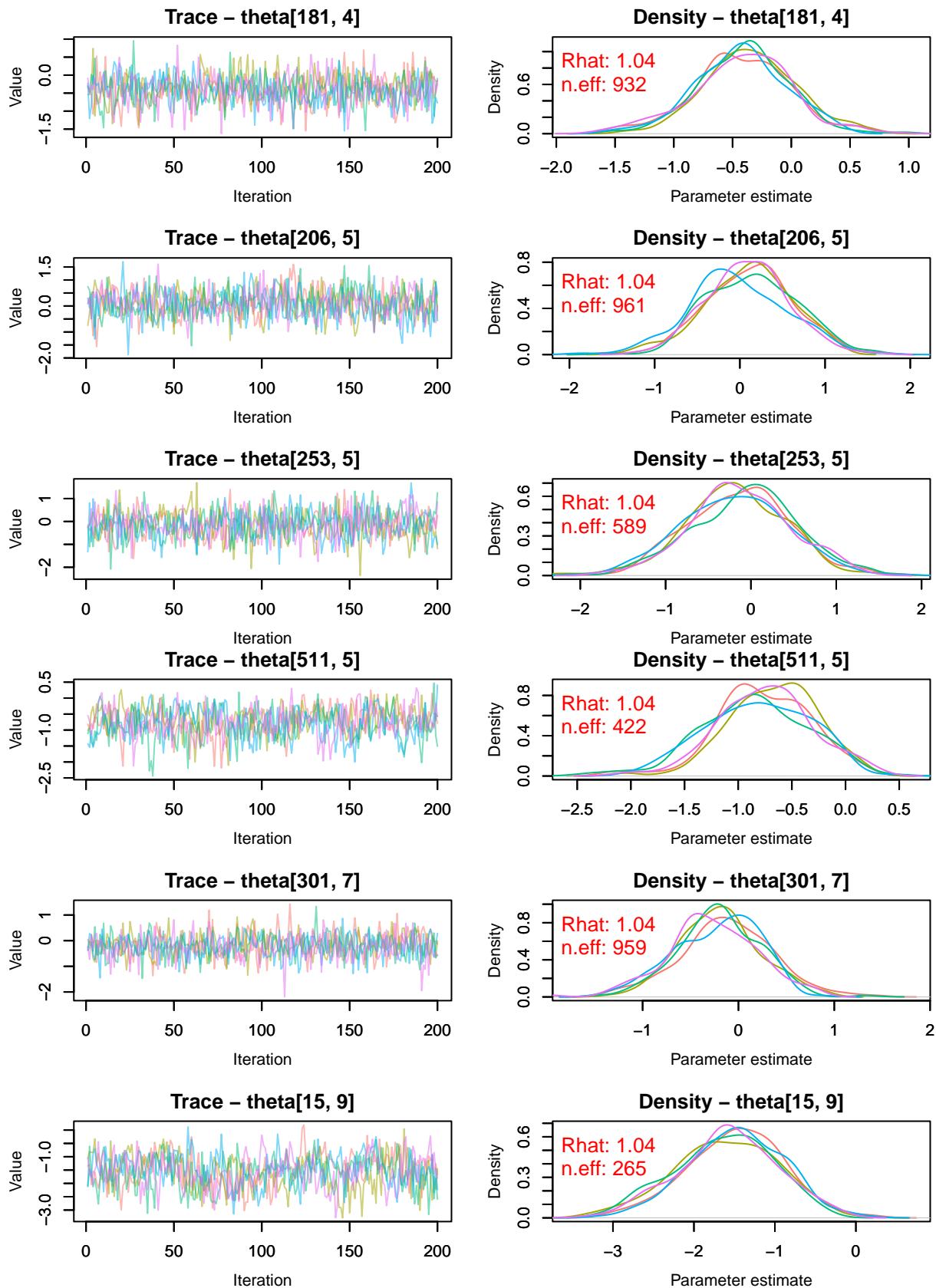
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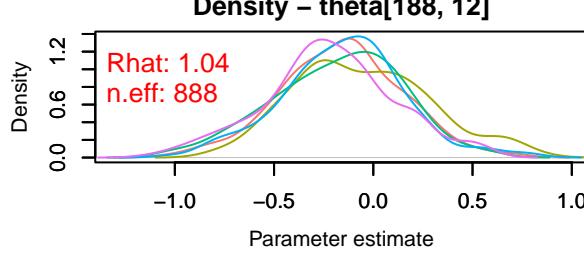
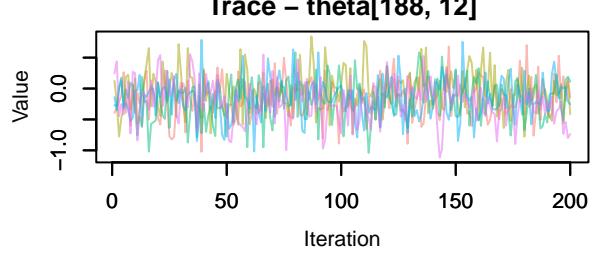
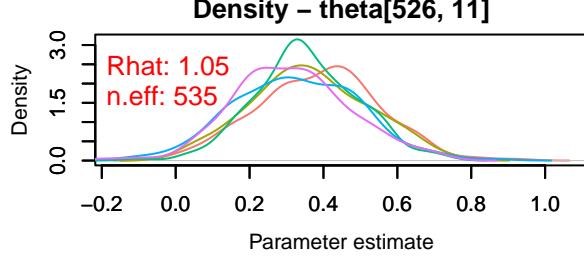
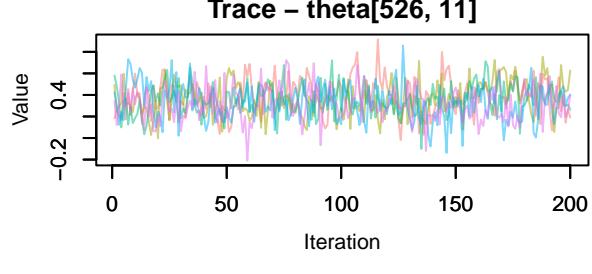
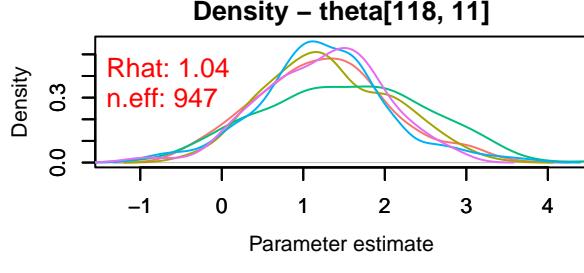
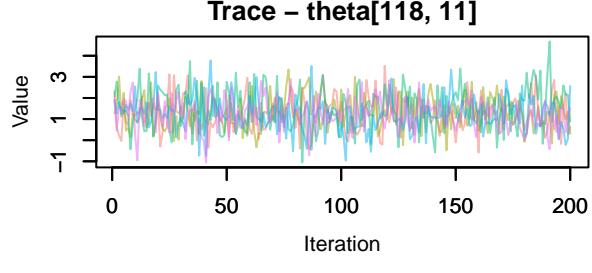
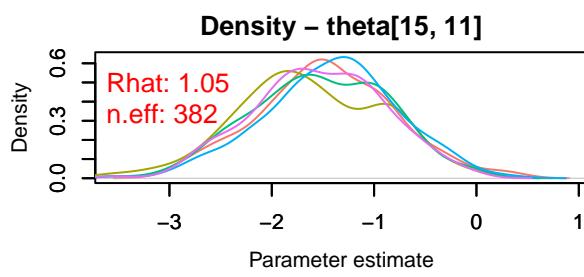
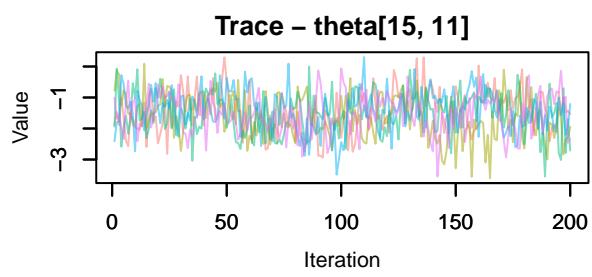
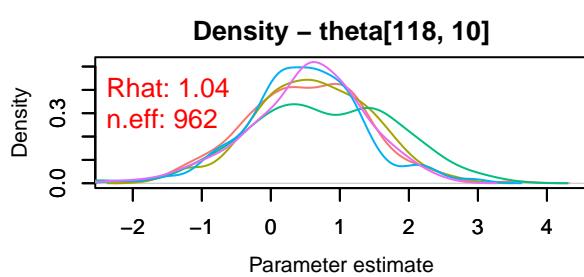
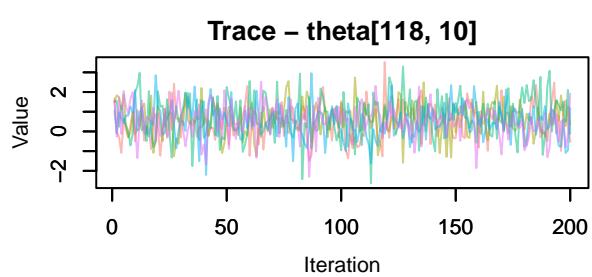
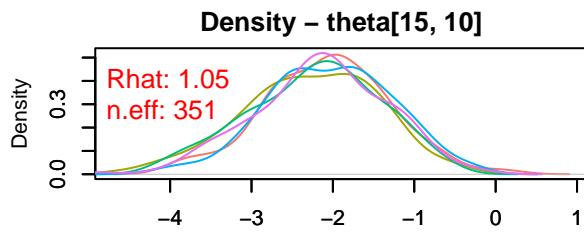
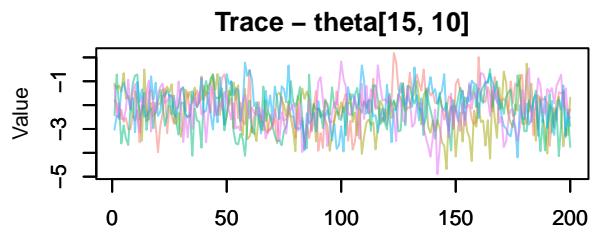










