

# Package ‘COMBO’

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**Title** Correcting Misclassified Binary Outcomes in Association Studies

**Version** 1.0.0

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**Description** Use frequentist and Bayesian methods to estimate parameters from a binary outcome misclassification model. These methods correct for the problem of “label switching” by assuming that correct outcome classification occurs in at least 50% of observations. A description of the analysis methods is available in Hochstedler and Wells (2023) <[arXiv:2303.10215](https://arxiv.org/abs/2303.10215)>.

**Depends** R (>= 4.2.0)

**Imports** dplyr (>= 1.0.10), tidyr (>= 1.2.1), Matrix (> 1.4-1), rjags (>= 4-13), turboEM (>= 2021.1), SAMBA (>= 0.9.0), utils (>= 4.2.0)

**Suggests** knitr (>= 1.40), kableExtra (>= 1.3.4)

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**VignetteBuilder** knitr

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'pi\_compute.R' 'COMBO\_data.R' 'expit.R'  
'perfect\_sensitivity\_EM.R' 'w\_j.R' 'q\_gamma\_f.R' 'q\_beta\_f.R'  
'em\_function.R' 'loglik.R' 'COMBO\_EM.R' 'pilde\_compute.R'  
'COMBO\_data\_2stage.R' 'w\_j\_2stage.R' 'q\_delta\_f.R'  
'em\_function\_2stage.R' 'loglik\_2stage.R' 'COMBO\_EM\_2stage.R'  
'label\_switch.R' 'check\_and\_fix\_chains.R'  
'mean\_pistarjj\_compute.R' 'pistar\_compute\_for\_chains.R'  
'pistar\_by\_chain.R' 'naive\_jags\_picker.R'  
'naive\_model\_picker.R' 'jags\_picker.R' 'model\_picker.R'  
'COMBO\_MCMC.R' 'model\_picker\_2stage.R' 'COMBO\_MCMC\_2stage.R'  
'check\_and\_fix\_chains\_2stage.R' 'jags\_picker\_2stage.R'  
'label\_switch\_2stage.R' 'misclassification\_prob.R'  
'misclassification\_prob2.R' 'naive\_jags\_picker\_2stage.R'

'naive\_loglik\_2stage.R' 'naive\_model\_picker\_2stage.R'  
 'piltide\_by\_chain.R' 'piltide\_compute\_for\_chains.R'  
 'true\_classification\_prob.R'

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*check\_and\_fix\_chains*    *Check Assumption and Fix Label Switching if Assumption is Broken for a List of MCMC Samples*

### Description

Check Assumption and Fix Label Switching if Assumption is Broken for a List of MCMC Samples

### Usage

```
check_and_fix_chains(
  n_chains,
  chains_list,
  pistarjj_matrix,
  dim_x,
  dim_z,
  n_cat
)
```

### Arguments

- `n_chains`        An integer specifying the number of MCMC chains to compute over.
- `chains_list`     A numeric list containing the samples from `n_chains` MCMC chains.
- `pistarjj_matrix`     A numeric matrix of the average conditional probability  $P(Y^* = j|Y = j, Z)$  across all subjects for each MCMC chain, obtained from the `pistar_by_chain` function.
- `dim_x`            The number of columns of the design matrix of the true outcome mechanism,  $X$ .
- `dim_z`            The number of columns of the design matrix of the observation mechanism,  $Z$ .
- `n_cat`            The number of categorical values that the true outcome,  $Y$ , and the observed outcome,  $Y^*$  can take.

### Value

`check_and_fix_chains` returns a numeric list of the samples from `n_chains` MCMC chains which have been corrected for label switching if the following assumption is not met:  $P(Y^* = j|Y = j, Z) > 0.50 \forall j$ .

---

check\_and\_fix\_chains\_2stage

*Check Assumption and Fix Label Switching if Assumption is Broken for a List of MCMC Samples*

---

## Description

Check Assumption and Fix Label Switching if Assumption is Broken for a List of MCMC Samples

## Usage

```
check_and_fix_chains_2stage(
  n_chains,
  chains_list,
  pistarjj_matrix,
  pitildejjj_matrix,
  dim_x,
  dim_z,
  dim_v,
  n_cat
)
```

## Arguments

n_chains	An integer specifying the number of MCMC chains to compute over.
chains_list	A numeric list containing the samples from n_chains MCMC chains.
pistarjj_matrix	A numeric matrix of the average conditional probability $P(Y^* = j   Y = j, Z)$ across all subjects for each MCMC chain, obtained from the pistar_by_chain function.
pitildejjj_matrix	A numeric matrix of the average conditional probability $P(\tilde{Y} = j   Y^* = j, Y = j, V)$ across all subjects for each MCMC chain. Rows of the matrix correspond to MCMC chains, up to n_chains. Obtained from the pitilde_by_chain function.
dim_x	The number of columns of the design matrix of the true outcome mechanism, X.
dim_z	The number of columns of the design matrix of the first-stage observation mechanism, Z.
dim_v	The number of columns of the design matrix of the second-stage observation mechanism, V.
n_cat	The number of categorical values that the true outcome, Y, and the observed outcome, Y* can take.

**Value**

check\_and\_fix\_chains returns a numeric list of the samples from `n_chains` MCMC chains which have been corrected for label switching if the following assumption is not met:  $P(Y^* = j|Y = j, Z) > 0.50 \forall j$ .

COMBO\_data

*Generate Data to use in COMBO Functions***Description**

Generate Data to use in COMBO Functions

**Usage**

```
COMBO_data(sample_size, x_mu, x_sigma, z_shape, beta, gamma)
```

**Arguments**

sample_size	An integer specifying the sample size of the generated data set.
x_mu	A numeric value specifying the mean of <code>x</code> predictors generated from a Normal distribution.
x_sigma	A positive numeric value specifying the standard deviation of <code>x</code> predictors generated from a Normal distribution.
z_shape	A positive numeric value specifying the shape parameter of <code>z</code> predictors generated from a Gamma distribution.
beta	A column matrix of $\beta$ parameter values (intercept, slope) to generate data under in the true outcome mechanism.
gamma	A numeric matrix of $\gamma$ parameters to generate data under in the observation mechanism. In matrix form, the gamma matrix rows correspond to intercept (row 1) and slope (row 2) terms. The gamma parameter matrix columns correspond to the true outcome categories $Y \in \{1, 2\}$ .

**Value**

COMBO\_data returns a list of generated data elements:

obs_Y	A vector of observed outcomes.
true_Y	A vector of true outcomes.
obs_Y_matrix	A numeric matrix of indicator variables (0, 1) for the observed outcome $Y^*$ . Rows of the matrix correspond to each subject. Columns of the matrix correspond to each observed outcome category. Each row contains exactly one 0 entry and exactly one 1 entry.
x	A vector of generated predictor values in the true outcome mechanism, from the Normal distribution.

`z` A vector of generated predictor values in the observation mechanism from the Gamma distribution.

`x_design_matrix` The design matrix for the x predictor.

`z_design_matrix` The design matrix for the z predictor.

