

# Package: MBSP (via r-universe)

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**Type** Package

**Title** Multivariate Bayesian Model with Shrinkage Priors

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**Description** Gibbs sampler for fitting multivariate Bayesian linear regression with shrinkage priors (MBSP), using the three parameter beta normal family. The method is described in Bai and Ghosh (2018) <[doi:10.1016/j.jmva.2018.04.010](https://doi.org/10.1016/j.jmva.2018.04.010)>.

**License** GPL-3

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matrix_normal	<i>Matrix-Normal Distribution</i>
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## Description

This function provides a way to draw a sample from the matrix-normal distribution, given the mean matrix, the covariance structure of the rows, and the covariance structure of the columns.

**Usage**

```
matrix_normal(M, U, V)
```

**Arguments**

M	mean $a \times b$ matrix
U	$a \times a$ covariance matrix (covariance of rows).
V	$b \times b$ covariance matrix (covariance of columns).

**Details**

This function provides a way to draw a random  $a \times b$  matrix from the matrix-normal distribution,

$$MN(M, U, V),$$

where  $M$  is the  $a \times b$  mean matrix,  $U$  is an  $a \times a$  covariance matrix, and  $V$  is a  $b \times b$  covariance matrix.

**Value**

A randomly drawn  $a \times b$  matrix from  $MN(M, U, V)$ .

**Author(s)**

Ray Bai and Malay Ghosh

**Examples**

```
# Draw a random 50x20 matrix from MN(0,U,V),
# where:
#   0 = zero matrix of dimension 50x20
#   U has AR(1) structure,
#   V has sigma^2*I structure

# Specify Mean.mat
p <- 50
q <- 20
Mean_mat <- matrix(0, nrow=p, ncol=q)

# Construct U
rho <- 0.5
times <- 1:p
H <- abs(outer(times, times, "-"))
U <- rho^H

# Construct V
sigma_sq <- 2
V <- sigma_sq*diag(q)

# Draw from MN(Mean_mat, U, V)
mn_draw <- matrix_normal(Mean_mat, U, V)
```

## Description

This function provides a fully Bayesian approach for obtaining a (nearly) sparse estimate of the  $p \times q$  regression coefficients matrix  $B$  in the multivariate linear regression model,

$$Y = XB + E,$$

using the three parameter beta normal (TPBN) family. Here  $Y$  is the  $n \times q$  matrix with  $n$  samples of  $q$  response variables,  $X$  is the  $n \times p$  design matrix with  $n$  samples of  $p$  covariates, and  $E$  is the  $n \times q$  noise matrix with independent rows. The complete model is described in Bai and Ghosh (2018).

If there are  $r$  confounding variables which *must* remain in the model and should *not* be regularized, then these can be included in the model by putting them in a separate  $n \times r$  confounding matrix  $Z$ . Then the model that is fit is

$$Y = XB + ZC + E,$$

where  $C$  is the  $r \times q$  regression coefficients matrix corresponding to the confounders. In this case, we put a flat prior on  $C$ . By default, confounders are not included.

If the user desires, two information criteria can be computed: the Deviance Information Criterion (DIC) of Spiegelhalter et al. (2002) and the widely applicable information criterion (WAIC) of Watanabe (2010).

## Usage

```
MBSP(Y, X, confounders=NULL, u=0.5, a=0.5, tau=NA,
      max_steps=6000, burnin=1000, save_samples=TRUE,
      model_criteria=FALSE)
```

## Arguments

$Y$	Response matrix of $n$ samples and $q$ response variables.
$X$	Design matrix of $n$ samples and $p$ covariates. The MBSP model regularizes the regression coefficients $B$ corresponding to $X$ .
confounders	Optional design matrix $Z$ of $n$ samples of $r$ confounding variables. By default, confounders are not included in the model (confounders=NULL). However, if there are some confounders that <i>must</i> remain in the model and should <i>not</i> be regularized, then the user can include them here.
$u$	The first parameter in the TPBN family. Defaults to $u = 0.5$ for the horseshoe prior.
$a$	The second parameter in the TPBN family. Defaults to $a = 0.5$ for the horseshoe prior.