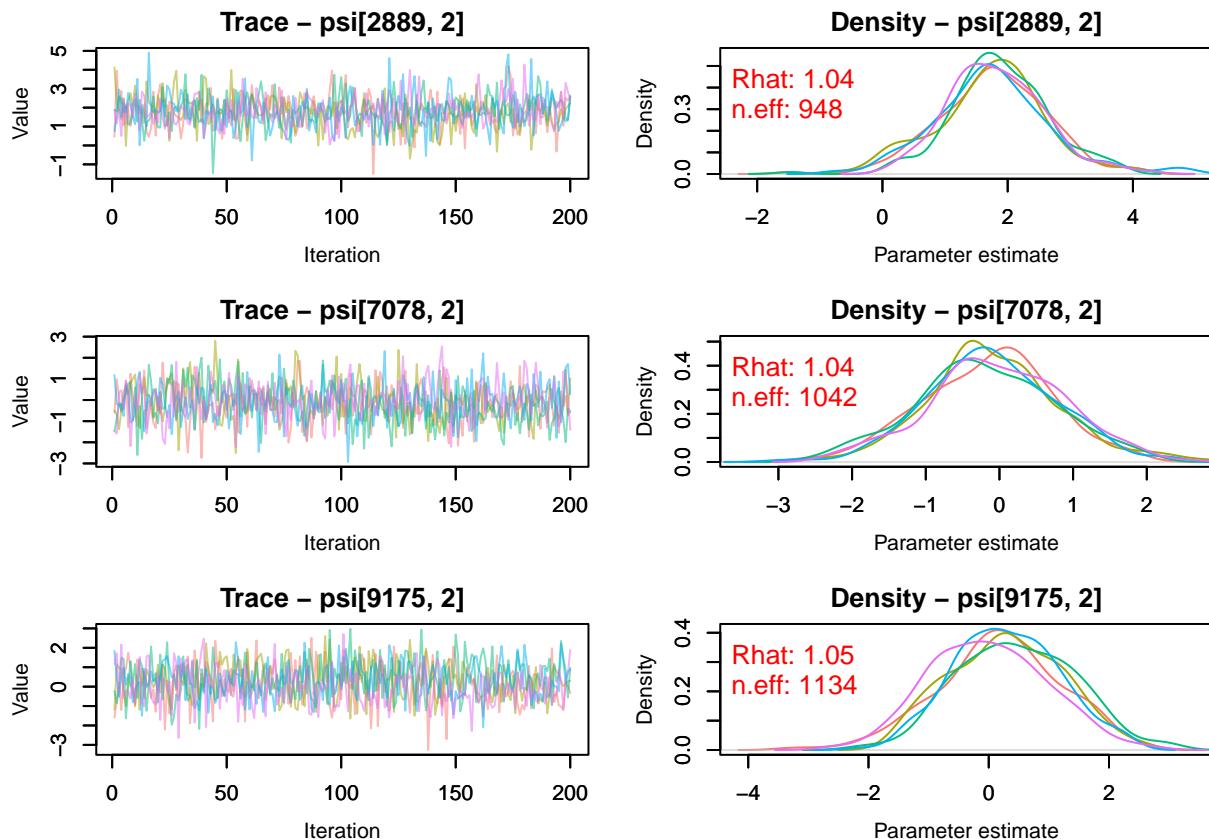


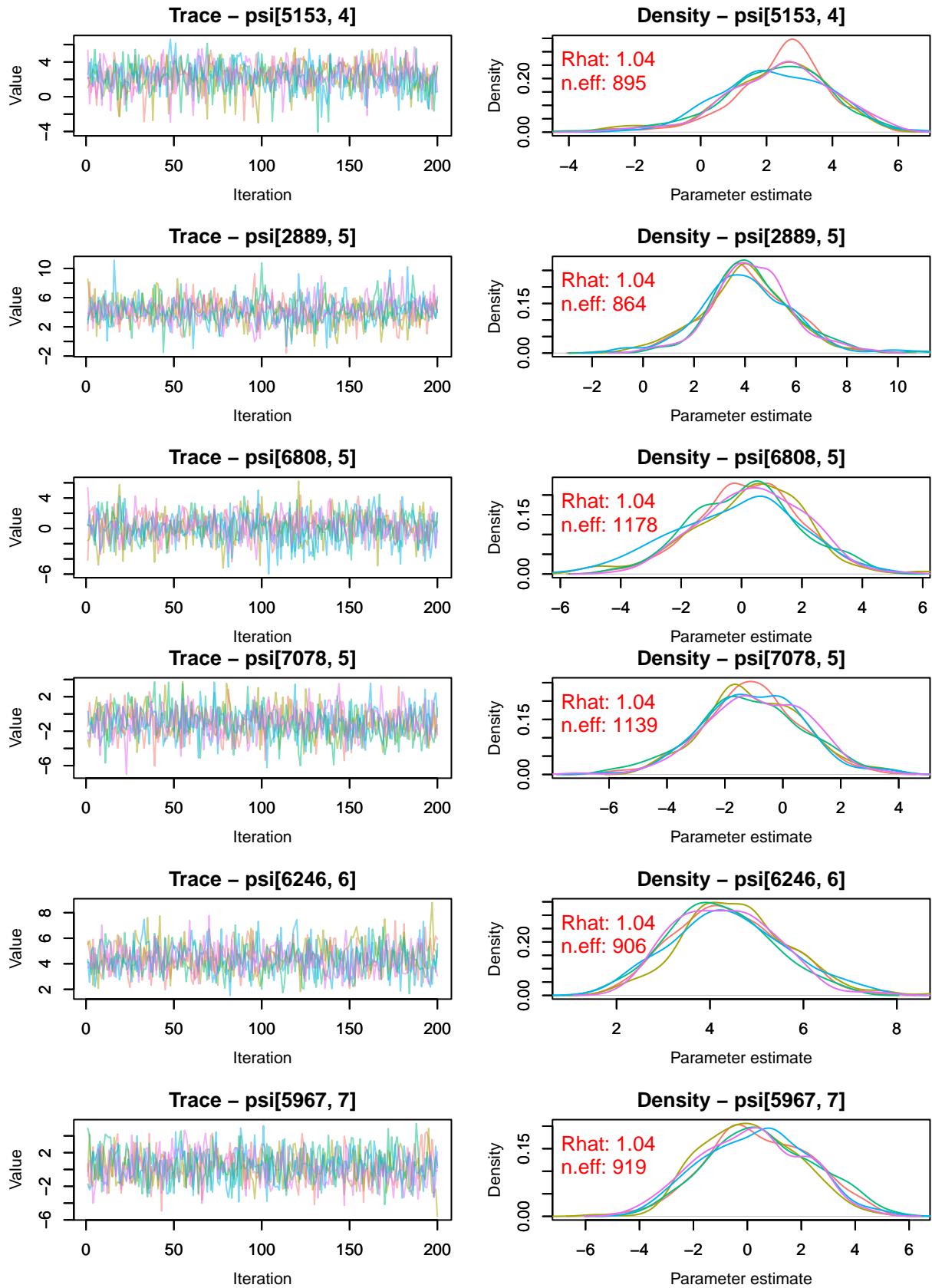
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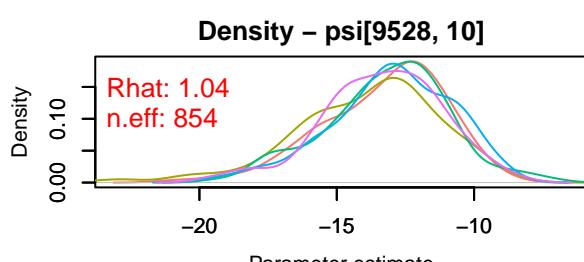
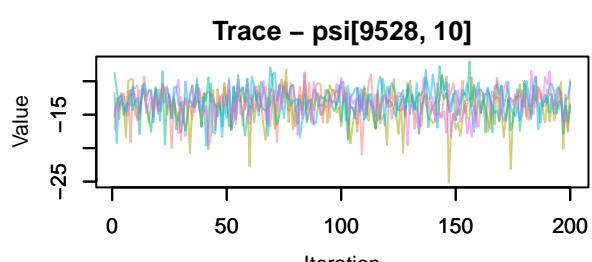
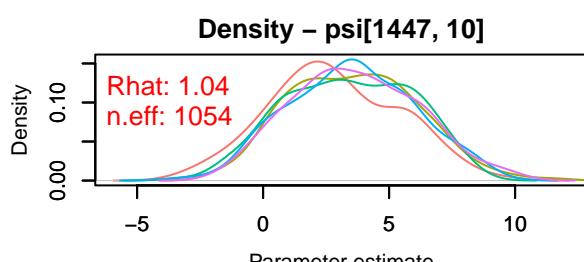
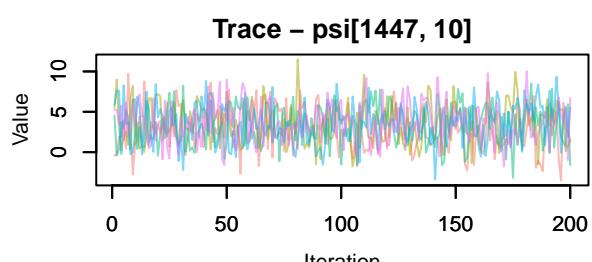
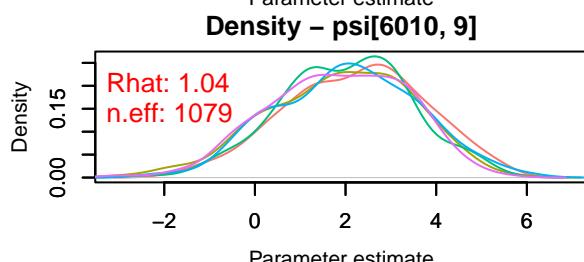