### Examples

```
set.seed(123)
n <- 500
x_mu <- 0
x_sigma <- 1
z_shape <- 1

true_beta <- matrix(c(1, -2), ncol = 1)
true_gamma <- matrix(c(.5, 1, -.5, -1), nrow = 2, byrow = FALSE)

my_data <- COMBO_data(sample_size = n,
                      x_mu = x_mu, x_sigma = x_sigma,
                      z_shape = z_shape,
                      beta = true_beta, gamma = true_gamma)
table(my_data[["obs_Y"]], my_data[["true_Y"]])
```

---

COMBO\_data\_2stage      *Generate Data to use in two-stage COMBO Functions*

---

### Description

Generate Data to use in two-stage COMBO Functions

### Usage

```
COMBO_data_2stage(
  sample_size,
  x_mu,
  x_sigma,
  z_shape,
  v_shape,
  beta,
  gamma,
  delta
)
```

**Arguments**

sample_size	An integer specifying the sample size of the generated data set.
x_mu	A numeric value specifying the mean of $x$ predictors generated from a Normal distribution.
x_sigma	A positive numeric value specifying the standard deviation of $x$ predictors generated from a Normal distribution.
z_shape	A positive numeric value specifying the shape parameter of $z$ predictors generated from a Gamma distribution.
v_shape	A positive numeric value specifying the shape parameter of $v$ predictors generated from a Gamma distribution.
beta	A column matrix of $\beta$ parameter values (intercept, slope) to generate data under in the true outcome mechanism.
gamma	A numeric matrix of $\gamma$ parameters to generate data under in the first-stage observation mechanism. In matrix form, the gamma matrix rows correspond to intercept (row 1) and slope (row 2) terms. The gamma parameter matrix columns correspond to the true outcome categories $Y \in \{1, 2\}$ .
delta	A numeric array of $\delta$ parameters to generate data under the second-stage observation mechanism. In array form, the delta matrix rows correspond to intercept (row 1) and slope (row 2) terms. The matrix columns correspond to first-stage observed outcome categories. The third dimension of the delta array is indexed by the true outcome categories.

**Value**

COMBO\_data\_2stage returns a list of generated data elements:

obs_Ystar	A vector of first-stage observed outcomes.
obs_Ytilde	A vector of second-stage observed outcomes.
true_Y	A vector of true outcomes.
obs_Ystar_matrix	A numeric matrix of indicator variables (0, 1) for the first-stage observed outcome $Y^*$ . Rows of the matrix correspond to each subject. Columns of the matrix correspond to each observed outcome category. Each row contains exactly one 0 entry and exactly one 1 entry.
obs_Ytilde_matrix	A numeric matrix of indicator variables (0, 1) for the second-stage observed outcome $Y^*$ . Rows of the matrix correspond to each subject. Columns of the matrix correspond to each observed outcome category. Each row contains exactly one 0 entry and exactly one 1 entry.
x	A vector of generated predictor values in the true outcome mechanism, from the Normal distribution.
z	A vector of generated predictor values in the first-stage observation mechanism from the Gamma distribution.
v	A vector of generated predictor values in the second-stage observation mechanism from the Gamma distribution.

`x_design_matrix`  
The design matrix for the x predictor.

`z_design_matrix`  
The design matrix for the z predictor.

`v_design_matrix`  
The design matrix for the v predictor.

### Examples

```
set.seed(123)
n <- 500
x_mu <- 0
x_sigma <- 1
z_shape <- 1
v_shape <- 1

true_beta <- matrix(c(1, -2), ncol = 1)
true_gamma <- matrix(c(.5, 1, -.5, -1), nrow = 2, byrow = FALSE)
true_delta <- array(c(1.5, 1, .5, .5, -.5, 0, -1, -1), dim = c(2, 2, 2))

my_data <- COMBO_data_2stage(sample_size = n,
                             x_mu = x_mu, x_sigma = x_sigma,
                             z_shape = z_shape, v_shape = v_shape,
                             beta = true_beta, gamma = true_gamma, delta = true_delta)
table(my_data[["obs_Ytilde"]], my_data[["obs_Ystar"]], my_data[["true_Y"]])
```

---

COMBO\_EM

*EM-Algorithm Estimation of the Binary Outcome Misclassification Model*

---

### Description

Jointly estimate  $\beta$  and  $\gamma$  parameters from the true outcome and observation mechanisms, respectively, in a binary outcome misclassification model.

### Usage

```
COMBO_EM(  
  Ystar,  
  x_matrix,  
  z_matrix,  
  beta_start,  
  gamma_start,  
  tolerance = 1e-07,  
  max_em_iterations = 1500,  
  em_method = "squarem"  
)
```



**Arguments**

<code>Ystar</code>	A numeric vector of indicator variables (1, 2) for the observed outcome $Y^*$ . There should be no NA terms. The reference category is 2.
<code>x_matrix</code>	A numeric matrix of covariates in the true outcome mechanism. <code>x_matrix</code> should not contain an intercept and no values should be NA.
<code>z_matrix</code>	A numeric matrix of covariates in the observation mechanism. <code>z_matrix</code> should not contain an intercept and no values should be NA.
<code>beta_start</code>	A numeric vector or column matrix of starting values for the $\beta$ parameters in the true outcome mechanism. The number of elements in <code>beta_start</code> should be equal to the number of columns of <code>x_matrix</code> plus 1.
<code>gamma_start</code>	A numeric vector or matrix of starting values for the $\gamma$ parameters in the observation mechanism. In matrix form, the <code>gamma_start</code> matrix rows correspond to parameters for the $Y^* = 1$ observed outcome, with the dimensions of <code>z_matrix</code> plus 1, and the <code>gamma</code> parameter matrix columns correspond to the true outcome categories $Y \in \{1, 2\}$ . A numeric vector for <code>gamma_start</code> is obtained by concatenating the <code>gamma</code> matrix, i.e. <code>gamma_start &lt;- c(gamma_matrix)</code> .
<code>tolerance</code>	A numeric value specifying when to stop estimation, based on the difference of subsequent log-likelihood estimates. The default is $1e-7$ .
<code>max_em_iterations</code>	An integer specifying the maximum number of iterations of the EM algorithm. The default is 1500.
<code>em_method</code>	A character string specifying which EM algorithm will be applied. Options are "em", "squarem", or "pem". The default and recommended option is "squarem".

**Value**

COMBO\_EM returns a data frame containing four columns. The first column, `Parameter`, represents a unique parameter value for each row. The next column contains the parameter `Estimates`, followed by the standard error estimates, `SE`. The final column, `Convergence`, reports whether or not the algorithm converged for a given parameter estimate.

Estimates are provided for the binary misclassification model, as well as two additional cases. The "SAMBA" parameter estimates are from the R Package, SAMBA, which uses the EM algorithm to estimate a binary outcome misclassification model that assumes there is perfect specificity. The "PSens" parameter estimates are estimated using the EM algorithm for the binary outcome misclassification model that assumes there is perfect sensitivity. The "Naive" parameter estimates are from a simple logistic regression  $Y^* \sim X$ .

**References**

Beesley, L. and Mukherjee, B. (2020). Statistical inference for association studies using electronic health records: Handling both selection bias and outcome misclassification. *Biometrics*, 78, 214-226.

**Examples**

```

set.seed(123)
n <- 1000
x_mu <- 0
x_sigma <- 1
z_shape <- 1

true_beta <- matrix(c(1, -2), ncol = 1)
true_gamma <- matrix(c(.5, 1, -.5, -1), nrow = 2, byrow = FALSE)

x_matrix = matrix(rnorm(n, x_mu, x_sigma), ncol = 1)
X = matrix(c(rep(1, n), x_matrix[,1]), ncol = 2, byrow = FALSE)
z_matrix = matrix(rgamma(n, z_shape), ncol = 1)
Z = matrix(c(rep(1, n), z_matrix[,1]), ncol = 2, byrow = FALSE)

exp_xb = exp(X %*% true_beta)
pi_result = exp_xb[,1] / (exp_xb[,1] + 1)
pi_matrix = matrix(c(pi_result, 1 - pi_result), ncol = 2, byrow = FALSE)

true_Y <- rep(NA, n)
for(i in 1:n){
  true_Y[i] = which(stats::rmultinom(1, 1, pi_matrix[i,]) == 1)
}

exp_zg = exp(Z %*% true_gamma)
pistar_denominator = matrix(c(1 + exp_zg[,1], 1 + exp_zg[,2]), ncol = 2, byrow = FALSE)
pistar_result = exp_zg / pistar_denominator

pistar_matrix = matrix(c(pistar_result[,1], 1 - pistar_result[,1],
                        pistar_result[,2], 1 - pistar_result[,2]),
                      ncol = 2, byrow = FALSE)

obs_Y <- rep(NA, n)
for(i in 1:n){
  true_j = true_Y[i]
  obs_Y[i] = which(rmultinom(1, 1,
                            pistar_matrix[c(i, n + i),
                            true_j]) == 1)
}

Ystar <- obs_Y

starting_values <- rep(1,6)
beta_start <- matrix(starting_values[1:2], ncol = 1)
gamma_start <- matrix(starting_values[3:6], ncol = 2, nrow = 2, byrow = FALSE)

EM_results <- COMBO_EM(Ystar, x_matrix = x_matrix, z_matrix = z_matrix,
                      beta_start = beta_start, gamma_start = gamma_start)

EM_results