<code>tau</code>	The global parameter. If the user does not specify this ( <code>tau=NA</code> ), the Gibbs sampler will use $\tau = 1/(p * n * \log(n))$ . The user may also specify any value for $\tau$ strictly greater than 0; otherwise it defaults to $1/(p * n * \log(n))$ .
<code>max_steps</code>	The total number of iterations to run in the Gibbs sampler. Defaults to 6000.
<code>burnin</code>	The number of burn-in iterations for the Gibbs sampler. Defaults to 1000.
<code>save_samples</code>	A Boolean variable for whether to save all of the posterior samples of the regression coefficients matrix $B$ and the covariance matrix $\Sigma$ . Defaults to "TRUE".
<code>model_criteria</code>	A Boolean variable for whether to compute the following information criteria: DIC (Deviance Information Criterion) and WAIC (widely applicable information criterion). Can be used to compare models with (for example) different choices of $u$ , $a$ , or $\tau$ . Defaults to "FALSE".

### Details

The function performs (nearly) sparse estimation of the regression coefficients matrix  $B$  and variable selection from the  $p$  covariates. The lower and upper endpoints of the 95 percent posterior credible intervals for each of the  $pq$  elements of  $B$  are also returned so that the user may assess uncertainty quantification.

In the three parameter beta normal (TPBN) family,  $(u, a) = (0.5, 0.5)$  corresponds to the horseshoe prior,  $(u, a) = (1, 0.5)$  corresponds to the Strawderman-Berger prior, and  $(u, a) = (1, a)$ ,  $a > 0$  corresponds to the normal-exponential-gamma (NEG) prior. This function uses the horseshoe prior as the default shrinkage prior.

The user also has the option of including an  $n \times r$  matrix with  $r$  confounding variables. These confounders are variables which are included in the model but should *not* be regularized.

Finally, if the user specifies `model_criteria=TRUE`, then the MBSP function will compute two model selection criteria: the Deviance Information Criterion (DIC) of Spiegelhalter et al. (2002) and the widely applicable information criterion (WAIC) of Watanabe (2010). This permits model comparisons between (for example) different choices of  $u$ ,  $a$ , and  $\tau$ . The default horseshoe prior and choice of  $\tau$  performs well, but the user may wish to experiment with  $u$ ,  $a$ , and  $\tau$ . In general, models with *lower* DIC or WAIC are preferred.

### Value

The function returns a list containing the following components:

<code>B_est</code>	The point estimate of the $p \times q$ matrix $B$ (taken as the componentwise posterior median for all $pq$ entries).
<code>B_CI_lower</code>	The 2.5th percentile of the posterior density (or the lower endpoint of the 95 percent credible interval) for all $pq$ entries of $B$ .
<code>B_CI_upper</code>	The 97.5th percentile of the posterior density (or the upper endpoint of the 95 percent credible interval) for all $pq$ entries of $B$ .
<code>active_predictors</code>	The row indices of the active (nonzero) covariates chosen by our model from the $p$ total predictors.
<code>B_samples</code>	All <code>max_steps</code> – <code>burnin</code> samples of $B$ .