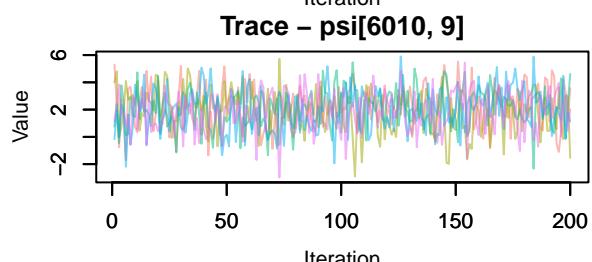
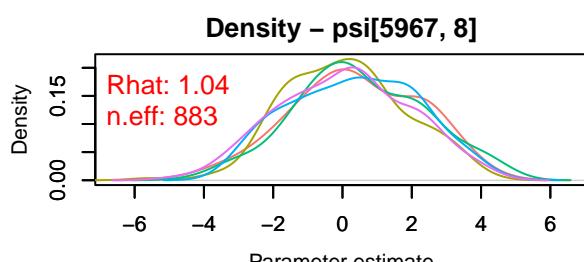
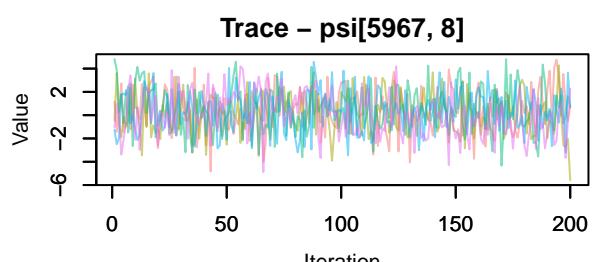
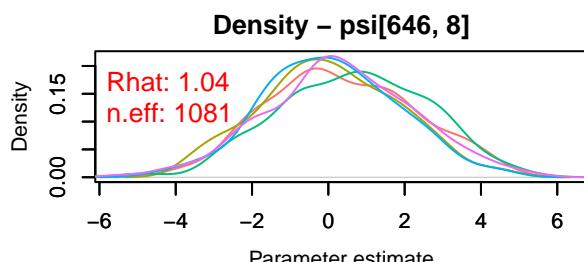
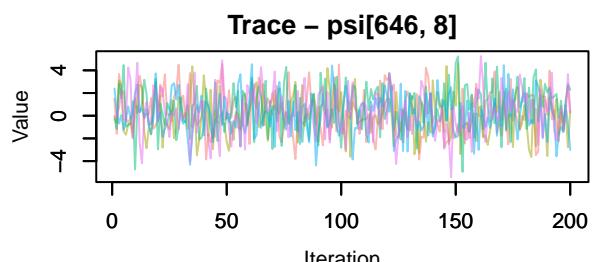
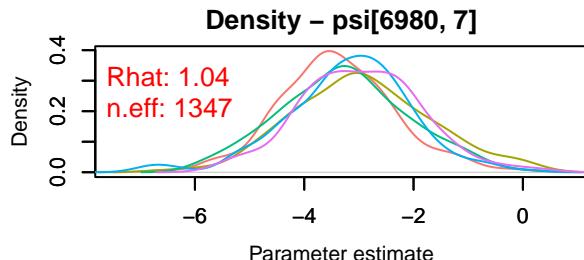
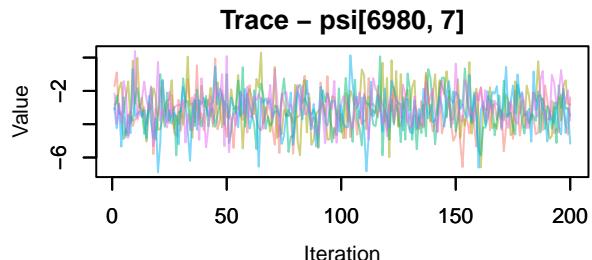
test <- "psi"