```

---

COMBO\_EM\_2stage      *EM-Algorithm Estimation of the Two-Stage Binary Outcome Misclassification Model*

---

### Description

Jointly estimate  $\beta$ ,  $\gamma$ ,  $\delta$  parameters from the true outcome, first-stage observation, and second-stage observation mechanisms, respectively, in a two-stage binary outcome misclassification model.

### Usage

```
COMBO_EM_2stage(
  Ystar,
  Ytilde,
  x_matrix,
  z_matrix,
  v_matrix,
  beta_start,
  gamma_start,
  delta_start,
  tolerance = 1e-07,
  max_em_iterations = 1500,
  em_method = "squarem"
)
```

### Arguments

Ystar	A numeric vector of indicator variables (1, 2) for the first-stage observed outcome $Y^*$ . There should be no NA terms. The reference category is 2.
Ytilde	A numeric vector of indicator variables (1, 2) for the second-stage observed outcome $\tilde{Y}$ . There should be no NA terms. The reference category is 2.
x_matrix	A numeric matrix of covariates in the true outcome mechanism. <code>x_matrix</code> should not contain an intercept and no values should be NA.
z_matrix	A numeric matrix of covariates in the first-stage observation mechanism. <code>z_matrix</code> should not contain an intercept and no values should be NA.
v_matrix	A numeric matrix of covariates in the second-stage observation mechanism. <code>v_matrix</code> should not contain an intercept and no values should be NA.
beta_start	A numeric vector or column matrix of starting values for the $\beta$ parameters in the true outcome mechanism. The number of elements in <code>beta_start</code> should be equal to the number of columns of <code>x_matrix</code> plus 1.
gamma_start	A numeric vector or matrix of starting values for the $\gamma$ parameters in the first-stage observation mechanism. In matrix form, the <code>gamma_start</code> matrix rows correspond to parameters for the $Y^* = 1$ first-stage observed outcome, with the dimensions of <code>z_matrix</code> plus 1, and the <code>gamma</code> parameter matrix columns correspond to the true outcome categories $Y \in \{1, 2\}$ . A numeric vector for <code>gamma_start</code> is obtained by concatenating the <code>gamma</code> matrix, i.e. <code>gamma_start &lt;- c(gamma_matrix)</code> .



```

z_matrix = my_data[["z"]],
v_matrix = my_data[["v"]],
beta_start = beta_start,
gamma_start = gamma_start,
delta_start = delta_start)

```

EM\_results

---

COMBO\_MCMC

*MCMC Estimation of the Binary Outcome Misclassification Model*

---

### Description

Jointly estimate  $\beta$  and  $\gamma$  parameters from the true outcome and observation mechanisms, respectively, in a binary outcome misclassification model.

### Usage

```

COMBO_MCMC(
  Ystar,
  x,
  z,
  prior,
  beta_prior_parameters,
  gamma_prior_parameters,
  number_MCMC_chains = 4,
  MCMC_sample = 2000,
  burn_in = 1000,
  display_progress = TRUE
)

```

### Arguments

Ystar	A numeric vector of indicator variables (1, 2) for the observed outcome $Y^*$ . The reference category is 2.
x	A numeric matrix of covariates in the true outcome mechanism. x should not contain an intercept.
z	A numeric matrix of covariates in the observation mechanism. z should not contain an intercept.
prior	A character string specifying the prior distribution for the $\beta$ and $\gamma$ parameters. Options are "t", "uniform", "normal", or "dexp" (double Exponential, or Weibull).
beta_prior_parameters	A numeric list of prior distribution parameters for the $\beta$ terms. For prior distributions "t", "uniform", "normal", or "dexp", the first element of the list should contain a matrix of location, lower bound, mean, or shape parameters,

respectively, for  $\beta$  terms. For prior distributions "t", "uniform", "normal", or "dexp", the second element of the list should contain a matrix of shape, upper bound, standard deviation, or scale parameters, respectively, for  $\beta$  terms. For prior distribution "t", the third element of the list should contain a matrix of the degrees of freedom for  $\beta$  terms. The third list element should be empty for all other prior distributions. All matrices in the list should have dimensions  $n\_cat \times \dim\_x$ , and all elements in the  $n\_cat$  row should be set to NA.

`gamma_prior_parameters`

A numeric list of prior distribution parameters for the  $\gamma$  terms. For prior distributions "t", "uniform", "normal", or "dexp", the first element of the list should contain an array of location, lower bound, mean, or shape parameters, respectively, for  $\gamma$  terms. For prior distributions "t", "uniform", "normal", or "dexp", the second element of the list should contain an array of shape, upper bound, standard deviation, or scale parameters, respectively, for  $\gamma$  terms. For prior distribution "t", the third element of the list should contain an array of the degrees of freedom for  $\gamma$  terms. The third list element should be empty for all other prior distributions. All arrays in the list should have dimensions  $n\_cat \times n\_cat \times \dim\_z$ , and all elements in the  $n\_cat$  row should be set to NA.

`number_MCMC_chains`

An integer specifying the number of MCMC chains to compute. The default is 4.

`MCMC_sample`

An integer specifying the number of MCMC samples to draw. The default is 2000.

`burn_in`

An integer specifying the number of MCMC samples to discard for the burn-in period. The default is 1000.

`display_progress`

A logical value specifying whether messages should be displayed during model compilation. The default is TRUE.

## Value

COMBO\_MCMC returns a list of the posterior samples and posterior means for both the binary outcome misclassification model and a naive logistic regression of the observed outcome,  $Y^*$ , predicted by the matrix  $x$ . The list contains the following components:

`posterior_sample_df`

A data frame containing three columns. The first column indicates the chain from which a sample is taken, from 1 to `number_MCMC_chains`. The second column specifies the parameter associated with a given row.  $\beta$  terms have dimensions  $\dim\_x \times n\_cat$ . The  $\gamma$  terms have dimensions  $n\_cat \times n\_cat \times \dim\_z$ , where the first index specifies the observed outcome category and the second index specifies the true outcome category. The final column provides the MCMC sample.

`posterior_means_df`

A data frame containing three columns. The first column specifies the parameter associated with a given row. Parameters are indexed as in the `posterior_sample_df`. The second column provides the posterior mean computed across all chains and all samples. The final column provides the posterior median computed across all chains and all samples.

`naive_posterior_sample_df`

A data frame containing three columns. The first column indicates the chain from which a sample is taken, from 1 to `number_MCMC_chains`. The second column specifies the parameter associated with a given row. Naive  $\beta$  terms have dimensions `dim_x` X `n_cat`. The final column provides the MCMC sample.

`naive_posterior_means_df`

A data frame containing three columns. The first column specifies the naive parameter associated with a given row. Parameters are indexed as in the `naive_posterior_sample_df`. The second column provides the posterior mean computed across all chains and all samples. The final column provides the posterior median computed across all chains and all samples.