C_est	The point estimate of the $r \times q$ matrix $C$ corresponding to the confounders (taken as the componentwise posterior median for all $rq$ entries). This matrix is not returned if there are no confounders (i.e. confounders=NULL).
C_CI_lower	The 2.5th percentile of the posterior density (or the lower endpoint of the 95 percent credible interval) for all $rq$ entries of $C$ . This is not returned if there are no confounders (i.e. confounders=NULL).
C_CI_upper	The 97.5th percentile of the posterior density (or the upper endpoint of the 95 percent credible interval) for all $rq$ entries of $C$ . This is not returned if there are no confounders (i.e. confounders=NULL).
C_samples	All max_steps-burnin samples of $C$ . This is not returned if there are no confounders (i.e. confounders=NULL).
Sigma_est	The point estimate of the $q \times q$ covariance matrix $\Sigma$ (taken as the componentwise posterior median for all $q^2$ entries).
Sigma_CI_lower	The 2.5th percentile of the posterior density (or the lower endpoint of the 95 percent credible interval) for all $q^2$ entries of $\Sigma$ .
Sigma_CI_upper	The 97.5th percentile of the posterior density (or the upper endpoint of the 95 percent credible interval) for all $q^2$ entries of $\Sigma$ .
Sigma_samples	All max_steps-burnin samples of $C$ .
DIC	The Deviance Information Criterion (DIC), which can be used for model comparison. Models with smaller DIC are preferred. This only returns a numeric value if model_criteria=TRUE is specified.
WAIC	The widely applicable information criterion (WAIC), which can be used for model comparison. Models with smaller WAIC are preferred. This only returns a numeric value if model_criteria=TRUE is specified. The WAIC tends to be more stable than DIC.

### Author(s)

Ray Bai and Malay Ghosh

### References

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Strawderman, W.E. (1971). Proper Bayes Minimax Estimators of the Multivariate Normal Mean. *Annals of Mathematical Statistics*, **42**(1): 385-388.

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## Examples

```
#####
# Set n, p, q, and sparsity level #
#####

n <- 100
p <- 40
q <- 3 # number of response variables is 3
p_act <- 5 # number of active (nonzero) predictors is 5

#####
# Generate design matrix X. #
#####
set.seed(1234)
times <- 1:p
rho <- 0.5
H <- abs(outer(times, times, "-"))
V <- rho^H
mu <- rep(0, p)
# Rows of X are simulated from MVN(0,V)
X <- mvtnorm::rmvnorm(n, mu, V)
# Center X
X <- scale(X, center=TRUE, scale=FALSE)

#####
# Generate true coefficient matrix B_true. #
#####
# Entries in nonzero rows are drawn from Unif[(-5,-0.5)U(0.5,5)]
B_act <- runif(p_act*q,-5,4)
disjoint <- function(x){
  if(x <= -0.5)
    return(x)
  else
    return(x+1)
}
B_act <- matrix(sapply(B_act, disjoint),p_act,q)
# Set rest of the rows equal to 0
B_true <- rbind(B_act,matrix(0,p-p_act,q))
B_true <- B_true[sample(1:p),] # permute the rows

#####
# Generate true error covariance Sigma. #
#####
sigma_sq=2
times <- 1:q
```

```

H <- abs(outer(times, times, "-"))
Sigma <- sigma_sq * rho^H

#####
# Generate noise matrix E. #
#####
mu <- rep(0,q)
E <- mvtnorm::rmvnorm(n, mu, Sigma)

#####
# Generate response matrix Y #
#####
Y <- crossprod(t(X),B_true) + E

# Note that there are no confounding variables in this synthetic example

#####
# Fit the MBSP model on synthetic data. #
#####

# Should use default of max_steps=6000, burnin=1000 in practice.
mbsp_model = MBSP(Y=Y, X=X, max_steps=1000, burnin=500, model_criteria=FALSE)

# Recommended to use the default, i.e. can simply use: mbsp_model = MBSP(Y, X)
# If you want to return the DIC and WAIC, have to set model_criteria=TRUE.

# indices of the true nonzero rows
true_active_predictors <- which(rowSums(B_true)!=0)
true_active_predictors

# variables selected by the MBSP model
mbsp_model$active_predictors

# true regression coefficients in the true nonzero rows
B_true[true_active_predictors, ]

# the MBSP model's estimates of the nonzero rows
mbsp_model$B_est[true_active_predictors, ]

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