MCMCtrace(object = salnimble3,
            pdf = FALSE, # no export to PDF
            ind = TRUE, # separate density lines per chain
            Rhat = TRUE,
            n.eff = TRUE,
            exact = TRUE,
            ISB = FALSE,
            params = rownames(salwinbugs3$summary[startsWith(labels(salwinbugs3$summary)[[1]], 
            test), ])[(salwinbugs3$summary[startsWith(labels(salwinbugs3$summary)[[1]], test),
            6] > 1.03) | (salwinbugs3$summary[startsWith(labels(salwinbugs3$summary)[[1]], test),
            7] < 200)])

```







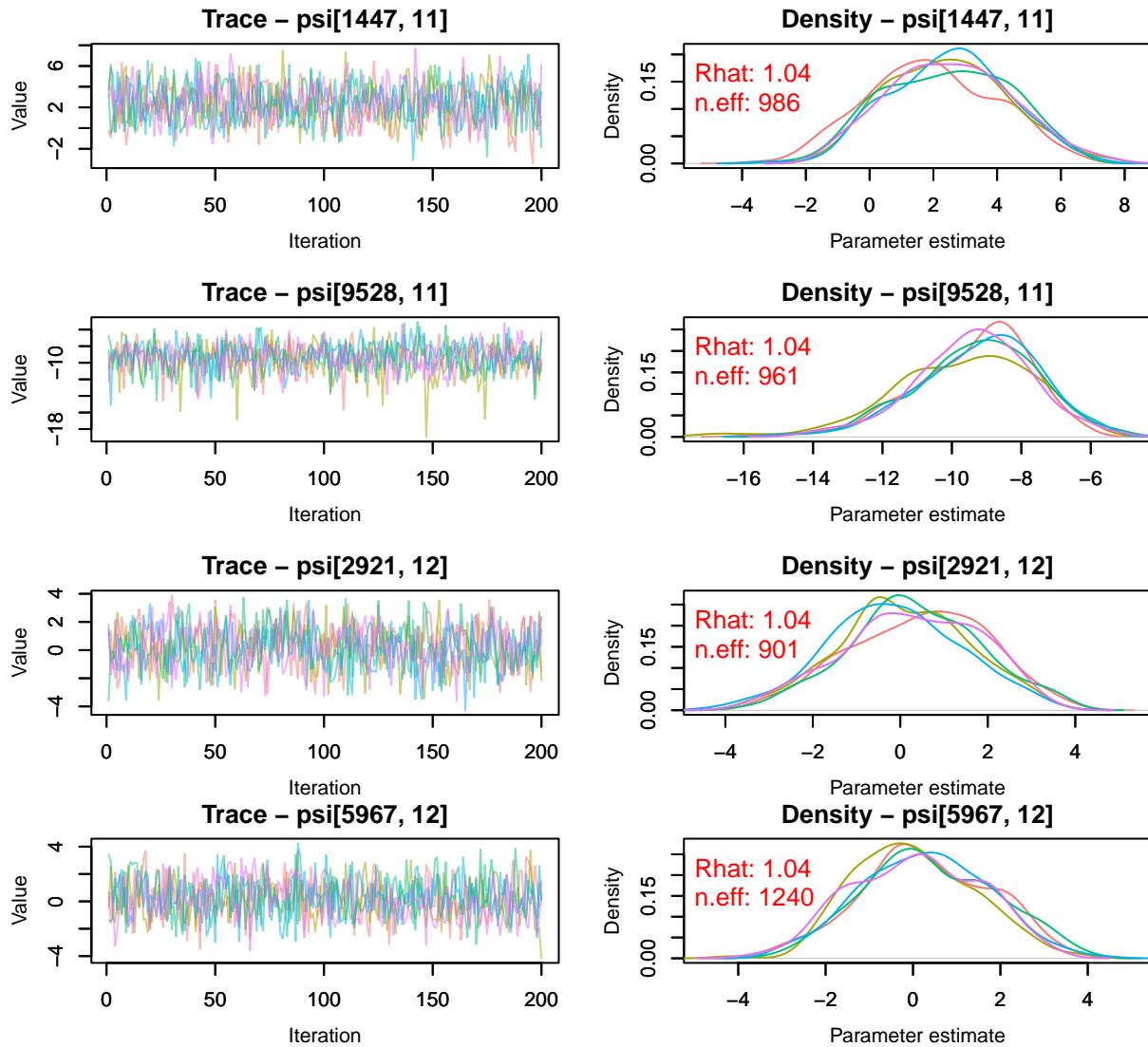


Figure 1: Maps of the RV - theta

```
# Cartography of the Region of Valencia
load(file.path("../", "data", "CartoCV.Rdata"))

n.sims <- salwinbugs3$n.sims
NMods <- 3
thetasim <- array(dim = c(n.sims, NMuni, NVars, NMods))
thetasim[, , 1] <- salwinbugs1$sims.list$theta
thetasim[, , 2] <- salwinbugs2$sims.list$theta
thetasim[, , 3] <- salwinbugs3$sims.list$theta

selection <- 1:4
NSel <- length(selection)
thetasim <- thetasim[, , selection, ]

# Fifteen equal-probability intervals
breaks <- c(min(apply(thetasim, 2:4, mean)) - 0.001, quantile(apply(thetasim, 2:4, mean), probs =
  seq(1/15, 14/15, length.out = 14)), max(apply(thetasim, 2:4, mean)))
```

```

breaks <- c(-2.20, -0.5, -0.35, -0.25, -0.20, -0.15, -0.10, -0.05,
           0.05, 0.10, 0.15, 0.20, 0.25, 0.35, 0.5, 2.20)

mod_labels <- c("Indep", "Corr", "CorrIRE")
for (Mod in 1:NMods) {
  for (Sel in 1:NSel) {
    carto_muni@data[[paste0(colnames(y)[selection[Sel]], "thetamean", mod_labels[Mod])]] <-
    ↪ cut(apply(thetasim[, , Sel, Mod], 2, mean), breaks = breaks, include.lowest = FALSE, right =
    ↪ TRUE)

  levels(carto_muni@data[[paste0(colnames(y)[selection[Sel]], "thetamean", mod_labels[Mod])]]) <-
    ↪ <- gsub("<=", "\u2264", c("<= -0.50", "(-0.50, -0.35]", "(-0.35, -0.25]", "(-0.25,
    ↪ -0.20]", "

```

```

    }
}

mod_labels <- c("CorrIRE", "Corr", "Indep")
all_labels <- matrix(nrow = NSel, ncol = NMods)
for (Sel in 1:NSel) {
  for (Mod in 1:NMods) {
    all_labels[Sel, Mod] <- paste0(labels[selection[Sel]], ".", mod_labels[Mod])
  }
}
all_labels <- as.character(all_labels)

```

```

spplot(cartogram,
       c(colnames(cartogram@data[, endsWith(colnames(cartogram@data), "CorrIRE")]),
         colnames(cartogram@data[, endsWith(colnames(cartogram@data), "Corr")]),
         colnames(cartogram@data[, endsWith(colnames(cartogram@data), "Indep")])),
       names.attr = all_labels,
       col.regions = colorRampPalette(brewer.pal(7, 'BrBG'))(15),
       cuts = 14,
       par.settings = list(layout.widths = list(left.padding = 0, right.padding = 0),
                           layout.heights = list(top.padding = 0, bottom.padding = 0),
                           axis.line = list(col = 'transparent')),
       strip = strip.custom(par.strip.text = list(cex = 0.95)),
       col = "black",
       lwd = 0.025,
       layout = c(NSel, NMods))

```

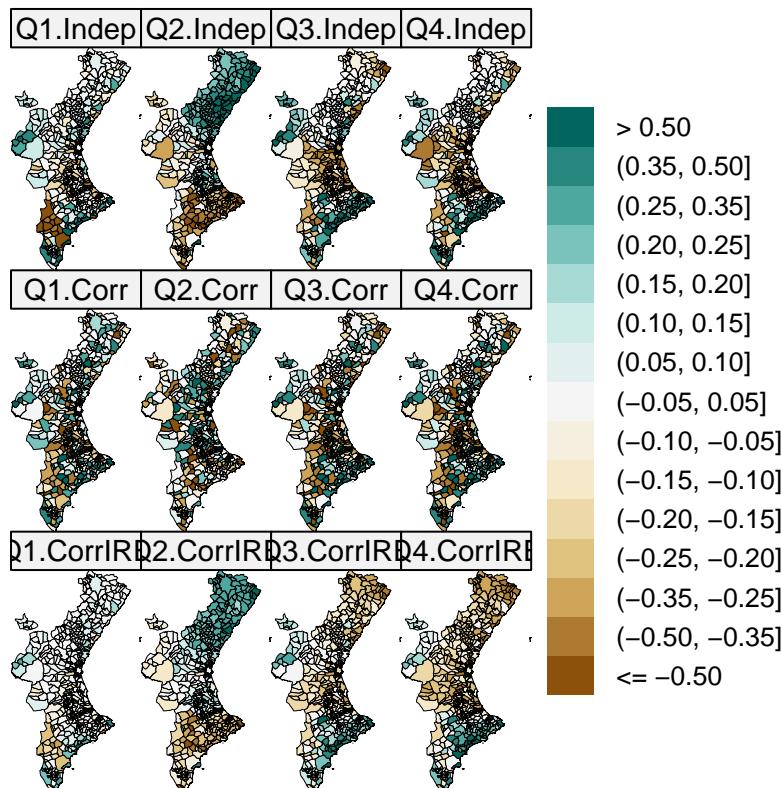


Figure 2: Maps of the RV -  $P(\theta < 0 | y)$