## Examples

```
set.seed(123)
n <- 1000
x_mu <- 0
x_sigma <- 1
z_shape <- 1

true_beta <- matrix(c(1, -2), ncol = 1)
true_gamma <- matrix(c(.5, 1, -.5, -1), nrow = 2, byrow = FALSE)

x_matrix = matrix(rnorm(n, x_mu, x_sigma), ncol = 1)
X = matrix(c(rep(1, n), x_matrix[,1]), ncol = 2, byrow = FALSE)
z_matrix = matrix(rgamma(n, z_shape), ncol = 1)
Z = matrix(c(rep(1, n), z_matrix[,1]), ncol = 2, byrow = FALSE)

exp_xb = exp(X %*% true_beta)
pi_result = exp_xb[,1] / (exp_xb[,1] + 1)
pi_matrix = matrix(c(pi_result, 1 - pi_result), ncol = 2, byrow = FALSE)

true_Y <- rep(NA, n)
for(i in 1:n){
  true_Y[i] = which(stats::rmultinom(1, 1, pi_matrix[i,]) == 1)
}

exp_zg = exp(Z %*% true_gamma)
pistar_denominator = matrix(c(1 + exp_zg[,1], 1 + exp_zg[,2]), ncol = 2, byrow = FALSE)
pistar_result = exp_zg / pistar_denominator

pistar_matrix = matrix(c(pistar_result[,1], 1 - pistar_result[,1],
                        pistar_result[,2], 1 - pistar_result[,2]),
                      ncol = 2, byrow = FALSE)

obs_Y <- rep(NA, n)
for(i in 1:n){
  true_j = true_Y[i]
  obs_Y[i] = which(rmultinom(1, 1,
                            pistar_matrix[c(i, n + i),
                            true_j]) == 1)
```

```

}

Ystar <- obs_Y

unif_lower_beta <- matrix(c(-5, -5, NA, NA), nrow = 2, byrow = TRUE)
unif_upper_beta <- matrix(c(5, 5, NA, NA), nrow = 2, byrow = TRUE)

unif_lower_gamma <- array(data = c(-5, NA, -5, NA, -5, NA, -5, NA),
                          dim = c(2,2,2))
unif_upper_gamma <- array(data = c(5, NA, 5, NA, 5, NA, 5, NA),
                          dim = c(2,2,2))

beta_prior_parameters <- list(lower = unif_lower_beta, upper = unif_upper_beta)
gamma_prior_parameters <- list(lower = unif_lower_gamma, upper = unif_upper_gamma)

MCMC_results <- COMBO_MCMC(Ystar, x = x_matrix, z = z_matrix,
                          prior = "uniform",
                          beta_prior_parameters = beta_prior_parameters,
                          gamma_prior_parameters = gamma_prior_parameters,
                          number_MCMC_chains = 2,
                          MCMC_sample = 200, burn_in = 100)

MCMC_results$posterior_means_df

```

---

COMBO\_MCMC\_2stage

*MCMC Estimation of the Two-Stage Binary Outcome Misclassification Model*


---

### Description

Jointly estimate  $\beta$ ,  $\gamma$ , and  $\delta$  parameters from the true outcome first-stage observation, and second-stage observation mechanisms, respectively, in a two-stage binary outcome misclassification model.

### Usage

```

COMBO_MCMC_2stage(
  Ystar,
  Ytilde,
  x,
  z,
  v,
  prior,
  beta_prior_parameters,
  gamma_prior_parameters,
  delta_prior_parameters,
  naive_delta_prior_parameters,
  number_MCMC_chains = 4,
  MCMC_sample = 2000,
  burn_in = 1000,
  display_progress = TRUE
)

```



**Arguments**

<code>Ystar</code>	A numeric vector of indicator variables (1, 2) for the observed outcome $Y^*$ . The reference category is 2.
<code>Ytilde</code>	A numeric vector of indicator variables (1, 2) for the second-stage observed outcome $\tilde{Y}$ . There should be no NA terms. The reference category is 2.
<code>x</code>	A numeric matrix of covariates in the true outcome mechanism. <code>x</code> should not contain an intercept.
<code>z</code>	A numeric matrix of covariates in the observation mechanism. <code>z</code> should not contain an intercept.
<code>v</code>	A numeric matrix of covariates in the second-stage observation mechanism. <code>v</code> should not contain an intercept and no values should be NA.
<code>prior</code>	A character string specifying the prior distribution for the $\beta$ , $\gamma$ , and $\delta$ parameters. Options are "t", "uniform", "normal", or "dexp" (double Exponential, or Weibull).
<code>beta_prior_parameters</code>	A numeric list of prior distribution parameters for the $\beta$ terms. For prior distributions "t", "uniform", "normal", or "dexp", the first element of the list should contain a matrix of location, lower bound, mean, or shape parameters, respectively, for $\beta$ terms. For prior distributions "t", "uniform", "normal", or "dexp", the second element of the list should contain a matrix of shape, upper bound, standard deviation, or scale parameters, respectively, for $\beta$ terms. For prior distribution "t", the third element of the list should contain a matrix of the degrees of freedom for $\beta$ terms. The third list element should be empty for all other prior distributions. All matrices in the list should have dimensions <code>n_cat X dim_x</code> , and all elements in the <code>n_cat</code> row should be set to NA.
<code>gamma_prior_parameters</code>	A numeric list of prior distribution parameters for the $\gamma$ terms. For prior distributions "t", "uniform", "normal", or "dexp", the first element of the list should contain an array of location, lower bound, mean, or shape parameters, respectively, for $\gamma$ terms. For prior distributions "t", "uniform", "normal", or "dexp", the second element of the list should contain an array of shape, upper bound, standard deviation, or scale parameters, respectively, for $\gamma$ terms. For prior distribution "t", the third element of the list should contain an array of the degrees of freedom for $\gamma$ terms. The third list element should be empty for all other prior distributions. All arrays in the list should have dimensions <code>n_cat X n_cat X dim_z</code> , and all elements in the <code>n_cat</code> row should be set to NA.
<code>delta_prior_parameters</code>	A numeric list of prior distribution parameters for the $\delta$ terms. For prior distributions "t", "uniform", "normal", or "dexp", the first element of the list should contain an array of location, lower bound, mean, or shape parameters, respectively, for $\delta$ terms. For prior distributions "t", "uniform", "normal", or "dexp", the second element of the list should contain an array of shape, upper bound, standard deviation, or scale parameters, respectively, for $\delta$ terms. For prior distribution "t", the third element of the list should contain an array of the degrees of freedom for $\delta$ terms. The third list element should be empty for all other prior distributions. All arrays in the list should have dimensions <code>n_cat X n_cat X n_cat X dim_v</code> , and all elements in the <code>n_cat</code> row should be set to NA.

<code>naive_delta_prior_parameters</code>	A numeric list of prior distribution parameters for the naive model $\delta$ terms. For prior distributions "t", "uniform", "normal", or "dexp", the first element of the list should contain an array of location, lower bound, mean, or shape parameters, respectively, for naive $\delta$ terms. For prior distributions "t", "uniform", "normal", or "dexp", the second element of the list should contain an array of shape, upper bound, standard deviation, or scale parameters, respectively, for naive $\delta$ terms. For prior distribution "t", the third element of the list should contain an array of the degrees of freedom for naive $\delta$ terms. The third list element should be empty for all other prior distributions. All arrays in the list should have dimensions $n\_cat \times n\_cat \times dim\_v$ , and all elements in the $n\_cat$ row should be set to NA. Note that prior distributions for the naive $\beta$ terms are inherited from the <code>beta_prior_parameters</code> argument.
<code>number_MCMC_chains</code>	An integer specifying the number of MCMC chains to compute. The default is 4.
<code>MCMC_sample</code>	An integer specifying the number of MCMC samples to draw. The default is 2000.
<code>burn_in</code>	An integer specifying the number of MCMC samples to discard for the burn-in period. The default is 1000.
<code>display_progress</code>	A logical value specifying whether messages should be displayed during model compilation. The default is TRUE.

## Value

COMBO\_MCMC\_2stage returns a list of the posterior samples and posterior means for both the binary outcome misclassification model and a naive logistic regression of the observed outcome,  $Y^*$ , predicted by the matrix  $x$ . The list contains the following components:

<code>posterior_sample_df</code>	A data frame containing three columns. The first column indicates the chain from which a sample is taken, from 1 to <code>number_MCMC_chains</code> . The second column specifies the parameter associated with a given row. $\beta$ terms have dimensions $dim\_x \times n\_cat$ . The $\gamma$ terms have dimensions $n\_cat \times n\_cat \times dim\_z$ , where the first index specifies the observed outcome category and the second index specifies the true outcome category. The final column provides the MCMC sample.
<code>posterior_means_df</code>	A data frame containing three columns. The first column specifies the parameter associated with a given row. Parameters are indexed as in the <code>posterior_sample_df</code> . The second column provides the posterior mean computed across all chains and all samples. The final column provides the posterior median computed across all chains and all samples.
<code>naive_posterior_sample_df</code>	A data frame containing three columns. The first column indicates the chain from which a sample is taken, from 1 to <code>number_MCMC_chains</code> . The second column specifies the parameter associated with a given row. Naive $\beta$ terms have dimensions $dim\_x \times n\_cat$ . The final column provides the MCMC sample.

naive\_posterior\_means\_df

A data frame containing three columns. The first column specifies the naive parameter associated with a given row. Parameters are indexed as in the naive\_posterior\_sample\_df. The second column provides the posterior mean computed across all chains and all samples. The final column provides the posterior median computed across all chains and all samples.

## Examples

```
# Helper functions
sum_every_n <- function(x, n){
  vector_groups = split(x,
                        ceiling(seq_along(x) / n))
  sum_x = Reduce(`+`, vector_groups)

  return(sum_x)
}

sum_every_n1 <- function(x, n){
  vector_groups = split(x,
                        ceiling(seq_along(x) / n))
  sum_x = Reduce(`+`, vector_groups) + 1

  return(sum_x)
}

# Example

set.seed(123)
n <- 1000
x_mu <- 0
x_sigma <- 1
z_shape <- 1
v_shape <- 1

true_beta <- matrix(c(1, -2), ncol = 1)
true_gamma <- matrix(c(.5, 1, -.5, -1), nrow = 2, byrow = FALSE)
true_delta <- array(c(1.5, 1, .5, .5, -.5, 0, -1, -1), dim = c(2, 2, 2))

x_matrix = matrix(rnorm(n, x_mu, x_sigma), ncol = 1)
X = matrix(c(rep(1, n), x_matrix[,1]), ncol = 2, byrow = FALSE)
z_matrix = matrix(rgamma(n, z_shape), ncol = 1)
Z = matrix(c(rep(1, n), z_matrix[,1]), ncol = 2, byrow = FALSE)
v_matrix = matrix(rgamma(n, v_shape), ncol = 1)
V = matrix(c(rep(1, n), v_matrix[,1]), ncol = 2, byrow = FALSE)

exp_xb = exp(X %*% true_beta)
pi_result = exp_xb[,1] / (exp_xb[,1] + 1)
pi_matrix = matrix(c(pi_result, 1 - pi_result), ncol = 2, byrow = FALSE)
```



```

}

Ytilde <- obs_Ytilde

unif_lower_beta <- matrix(c(-5, -5, NA, NA), nrow = 2, byrow = TRUE)
unif_upper_beta <- matrix(c(5, 5, NA, NA), nrow = 2, byrow = TRUE)

unif_lower_gamma <- array(data = c(-5, NA, -5, NA, -5, NA, -5, NA),
                          dim = c(2,2,2))
unif_upper_gamma <- array(data = c(5, NA, 5, NA, 5, NA, 5, NA),
                          dim = c(2,2,2))

unif_upper_delta <- array(rep(c(5, NA), 8), dim = c(2,2,2,2))
unif_lower_delta <- array(rep(c(-5, NA), 8), dim = c(2,2,2,2))

unif_lower_naive_delta <- array(data = c(-5, NA, -5, NA, -5, NA, -5, NA),
                                dim = c(2,2,2))
unif_upper_naive_delta <- array(data = c(5, NA, 5, NA, 5, NA, 5, NA),
                                dim = c(2,2,2))

beta_prior_parameters <- list(lower = unif_lower_beta, upper = unif_upper_beta)
gamma_prior_parameters <- list(lower = unif_lower_gamma, upper = unif_upper_gamma)
delta_prior_parameters <- list(lower = unif_lower_delta, upper = unif_upper_delta)
naive_delta_prior_parameters <- list(lower = unif_lower_naive_delta,
                                     upper = unif_upper_naive_delta)

MCMC_results <- COMBO_MCMC_2stage(Ystar, Ytilde,
                                x = x_matrix, z = z_matrix,
                                v = v_matrix,
                                prior = "uniform",
                                beta_prior_parameters = beta_prior_parameters,
                                gamma_prior_parameters = gamma_prior_parameters,
                                delta_prior_parameters = delta_prior_parameters,
                                naive_delta_prior_parameters = naive_delta_prior_parameters,
                                number_MCMC_chains = 2,
                                MCMC_sample = 200, burn_in = 100)

MCMC_results$posterior_means_df

```

---

em\_function

*EM-Algorithm Function for Estimation of the Misclassification Model*


---

## Description

EM-Algorithm Function for Estimation of the Misclassification Model

## Usage

```
em_function(param_current, obs_Y_matrix, X, Z, sample_size, n_cat)
```

**Arguments**

param_current	A numeric vector of regression parameters, in the order $\beta, \gamma$ . The $\gamma$ vector is obtained from the matrix form. In matrix form, the gamma parameter matrix rows correspond to parameters for the $Y^* = 1$ observed outcome, with the dimensions of Z. In matrix form, the gamma parameter matrix columns correspond to the true outcome categories $j = 1, \dots, n\_cat$ . The numeric vector gamma_v is obtained by concatenating the gamma matrix, i.e. <code>gamma_v &lt;- c(gamma_matrix)</code> .
obs_Y_matrix	A numeric matrix of indicator variables (0, 1) for the observed outcome $Y^*$ . Rows of the matrix correspond to each subject. Columns of the matrix correspond to each observed outcome category. Each row should contain exactly one 0 entry and exactly one 1 entry.
X	A numeric design matrix for the true outcome mechanism.
Z	A numeric design matrix for the observation mechanism.
sample_size	An integer value specifying the number of observations in the sample. This value should be equal to the number of rows of the design matrix, X or Z.
n_cat	The number of categorical values that the true outcome, Y, and the observed outcome, $Y^*$ can take.

**Value**

em\_function returns a numeric vector of updated parameter estimates from one iteration of the EM-algorithm.