```

# Cartography of the Region of Valencia
load(file.path("../", "data", "CartoCV.Rdata"))

NMods <- 3
mod_labels <- c("Indep", "Corr", "CorrIRE")
thetasim <- array(dim = c(n.sims, NMuni, NVars, NMods))
thetasim[, , , 1] <- salwinbugs1$sims.list$theta
thetasim[, , , 2] <- salwinbugs2$sims.list$theta
thetasim[, , , 3] <- salwinbugs3$sims.list$theta

# Checking when theta is LESS than zero
stepsim <- array(dim = c(n.sims, NMuni, NVars, NMods))
for (Mod in 1:NMods) {
  for (Var in 1:NVars) {
    for (sim in 1:n.sims) {
      for (Muni in 1:NMuni) {
        stepsim[sim, Muni, Var, Mod] <- ifelse(thetasim[sim, Muni, Var, Mod] < 0, 1, 0)
      }
    }
  }
}

selection <- 1:4
NSel <- length(selection)
stepsim <- stepsim[, , selection, ]

mod_labels <- c("Indep", "Corr", "CorrIRE")
for (Mod in 1:NMods) {
  for (Sel in 1:NSel) {
    carto_muni@data[[paste0(colnames(y)[selection[Sel]], "probmean", mod_labels[Mod])]] <-
      apply(stepsim[, , Sel, Mod], 2, mean)
  }
}

kk <- unlist(carto_muni@data[, startsWith(colnames(carto_muni@data), "P8_")])

limit <- max(kk) + 0.01

mod_labels <- c("CorrIRE", "Corr", "Indep")
all_labels <- matrix(nrow = NSel, ncol = NMods)
for (Sel in 1:NSel) {
  for (Mod in 1:NMods) {
    all_labels[Sel, Mod] <- paste0(labels[selection[Sel]], ".", mod_labels[Mod])
  }
}
all_labels <- as.character(all_labels)

```

```

spplot(carto_muni,
       c(colnames(carto_muni@data[, endsWith(colnames(carto_muni@data), "CorrIRE")]),
         colnames(carto_muni@data[, endsWith(colnames(carto_muni@data), "Corr")]),
         colnames(carto_muni@data[, endsWith(colnames(carto_muni@data), "Indep")])),
       names.attr = all_labels,
       col.regions = colorRampPalette(brewer.pal(7, 'RdYlGn'))(15)[15:1],
       par.settings = list(axis.line = list(col = 'transparent')),
       strip = strip.custom(par.strip.text = list(cex = 0.95)),

```

```

    col = "black",
    at = seq(0, limit, length.out = 16),
    lwd = 0.025,
    layout = c(NSel, NMods))

```

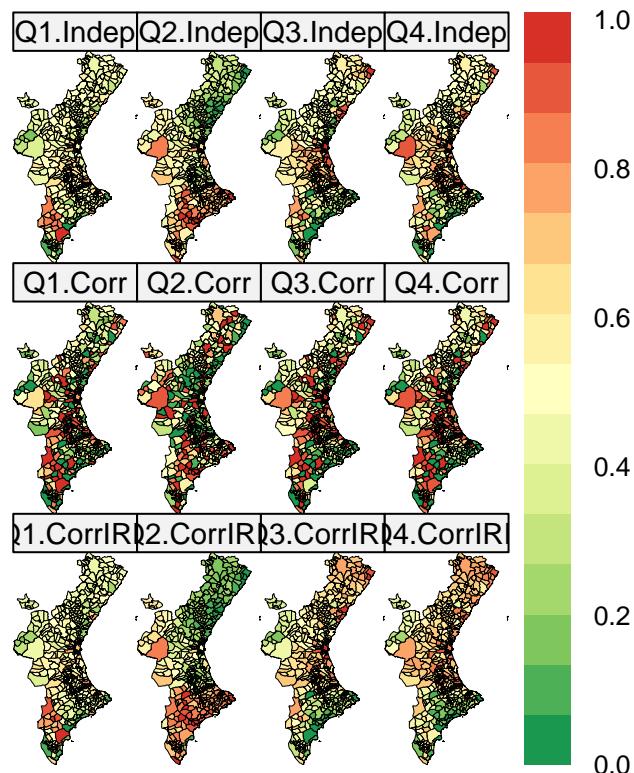


Figure 3: Individual correlation matrix for Model-Corr&IRE

```

SurveyMapping.Sigma.Resp <- function(salwinbugs) {

  n.sims <- salwinbugs$n.sims
  NVars <- dim(salwinbugs$sims.list$theta)[3]
  M.Resp <- salwinbugs$sims.list$M.Resp

  Sigma.Resp <- array(dim = c(n.sims, NVars, NVars))

  for (sim in 1:n.sims) {
    Sigma.Resp[sim, , ] <- t(M.Resp[sim, , ]) %*% M.Resp[sim, , ]
  }
  return(Sigma.Resp)
}

salwinbugs <- salwinbugs3

n.sims <- salwinbugs$n.sims
Sigma.Respsim <- SurveyMapping.Sigma.Resp(salwinbugs = salwinbugs)
Corr <- array(dim = c(n.sims, NVars, NVars))

# Set of the n.sims correlation matrices

```

```

for (sim in 1:n.sims) {
  Corr[sim, , ] <- diag(diag(Sigma.Respsim[sim, , ])^( $-1/2$ )) %*% Sigma.Respsim[sim, , ] %*%
  → diag(diag(Sigma.Respsim[sim, , ])^( $-1/2$ ))
}

Corr.mean <- matrix(ncol = NVars, nrow = NVars)
Corr.quantileL <- matrix(ncol = NVars, nrow = NVars)
Corr.quantileU <- matrix(ncol = NVars, nrow = NVars)
Sigma.Respmean <- matrix(ncol = NVars, nrow = NVars)
for (Var1 in 1:NVars) {
  for (Var2 in 1:NVars) {
    Corr.mean[Var1, Var2] <- mean(Corr[, Var1, Var2])
    Corr.quantileL[Var1, Var2] <- quantile(Corr[, Var1, Var2], probs = 0.025)
    Corr.quantileU[Var1, Var2] <- quantile(Corr[, Var1, Var2], probs = 0.975)
    Sigma.Respmean[Var1, Var2] <- mean(Sigma.Respsim[, Var1, Var2])
  }
}
rm(Corr); rm(Sigma.Respsim)

Corr.mean <- data.frame(Corr.mean); rownames(Corr.mean) <- labels; colnames(Corr.mean) <- labels
orden <- corrMatOrder(as.matrix(Corr.mean), order = "hclust", hclust.method = "ward.D2")

Corr.mean.orden <- as.matrix(Corr.mean)
Corr.mean.orden <- Corr.mean.orden[orden, orden]

Corr.quantileL <- data.frame(Corr.quantileL); rownames(Corr.quantileL) <- labels;
colnames(Corr.quantileL) <- labels

Corr.quantileL.orden <- as.matrix(Corr.quantileL)
Corr.quantileL.orden <- Corr.quantileL.orden[orden, orden]

Corr.quantileU <- data.frame(Corr.quantileU); rownames(Corr.quantileU) <- labels;
colnames(Corr.quantileU) <- labels

Corr.quantileU.orden <- as.matrix(Corr.quantileU)
Corr.quantileU.orden <- Corr.quantileU.orden[orden, orden]

Relevance <- matrix(as.numeric(Corr.quantileL.orden > 0 | Corr.quantileU.orden < 0), ncol =
  → NVars, nrow = NVars, byrow = FALSE)
colnames(Relevance) <- rownames(Relevance) <- colnames(Corr.mean.orden)
Relevance <- (Relevance - 1) * (-1)
for (Var in 1:NVars) { Relevance[Var, Var] <- 1 }

```

```

# First: ellipses in lower triangular
corrplot(as.matrix(Corr.mean.orden),
          type = "lower", method = "ellipse",
          p.mat = Relevance, sig.level = 0.05, insig = "label_sig",
          pch.cex = 1.5, pch.col = "grey20",
          addCoef.col = "black", number.cex = 0.8,
          tl.pos = "d", tl.cex = 0.9, cl.pos = "r")

# Second: CI in upper triangular
corrplot(as.matrix(Corr.mean.orden),
          type = "upper", method = "square",
          diag = FALSE, add = TRUE, cl.pos = "n",
          plotCI = "rect", lowCI = as.matrix(Corr.quantileL.orden),

```

```
uppCI = as.matrix(Corr.quantileU.orden), rect.col = "navy", tl.pos = "n")
```

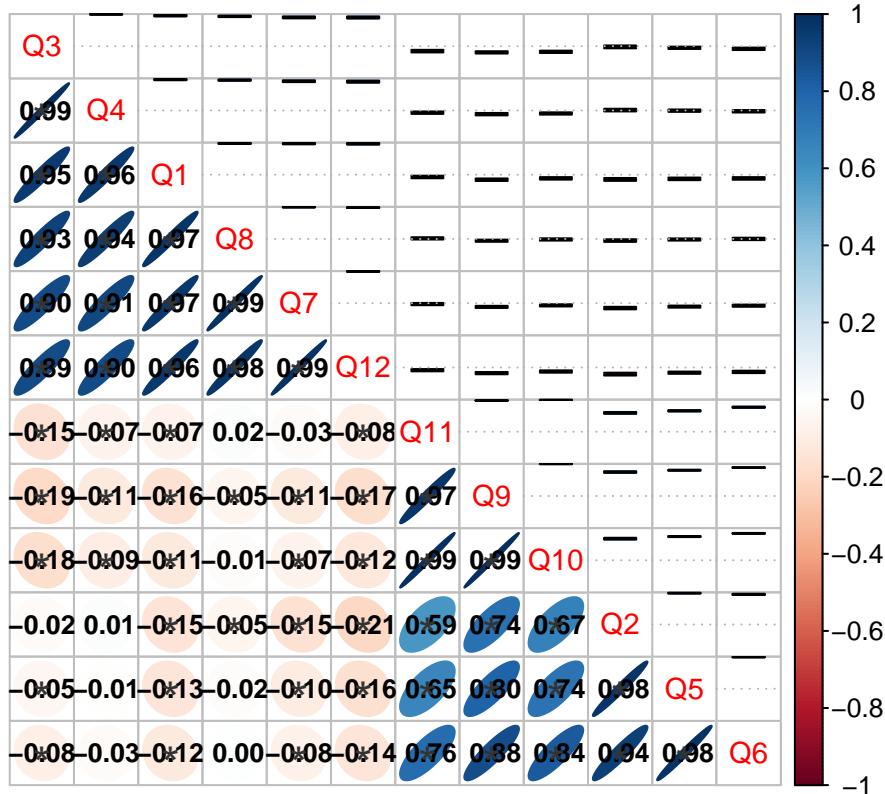


Figure 4: Spatial correlation matrix for Model-Corr&IRE

```
SurveyMapping.Sigma.Muni <- function(salwinbugs) {

  n.sims <- salwinbugs$n.sims
  NVars <- dim(salwinbugs$sims.list$theta)[3]
  M.Muni <- salwinbugs$sims.list$M.Muni

  Sigma.Muni <- array(dim = c(n.sims, NVars, NVars))

  for (sim in 1:n.sims) {
    Sigma.Muni[sim, , ] <- t(M.Muni[sim, , ]) %*% M.Muni[sim, , ]
  }
  return(Sigma.Muni)
}

salwinbugs <- salwinbugs3
n.sims <- salwinbugs$n.sims
Sigma.Munisim <- SurveyMapping.Sigma.Muni(salwinbugs = salwinbugs)
Corr <- array(dim = c(n.sims, NVars, NVars))

# Set of the n.sims correlation matrices
for (sim in 1:n.sims) {
  Corr[sim, , ] <- diag(diag(Sigma.Munisim[sim, , ])^( -1/2)) %*% Sigma.Munisim[sim, , ] %*%
    diag(diag(Sigma.Munisim[sim, , ])^( -1/2))
```

```

}

Corr.mean <- matrix(ncol = NVars, nrow = NVars)
Corr.quantileL <- matrix(ncol = NVars, nrow = NVars)
Corr.quantileU <- matrix(ncol = NVars, nrow = NVars)
Sigma.Munimean <- matrix(ncol = NVars, nrow = NVars)
for (Var1 in 1:NVars) {
  for (Var2 in 1:NVars) {
    Corr.mean[Var1, Var2] <- mean(Corr[, Var1, Var2])
    Corr.quantileL[Var1, Var2] <- quantile(Corr[, Var1, Var2], probs = 0.025)
    Corr.quantileU[Var1, Var2] <- quantile(Corr[, Var1, Var2], probs = 0.975)
    Sigma.Munimean[Var1, Var2] <- mean(Sigma.Munisim[, Var1, Var2])
  }
}
rm(Corr); rm(Sigma.Munisim)

Corr.mean <- data.frame(Corr.mean); rownames(Corr.mean) <- labels;
colnames(Corr.mean) <- labels

Corr.mean.orden <- as.matrix(Corr.mean)
Corr.mean.orden <- Corr.mean.orden[orden, orden]

Corr.quantileL <- data.frame(Corr.quantileL); rownames(Corr.quantileL) <- labels;
colnames(Corr.quantileL) <- labels

Corr.quantileL.orden <- as.matrix(Corr.quantileL)
Corr.quantileL.orden <- Corr.quantileL.orden[orden, orden]

Corr.quantileU <- data.frame(Corr.quantileU); rownames(Corr.quantileU) <- labels;
colnames(Corr.quantileU) <- labels

Corr.quantileU.orden <- as.matrix(Corr.quantileU)
Corr.quantileU.orden <- Corr.quantileU.orden[orden, orden]

Relevance <- matrix(as.numeric(Corr.quantileL.orden > 0 | Corr.quantileU.orden < 0), ncol =
  ~ NVars, nrow = NVars, byrow = FALSE)
colnames(Relevance) <- rownames(Relevance) <- colnames(Corr.mean.orden)
Relevance <- (Relevance - 1) * (-1)
for (Var in 1:NVars) { Relevance[Var, Var] <- 1 }

```

```

# First: ellipses in lower triangular
corrplot(as.matrix(Corr.mean.orden),
         type = "lower", method = "ellipse",
         p.mat = Relevance, sig.level = 0.05, insig = "label_sig",
         pch.cex = 1.5, pch.col = "grey20",
         addCoef.col = "black", number.cex = 0.8,
         tl.pos = "d", tl.cex = 0.9, cl.pos = "r")

# Second: CI in upper triangular
corrplot(as.matrix(Corr.mean.orden),
         type = "upper", method = "square",
         diag = FALSE, add = TRUE, cl.pos = "n",
         plotCI = "rect", lowCI = as.matrix(Corr.quantileL.orden),
         uppCI = as.matrix(Corr.quantileU.orden), rect.col = "navy", tl.pos = "n")

```

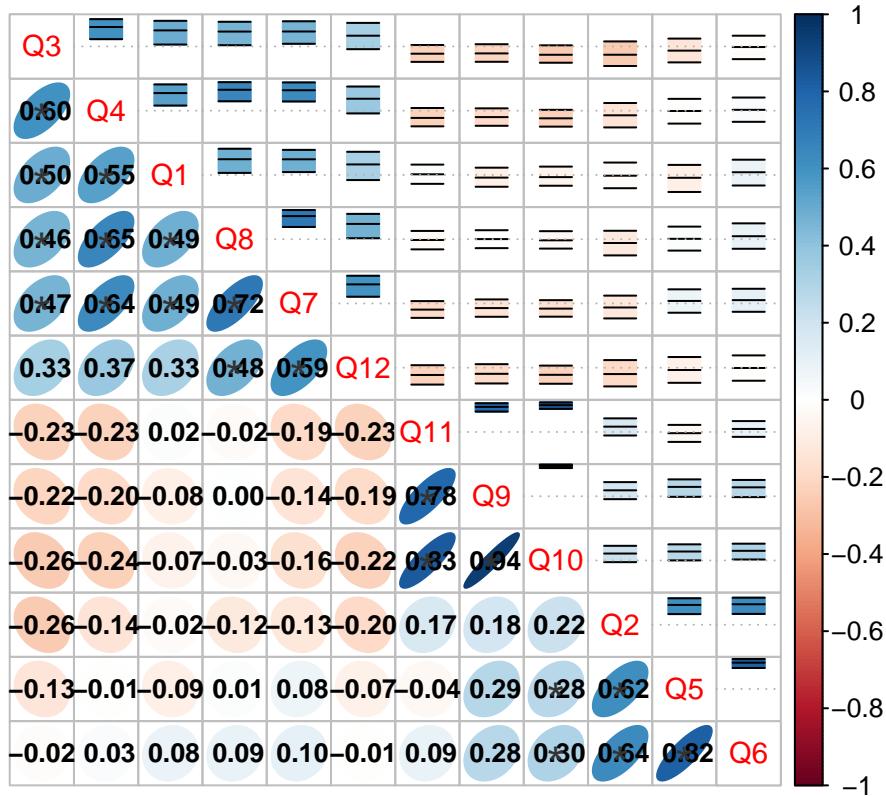


Figure 5: Maps of the RV - PCA