---

em_function_2stage	<i>EM-Algorithm Function for Estimation of the Two-Stage Misclassification Model</i>
--------------------	--

---

**Description**

EM-Algorithm Function for Estimation of the Two-Stage Misclassification Model

**Usage**

```
em_function_2stage(
  param_current,
  obs_Ystar_matrix,
  obs_Ytilde_matrix,
  X,
  Z,
  V,
  sample_size,
  n_cat
)
```

**Arguments**

- `param_current` A numeric vector of regression parameters, in the order  $\beta, \gamma, \delta$ . The  $\gamma$  vector is obtained from the matrix form. In matrix form, the gamma parameter matrix rows correspond to parameters for the  $Y^* = 1$  observed outcome, with the dimensions of  $Z$ . In matrix form, the gamma parameter matrix columns correspond to the true outcome categories  $j = 1, \dots, n\_cat$ . The numeric vector  $\gamma$  is obtained by concatenating the gamma matrix, i.e. `gamma_v <- c(gamma_matrix)`. The  $\delta$  vector is obtained from the array form. In array form, the first dimension (matrix rows) of `delta` corresponds to parameters for the  $\tilde{Y} = 1$  second-stage observed outcome, with the dimensions of the  $V$ . The second dimension (matrix columns) correspond to the first-stage observed outcome categories  $Y^* \in \{1, 2\}$ . The third dimension of `delta_start` corresponds to to the true outcome categories  $Y \in \{1, 2\}$ . The numeric vector  $\delta$  is obtained by concatenating the delta array, i.e. `delta_vector <- c(delta_array)`.
- `obs_Ystar_matrix` A numeric matrix of indicator variables (0, 1) for the first-stage observed outcome  $Y^*$ . Rows of the matrix correspond to each subject. Columns of the matrix correspond to each observed outcome category. Each row should contain exactly one 0 entry and exactly one 1 entry.
- `obs_Ytilde_matrix` A numeric matrix of indicator variables (0, 1) for the second-stage observed outcome  $\tilde{Y}$ . Rows of the matrix correspond to each subject. Columns of the matrix correspond to each observed outcome category. Each row should contain exactly one 0 entry and exactly one 1 entry.
- `X` A numeric design matrix for the true outcome mechanism.
- `Z` A numeric design matrix for the first-stage observation mechanism.
- `V` A numeric design matrix for the second-stage observation mechanism.
- `sample_size` An integer value specifying the number of observations in the sample. This value should be equal to the number of rows of the design matrices,  $X$ ,  $Z$ , and  $V$ .
- `n_cat` The number of categorical values that the true outcome,  $Y$ , and the observed outcomes,  $Y^*$  and  $\tilde{Y}$ , can take.

**Value**

`em_function_2stage` returns a numeric vector of updated parameter estimates from one iteration of the EM-algorithm.

---

expit

*Expit function*

---

**Description**

$$\frac{\exp\{x\}}{1+\exp\{x\}}$$

**Usage**

```
expit(x)
```

**Arguments**

x                    A numeric value or vector to compute the expit function on.

**Value**

expit returns the result of the function  $f(x) = \frac{\exp\{x\}}{1+\exp\{x\}}$  for a given x.

---

jags_picker	<i>Set up a Binary Outcome Misclassification jags.model Object for a Given Prior</i>
-------------	--

---

**Description**

Set up a Binary Outcome Misclassification jags.model Object for a Given Prior

**Usage**

```
jags_picker(
  prior,
  sample_size,
  dim_x,
  dim_z,
  n_cat,
  Ystar,
  X,
  Z,
  beta_prior_parameters,
  gamma_prior_parameters,
  number_MCMC_chains,
  model_file,
  display_progress = TRUE
)
```

**Arguments**

prior                A character string specifying the prior distribution for the  $\beta$  and  $\gamma$  parameters. Options are "t", "uniform", "normal", or "dexp" (double Exponential, or Weibull).

sample\_size        An integer value specifying the number of observations in the sample.

dim\_x               An integer specifying the number of columns of the design matrix of the true outcome mechanism, X.

dim\_z               An integer specifying the number of columns of the design matrix of the observation mechanism, Z.



n_cat	An integer specifying the number of categorical values that the true outcome, $Y$ , and the observed outcome, $Y^*$ can take.
Ystar	A numeric vector of indicator variables (1, 2) for the observed outcome $Y^*$ . The reference category is 2.
X	A numeric design matrix for the true outcome mechanism.
Z	A numeric design matrix for the observation mechanism.
beta_prior_parameters	A numeric list of prior distribution parameters for the $\beta$ terms. For prior distributions "t", "uniform", "normal", or "dexp", the first element of the list should contain a matrix of location, lower bound, mean, or shape parameters, respectively, for $\beta$ terms. For prior distributions "t", "uniform", "normal", or "dexp", the second element of the list should contain a matrix of shape, upper bound, standard deviation, or scale parameters, respectively, for $\beta$ terms. For prior distribution "t", the third element of the list should contain a matrix of the degrees of freedom for $\beta$ terms. The third list element should be empty for all other prior distributions. All matrices in the list should have dimensions $\text{dim}_x \times X \times n\_cat$ , and all elements in the $n\_cat$ column should be set to NA.
gamma_prior_parameters	A numeric list of prior distribution parameters for the $\gamma$ terms. For prior distributions "t", "uniform", "normal", or "dexp", the first element of the list should contain an array of location, lower bound, mean, or shape parameters, respectively, for $\gamma$ terms. For prior distributions "t", "uniform", "normal", or "dexp", the second element of the list should contain an array of shape, upper bound, standard deviation, or scale parameters, respectively, for $\gamma$ terms. For prior distribution "t", the third element of the list should contain an array of the degrees of freedom for $\gamma$ terms. The third list element should be empty for all other prior distributions. All arrays in the list should have dimensions $n\_cat \times n\_cat \times \text{dim}_z$ , and all elements in the $n\_cat$ row should be set to NA.
number_MCMC_chains	An integer specifying the number of MCMC chains to compute.
model_file	A .BUG file and used for MCMC estimation with rjags.
display_progress	A logical value specifying whether messages should be displayed during model compilation. The default is TRUE.

## Value

jags\_picker returns a `jags.model` object for a binary outcome misclassification model. The object includes the specified prior distribution, model, number of chains, and data.

---

jags_picker_2stage	<i>Set up a Two-Stage Binary Outcome Misclassification</i> <code>jags.model</code> <i>Object for a Given Prior</i>
--------------------	---

---

**Description**

Set up a Two-Stage Binary Outcome Misclassification `jags.model` Object for a Given Prior

**Usage**

```
jags_picker_2stage(
  prior,
  sample_size,
  dim_x,
  dim_z,
  dim_v,
  n_cat,
  Ystar,
  Ytilde,
  X,
  Z,
  V,
  beta_prior_parameters,
  gamma_prior_parameters,
  delta_prior_parameters,
  number_MCMC_chains,
  model_file,
  display_progress = TRUE
)
```

**Arguments**

<code>prior</code>	A character string specifying the prior distribution for the $\beta$ , $\gamma$ , and $\delta$ parameters. Options are "t", "uniform", "normal", or "dexp" (double Exponential, or Weibull).
<code>sample_size</code>	An integer value specifying the number of observations in the sample.
<code>dim_x</code>	An integer specifying the number of columns of the design matrix of the true outcome mechanism, $X$ .
<code>dim_z</code>	An integer specifying the number of columns of the design matrix of the first-stage observation mechanism, $Z$ .
<code>dim_v</code>	An integer specifying the number of columns of the design matrix of the second-stage observation mechanism, $V$ .
<code>n_cat</code>	An integer specifying the number of categorical values that the true outcome, $Y$ , and the observed outcomes, $Y^*$ and $\tilde{Y}$ , can take.
<code>Ystar</code>	A numeric vector of indicator variables (1, 2) for the first-stage observed outcome $Y^*$ . The reference category is 2.
<code>Ytilde</code>	A numeric vector of indicator variables (1, 2) for the second-stage observed outcome $\tilde{Y}$ . The reference category is 2.
<code>X</code>	A numeric design matrix for the true outcome mechanism.
<code>Z</code>	A numeric design matrix for the first-stage observation mechanism.

- V** A numeric design matrix for the second-stage observation mechanism.
- beta\_prior\_parameters**  
A numeric list of prior distribution parameters for the  $\beta$  terms. For prior distributions "t", "uniform", "normal", or "dexp", the first element of the list should contain a matrix of location, lower bound, mean, or shape parameters, respectively, for  $\beta$  terms. For prior distributions "t", "uniform", "normal", or "dexp", the second element of the list should contain a matrix of shape, upper bound, standard deviation, or scale parameters, respectively, for  $\beta$  terms. For prior distribution "t", the third element of the list should contain a matrix of the degrees of freedom for  $\beta$  terms. The third list element should be empty for all other prior distributions. All matrices in the list should have dimensions  $\text{dim}_x \times n_{\text{cat}}$ , and all elements in the  $n_{\text{cat}}$  column should be set to NA.
- gamma\_prior\_parameters**  
A numeric list of prior distribution parameters for the  $\gamma$  terms. For prior distributions "t", "uniform", "normal", or "dexp", the first element of the list should contain an array of location, lower bound, mean, or shape parameters, respectively, for  $\gamma$  terms. For prior distributions "t", "uniform", "normal", or "dexp", the second element of the list should contain an array of shape, upper bound, standard deviation, or scale parameters, respectively, for  $\gamma$  terms. For prior distribution "t", the third element of the list should contain an array of the degrees of freedom for  $\gamma$  terms. The third list element should be empty for all other prior distributions. All arrays in the list should have dimensions  $n_{\text{cat}} \times n_{\text{cat}} \times \text{dim}_z$ , and all elements in the  $n_{\text{cat}}$  row should be set to NA.
- delta\_prior\_parameters**  
A numeric list of prior distribution parameters for the  $\delta$  terms. For prior distributions "t", "uniform", "normal", or "dexp", the first element of the list should contain an array of location, lower bound, mean, or shape parameters, respectively, for  $\delta$  terms. For prior distributions "t", "uniform", "normal", or "dexp", the second element of the list should contain an array of shape, upper bound, standard deviation, or scale parameters, respectively, for  $\delta$  terms. For prior distribution "t", the third element of the list should contain an array of the degrees of freedom for  $\delta$  terms. The third list element should be empty for all other prior distributions. All arrays in the list should have dimensions  $n_{\text{cat}} \times n_{\text{cat}} \times n_{\text{cat}} \times \text{dim}_v$ , and all elements in the  $n_{\text{cat}}$  row should be set to NA.
- number\_MCMC\_chains**  
An integer specifying the number of MCMC chains to compute.
- model\_file** A .BUG file and used for MCMC estimation with rjags.
- display\_progress**  
A logical value specifying whether messages should be displayed during model compilation. The default is TRUE.

**Value**

jags\_picker returns a jags.model object for a two-stage binary outcome misclassification model. The object includes the specified prior distribution, model, number of chains, and data.

---

label_switch	<i>Fix Label Switching in MCMC Results from a Binary Outcome Misclassification Model</i>
--------------	--

---

**Description**

Fix Label Switching in MCMC Results from a Binary Outcome Misclassification Model

**Usage**

```
label_switch(chain_matrix, dim_x, dim_z, n_cat)
```

**Arguments**

chain_matrix	A numeric matrix containing the posterior samples for all parameters in a given MCMC chain. chain_matrix must be a named object (i.e. each parameter must be named as beta[j, p] or gamma[k, j, p]).
dim_x	An integer specifying the number of columns of the design matrix of the true outcome mechanism, X.
dim_z	An integer specifying the number of columns of the design matrix of the observation mechanism, Z.
n_cat	An integer specifying the number of categorical values that the true outcome, Y, and the observed outcome, Y* can take.

**Value**

label\_switch returns a named matrix of MCMC posterior samples for all parameters after performing label switching according the following pattern: all  $\beta$  terms are multiplied by -1, all  $\gamma$  terms are "swapped" with the opposite j index.

---

label_switch_2stage	<i>Fix Label Switching in MCMC Results from a Binary Outcome Misclassification Model</i>
---------------------	--

---

**Description**

Fix Label Switching in MCMC Results from a Binary Outcome Misclassification Model

**Usage**

```
label_switch_2stage(chain_matrix, dim_x, dim_z, dim_v, n_cat)
```

**Arguments**

chain_matrix	A numeric matrix containing the posterior samples for all parameters in a given MCMC chain. chain_matrix must be a named object (i.e. each parameter must be named as beta[j, p], gamma[k, j, p], or delta[l, k, j, p]).
dim_x	An integer specifying the number of columns of the design matrix of the true outcome mechanism, X.
dim_z	An integer specifying the number of columns of the design matrix of the first-stage observation mechanism, Z.
dim_v	An integer specifying the number of columns of the design matrix of the second-stage observation mechanism, V.
n_cat	An integer specifying the number of categorical values that the true outcome, Y, the first-stage observed outcome, Y*, and the second-stage observed outcome $\tilde{Y}$ can take.

**Value**

label\_switch\_2stage returns a named matrix of MCMC posterior samples for all parameters after performing label switching according the following pattern: all  $\beta$  terms are multiplied by -1, all  $\gamma$  and  $\delta$  terms are "swapped" with the opposite j index.

---

loglik	<i>Expected Complete Data Log-Likelihood Function for Estimation of the Misclassification Model</i>
--------	---

---

**Description**

Expected Complete Data Log-Likelihood Function for Estimation of the Misclassification Model

**Usage**

```
loglik(param_current, obs_Y_matrix, X, Z, sample_size, n_cat)
```

**Arguments**

param_current	A numeric vector of regression parameters, in the order $\beta, \gamma$ . The $\gamma$ vector is obtained from the matrix form. In matrix form, the gamma parameter matrix rows correspond to parameters for the $Y^* = 1$ observed outcome, with the dimensions of Z. In matrix form, the gamma parameter matrix columns correspond to the true outcome categories $j = 1, \dots, n\_cat$ . The numeric vector gamma_v is obtained by concatenating the gamma matrix, i.e. gamma_v <- c(gamma_matrix).
obs_Y_matrix	A numeric matrix of indicator variables (0, 1) for the observed outcome $Y^*$ . Rows of the matrix correspond to each subject. Columns of the matrix correspond to each observed outcome category. Each row should contain exactly one 0 entry and exactly one 1 entry.
X	A numeric design matrix for the true outcome mechanism.

Z	A numeric design matrix for the observation mechanism.
sample_size	Integer value specifying the number of observations in the sample. This value should be equal to the number of rows of the design matrix, X or Z.
n_cat	The number of categorical values that the true outcome, Y, and the observed outcome, Y* can take.

### Value

loglik returns the negative value of the expected log-likelihood function,  $Q = \sum_{i=1}^N \left[ \sum_{j=1}^2 w_{ij} \log\{\pi_{ij}\} + \sum_{j=1}^2 \sum_{k=1}^2 w_{ij} y_{ik}^* \log\{\pi_{ik}^*\} \right]$ , at the provided inputs.

---

loglik_2stage	<i>Expected Complete Data Log-Likelihood Function for Estimation of the Two-Stage Misclassification Model</i>
---------------	---

---

### Description

Expected Complete Data Log-Likelihood Function for Estimation of the Two-Stage Misclassification Model

### Usage

```
loglik_2stage(
  param_current,
  obs_Ystar_matrix,
  obs_Ytilde_matrix,
  X,
  Z,
  V,
  sample_size,
  n_cat
)
```

### Arguments

param\_current A numeric vector of regression parameters, in the order  $\beta, \gamma, \delta$ . The  $\gamma$  vector is obtained from the matrix form. In matrix form, the gamma parameter matrix rows correspond to parameters for the  $Y^* = 1$  observed outcome, with the dimensions of Z. In matrix form, the gamma parameter matrix columns correspond to the true outcome categories  $j = 1, \dots, n\_cat$ . The numeric vector  $\gamma$  is obtained by concatenating the gamma matrix, i.e. `gamma_v <- c(gamma_matrix)`. The  $\delta$  vector is obtained from the array form. In array form, the first dimension (matrix rows) of delta corresponds to parameters for the  $\tilde{Y} = 1$  second-stage observed outcome, with the dimensions of the V. The second dimension (matrix columns) correspond to the first-stage observed outcome categories  $Y^* \in \{1, 2\}$ . The third dimension of delta\_start corresponds to to the true outcome categories

$Y \in \{1, 2\}$ . The numeric vector  $\delta$  is obtained by concatenating the delta array, i.e. `delta_vector <- c(delta_array)`.