```
salwinbugs <- salwinbugs3
thetasim <- salwinbugs$sims.list$theta
thetamean <- apply(thetasim, 2:3, mean)
acp <- princomp(thetamean, cor = TRUE)
acp$loadings[, 1:3]
```

```
##          Comp.1     Comp.2     Comp.3
## [1,] 0.1500401 0.46181484 0.15012780
## [2,] -0.2984278 0.23852458 -0.28661029
## [3,] 0.3397215 0.16086642 0.04076247
## [4,] 0.3412119 0.21268818 0.04785622
## [5,] -0.2052693 0.37894367 -0.45563317
## [6,] -0.2249631 0.43823141 -0.35853430
## [7,] 0.3246205 0.27712025 0.02077444
## [8,] 0.2802306 0.35851188 0.22584355
## [9,] -0.2963037 0.20552491 0.39755914
## [10,] -0.3065521 0.20412406 0.37866329
## [11,] -0.2994604 0.15756273 0.44765771
## [12,] 0.3293849 0.09494317 -0.04407364
```

```
thetaComp <- acp$scores[, 1:3]
cor(thetaComp)
```

```

##          Comp.1      Comp.2      Comp.3
## Comp.1 1.000000e+00 3.307950e-17 -4.689014e-16
## Comp.2 3.307950e-17 1.000000e+00 7.081673e-16
## Comp.3 -4.689014e-16 7.081673e-16 1.000000e+00

carto_muni@data$ACP1 <- thetaComp[, 1]

# Fifteen equal-probability intervals
breaks <- c(min(carto_muni@data$ACP1) - 0.001, quantile(carto_muni@data$ACP1, probs = seq(1/15,
→ 14/15, length.out = 14)), max(carto_muni@data$ACP1))
breaks <- c(-17.50, -3.00, -2.50, -2.00, -1.50, -1.00, -0.50, -0.25,
0.25, 0.50, 1.00, 1.50, 2.00, 2.50, 3.00, 17.50)

carto_muni@data$ACP1 <- cut(carto_muni@data$ACP1, breaks = breaks, include.lowest = FALSE, right
→ = TRUE)
levels(carto_muni@data$ACP1) <- c("Worse S1", "Better S2", " ", " ", " ", " ",
" ", " ", " ", " ", " ", " ",
" ", " ", " ", " ", " ",
" ", " ", "Worse S2", "Better S1", " ")

carto_muni@data$ACP2 <- thetaComp[, 2]

# Fifteen equal-probability intervals
breaks <- c(min(carto_muni@data$ACP2) - 0.001, quantile(carto_muni@data$ACP2, probs = seq(1/15,
→ 14/15, length.out = 14)), max(carto_muni@data$ACP2))

carto_muni@data$ACP2 <- cut(carto_muni@data$ACP2, breaks = breaks, include.lowest = FALSE, right
→ = TRUE)
levels(carto_muni@data$ACP2) <- c("Worse MH", " ", " ", " ", " ", " ",
" ", " ", " ", " ", " ",
" ", " ", " ", " ", " ",
" ", " ", " ", " ", " ",
" ", " ", " ", " ", "Better MH")
rm(list = c("thetasim", "stepsim"))

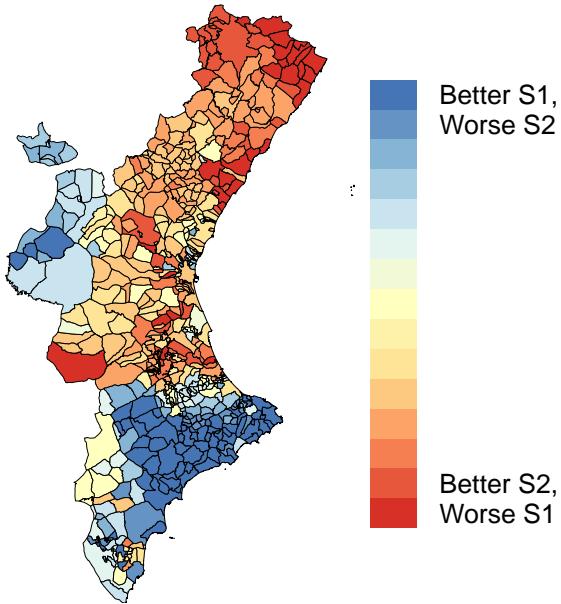
```

```

grid.arrange(spplot(carto_muni,
c("ACP1"),
main = expression("(A"),
col.regions = colorRampPalette(brewer.pal(7, 'RdYlBu'))(15),
cuts = 14,
par.settings = list(axis.line = list(col = 'transparent')),
strip = strip.custom(par.strip.text = list(cex = 0.95)),
col = "black",
lwd = 0.025),
spplot(carto_muni,
c("ACP2"),
main = expression("(B"),
col.regions = colorRampPalette(brewer.pal(7, 'Blues'))(15),
cuts = 14,
par.settings = list(axis.line = list(col = 'transparent')),
strip = strip.custom(par.strip.text = list(cex = 0.95)),
col = "black",
lwd = 0.025),
ncol = 2)

```

(A)



(B)

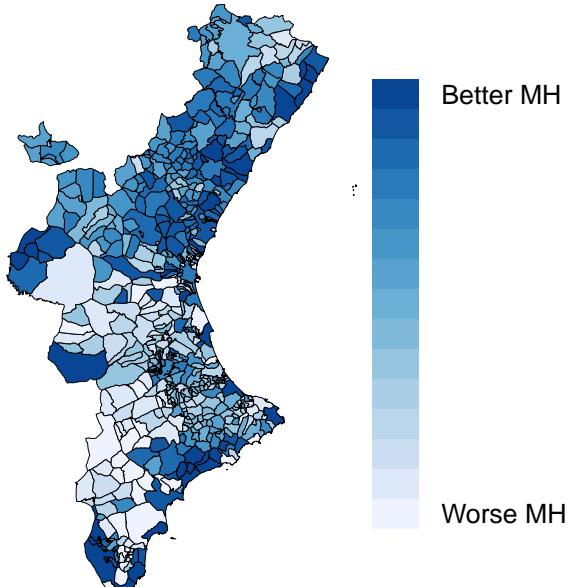


Table 2: Model assessment

```

# Model-Indep
# SurveyMapping.prlevels:
# - computes the n.sims simulated probabilities for each respondent

SurveyMapping.prlevels <- function(salwinbugs) {

  n.sims <- salwinbugs$n.sims
  n.chains <- salwinbugs$n.chains
  p.gamma <- array(dim = c(n.sims, NResp, NVars, NCats - 1))
  prlevels <- array(dim = c(n.sims, NResp, NVars, NCats))
  for (sim in 1:n.sims) {
    for (Resp in 1:NResp) {
      for (Var in 1:NVars) {
        for (Cat in 1:(NCats - 1)) {
          p.gamma[sim, Resp, Var, Cat] <-
            ilogit(salwinbugs$sims.list$kappa[sim, sex[Resp], age[Resp], Cat, Var] +
                    salwinbugs$sims.list$sd.theta[sim, Var] * salwinbugs$sims.list$theta[sim,
→ muni[Resp], Var])
        }
      }
      prlevels[sim, Resp, Var, 1] <- p.gamma[sim, Resp, Var, 1]
      prlevels[sim, Resp, Var, NCats] <- 1 - p.gamma[sim, Resp, Var, NCats - 1]

      for (Cat in 2:(NCats - 1)) {
        prlevels[sim, Resp, Var, Cat] <-
          p.gamma[sim, Resp, Var, Cat] - p.gamma[sim, Resp, Var, Cat-1]
      }
    }
  }

  if (sim %in% c(1, seq(n.sims/n.chains, n.sims, n.sims/n.chains))) {

```

```

        cat(sim, "of", n.sims, "simulations", "\n")
    } else {}
}

return(prlevels)
}

# # This may take a minute
# prlevels <- SurveyMapping.prlevels(salwinbugs = salwinbugs1)

# Model-Corr
# SurveyMapping.prlevels:
# - computes the n.sims simulated probabilities for each respondent

SurveyMapping.prlevels <- function(salwinbugs) {

  n.sims <- salwinbugs$n.sims
  n.chains <- salwinbugs$n.chains
  p.gamma <- array(dim = c(n.sims, NResp, NVars, NCats - 1))
  prlevels <- array(dim = c(n.sims, NResp, NVars, NCats))
  for (sim in 1:n.sims) {
    for (Resp in 1:NResp) {
      for (Var in 1:NVars) {
        for (Cat in 1:(NCats - 1)) {
          p.gamma[sim, Resp, Var, Cat] <-
            ilogit(salwinbugs$sims.list$kappa[sim, sex[Resp], age[Resp], Cat, Var] +
                    salwinbugs$sims.list$theta[sim, muni[Resp], Var])
        }
      }
      prlevels[sim, Resp, Var, 1] <- p.gamma[sim, Resp, Var, 1]
      prlevels[sim, Resp, Var, NCats] <- 1 - p.gamma[sim, Resp, Var, NCats - 1]

      for (Cat in 2:(NCats - 1)) {
        prlevels[sim, Resp, Var, Cat] <-
          p.gamma[sim, Resp, Var, Cat] - p.gamma[sim, Resp, Var, Cat-1]
      }
    }
  }

  if (sim %in% c(1, seq(n.sims/n.chains, n.sims, n.sims/n.chains))) {
    cat(sim, "of", n.sims, "simulations", "\n")
  } else {}
}

return(prlevels)
}

# # This may take a minute
# prlevels <- SurveyMapping.prlevels(salwinbugs = salwinbugs2)

# Model-Corr&IRE
# SurveyMapping.prlevels:
# - computes the n.sims simulated probabilities for each respondent

SurveyMapping.prlevels <- function(salwinbugs) {

  n.sims <- salwinbugs$n.sims
  n.chains <- salwinbugs$n.chains
  p.gamma <- array(dim = c(n.sims, NResp, NVars, NCats - 1))
}

```

```

prlevels <- array(dim = c(n.sims, NResp, NVars, NCats))
for (sim in 1:n.sims) {
  for (Resp in 1:NResp) {
    for (Var in 1:NVars) {
      for (Cat in 1:(NCats - 1)) {
        p.gamma[sim, Resp, Var, Cat] <-
          ilogit(salwinbugs$sims.list$kappa[sim, sex[Resp], age[Resp], Cat, Var] +
                  salwinbugs$sims.list$theta[sim, muni[Resp], Var] +
                  salwinbugs$sims.list$psi[sim, Resp, Var])
      }
    }
    prlevels[sim, Resp, Var, 1] <- p.gamma[sim, Resp, Var, 1]
    prlevels[sim, Resp, Var, NCats] <- 1 - p.gamma[sim, Resp, Var, NCats - 1]

    for (Cat in 2:(NCats - 1)) {
      prlevels[sim, Resp, Var, Cat] <-
        p.gamma[sim, Resp, Var, Cat] - p.gamma[sim, Resp, Var, Cat-1]
    }
  }
}

if (sim %in% c(1, seq(n.sims/n.chains, n.sims, n.sims/n.chains))) {
  cat(sim, "of", n.sims, "simulations", "\n")
} else {}
}

return(prlevels)
}

# # This may take a minute
# prlevels <- SurveyMapping.prlevels(salwinbugs = salwinbugs3)

# Validation

# Sample size of each municipality, sex and age group:
sample <- array(dim = c(NMuni, NSex, NAges))
for (Muni in 1:NMuni) {
  for (SexGroup in 1:NSex) {
    for (AgeGroup in 1:NAges) {
      sample[Muni, SexGroup, AgeGroup] <- sum(muni == Muni & sex == SexGroup & age == AgeGroup)
    }
  }
}

SurveyMapping.Validation <- function(prlevels, Muni) {

  NSamp <- sum(sample[Muni, , ])
  index <- which(muni == Muni)
  realvalue <- matrix(nrow = NVars, ncol = NCats)
  predictive <- array(dim = c(n.sims, NSamp, NVars))
  predictive.muni <- array(dim = c(n.sims, NVars, NCats))
  for (sim in 1:n.sims) {
    for (Var in 1:NVars) {
      for (Resp in 1:NSamp) {
        predictive[sim, Resp, Var] <- which(
          rmultinom(n = 1,
                     size = 1,
                     prob = prlevels[sim, index[Resp], Var, ] == 1)
      }
    }
  }
}

```

```

    predictive.muni[sim, Var, ] <- table(factor(predictive[sim, , Var], levels =
→ 1:NCats))/NSamp * 100
}

if (sim %in% c(1, seq(n.sims/n.chains, n.sims, n.sims/n.chains))) {
  cat(sim, "of", n.sims, "simulations", "\n")
} else {}
}

posteriormean <- round(apply(predictive.muni, 2:3, mean), 2)
PIInterval0.025 <- round(apply(predictive.muni, 2:3, quantile, prob = 0.025), 2)
PIInterval0.975 <- round(apply(predictive.muni, 2:3, quantile, prob = 0.975), 2)
for (Var in 1:NVars) {
  realvalue[Var, ] <- round(table(factor(y[muni == Muni, Var], levels = 1:NCats))/NSamp * 100,
→ 2)
}
return(list("mean" = posteriormean,
           "PI" = list("lower" = PIInterval0.025, "upper" = PIInterval0.975),
           "real" = realvalue))
return(predictive.muni)
}

# Four municipalities with the largest population in the RV
Munis <- order(apply(sample, 1, sum), decreasing = TRUE)[1:6]

# validation <- list()
# for (Muni in 1:length(Munis)) {
#   set.seed(9747783)
#   validation[[Muni]] <- SurveyMapping.Validation(prlevels = prlevels, Muni = Munis[Muni])
# }

# saveRDS(validation, file = file.path("results", "multi-2022-nimble-MH-indep-assessment.rds"))
# saveRDS(validation, file = file.path("results", "multi-2022-nimble-MH-corr-assessment.rds"))
# saveRDS(validation, file = file.path("results",
→ "multi-2022-nimble-MH-corr-ire-assessment.rds"))

indep <- readRDS(file = file.path("../", "results", "multi-2022-nimble-MH-indep-assessment.rds"))
corr <- readRDS(file = file.path("../", "results", "multi-2022-nimble-MH-corr-assessment.rds"))
corrire <- readRDS(file = file.path("../", "results",
→ "multi-2022-nimble-MH-corr-ire-assessment.rds"))

# Valencia results
# Model-Indep
indep[[1]]$mean[5, ]; indep[[1]]$PI$lower[5, ]; indep[[1]]$PI$upper[5, ]; indep[[1]]$real[5, ]

```

```
## [1] 17.81 56.02 20.73 5.43
```

```
## [1] 15.18 52.91 18.00 4.00
```

```
## [1] 20.55 59.27 23.73 7.00
```

```
## [1] 16.91 58.55 20.18 4.27
```

```
# Model-Corr
corr[[1]]$mean[5, ]; corr[[1]]$PI$lower[5, ]; corr[[1]]$PI$upper[5, ]; corr[[1]]$real[5, ]
```

```

## [1] 17.18 56.58 20.91  5.32

## [1] 14.45 53.45 18.09  4.00

## [1] 19.91 59.82 23.64  6.82

## [1] 16.91 58.55 20.18  4.27

# Model-Correlation
corriere[[1]]$mean[5, ]; corriere[[1]]$PI$lower[5, ]; corriere[[1]]$PI$upper[5, ];
→ corriere[[1]]$real[5, ]

```

```

## [1] 17.41 57.31 20.50  4.78

## [1] 15.73 54.82 18.45  3.91

## [1] 19.09 59.64 22.55  5.73

## [1] 16.91 58.55 20.18  4.27

```