`obs_Ystar_matrix` A numeric matrix of indicator variables (0, 1) for the first-stage observed outcome  $Y^*$ . Rows of the matrix correspond to each subject. Columns of the matrix correspond to each observed outcome category. Each row should contain exactly one 0 entry and exactly one 1 entry.

`obs_Ytilde_matrix` A numeric matrix of indicator variables (0, 1) for the second-stage observed outcome  $\tilde{Y}$ . Rows of the matrix correspond to each subject. Columns of the matrix correspond to each observed outcome category. Each row should contain exactly one 0 entry and exactly one 1 entry.

`X` A numeric design matrix for the true outcome mechanism.

`Z` A numeric design matrix for the first-stage observation mechanism.

`V` A numeric design matrix for the second-stage observation mechanism.

`sample_size` An integer value specifying the number of observations in the sample. This value should be equal to the number of rows of the design matrices, X, Z, and V.

`n_cat` The number of categorical values that the true outcome, Y, and the observed outcomes,  $Y^*$  and  $\tilde{Y}$ , can take.

**Value**

`loglik_2stage` returns the negative value of the expected log-likelihood function,  $Q = \sum_{i=1}^N \left[ \sum_{j=1}^2 w_{ij} \log\{\pi_{ij}\} + \sum_{j=1}^2 \sum_{k=1}^2 w_{ij} y_{ik}^* \log\{\pi_{ikj}^*\} + \sum_{j=1}^2 \sum_{k=1}^2 \sum_{\ell=1}^2 w_{ij} y_{ik}^* \tilde{y}_{i\ell} \log\{\tilde{\pi}_{i\ell kj}\} \right]$ , at the provided inputs.

---

`mean_pistarjj_compute` *Compute the Mean Conditional Probability of Correct Classification, by True Outcome Across all Subjects*

---

**Description**

Compute the Mean Conditional Probability of Correct Classification, by True Outcome Across all Subjects

**Usage**

```
mean_pistarjj_compute(pistar_matrix, j, sample_size)
```

**Arguments**

`pistar_matrix` A numeric matrix of conditional probabilities obtained from the internal function `pistar_compute_for_chains`. Rows of the matrix correspond to each subject and to each observed outcome category. Columns of the matrix correspond to each true, latent outcome category.

- `j` An integer value representing the true outcome category to compute the average conditional probability of correct classification for. `j` can take on values 1 and 2.
- `sample_size` An integer value specifying the number of observations in the sample.

**Value**

`mean_pistarjj_compute` returns a numeric value equal to the average conditional probability  $P(Y^* = j | Y = j, Z)$  across all subjects.

---

`misclassification_prob`

*Compute Conditional Probability of Each Observed Outcome Given Each True Outcome, for Every Subject*

---

**Description**

Compute the conditional probability of observing outcome  $Y^* \in \{1, 2\}$  given the latent true outcome  $Y \in \{1, 2\}$  as  $\frac{\exp\{\gamma_{k,j0} + \gamma_{k,j}Z_i\}}{1 + \exp\{\gamma_{k,j0} + \gamma_{k,j}Z_i\}}$  for each of the  $i = 1, \dots, n$  subjects.

**Usage**

```
misclassification_prob(gamma_matrix, z_matrix)
```

**Arguments**

- `gamma_matrix` A numeric matrix of estimated regression parameters for the observation mechanism,  $Y^* | Y$  (observed outcome, given the true outcome)  $\sim Z$  (misclassification predictor matrix). Rows of the matrix correspond to parameters for the  $Y^* = 1$  observed outcome, with the dimensions of `z_matrix`. Columns of the matrix correspond to the true outcome categories  $j = 1, \dots, n\_cat$ . The matrix should be obtained by `COMBO_EM` or `COMBO_MCMC`.
- `z_matrix` A numeric matrix of covariates in the observation mechanism. `z_matrix` should not contain an intercept.

**Value**

`misclassification_prob` returns a dataframe containing four columns. The first column, `Subject`, represents the subject ID, from 1 to  $n$ , where  $n$  is the sample size, or equivalently, the number of rows in `z_matrix`. The second column, `Y`, represents a true, latent outcome category  $Y \in \{1, 2\}$ . The third column, `Ystar`, represents an observed outcome category  $Y^* \in \{1, 2\}$ . The last column, `Probability`, is the value of the equation  $\frac{\exp\{\gamma_{k,j0} + \gamma_{k,j}Z_i\}}{1 + \exp\{\gamma_{k,j0} + \gamma_{k,j}Z_i\}}$  computed for each subject, observed outcome category, and true, latent outcome category.



**Examples**

```

set.seed(123)
sample_size <- 1000
cov1 <- rnorm(sample_size)
cov2 <- rnorm(sample_size, 1, 2)
z_matrix <- matrix(c(cov1, cov2), nrow = sample_size, byrow = FALSE)
estimated_gammas <- matrix(c(1, -1, .5, .2, -.6, 1.5), ncol = 2)
P_Ystar_Y <- misclassification_prob(estimated_gammas, z_matrix)
head(P_Ystar_Y)

```

---

```

misclassification_prob2

```

*Compute Conditional Probability of Each Second-Stage Observed Outcome Given Each True Outcome and First-Stage Observed Outcome, for Every Subject*

---

**Description**

Compute the conditional probability of observing second-stage outcome  $\tilde{Y} \in \{1, 2\}$  given the latent true outcome  $Y \in \{1, 2\}$  and the first-stage outcome  $Y^* \in \{1, 2\}$  as  $\frac{\exp\{\tilde{\delta}_{\ell k j 0} + \tilde{\delta}_{\ell k j V} V_i\}}{1 + \exp\{\tilde{\delta}_{\ell k j 0} + \tilde{\delta}_{\ell k j V} V_i\}}$  for each of the  $i = 1, \dots, n$  subjects.

**Usage**

```

misclassification_prob2(delta_array, v_matrix)

```

**Arguments**

delta_array	A numeric array of estimated regression parameters for the observation mechanism, $\tilde{Y} Y^*, Y$ (second-stage observed outcome, given the first-stage observed outcome and the true outcome) $\sim V$ (second-stage misclassification predictor matrix). Rows of the array correspond to parameters for the $\tilde{Y} = 1$ observed outcome, with the dimensions of <code>v_matrix</code> . Columns of the array correspond to the first-stage outcome categories $k = 1, \dots, n\_cat$ . The third stage of the array corresponds to the true outcome categories $j = 1, \dots, n\_cat$ . The array should be obtained by COMBO_EM or COMBO_MCMC.
v_matrix	A numeric matrix of covariates in the second-stage observation mechanism. <code>v_matrix</code> should not contain an intercept.

**Value**

`misclassification_prob2` returns a dataframe containing five columns. The first column, `Subject`, represents the subject ID, from 1 to  $n$ , where  $n$  is the sample size, or equivalently, the number of rows in `v_matrix`. The second column, `Y`, represents a true, latent outcome category  $Y \in \{1, 2\}$ . The third column, `Ystar`, represents a first-stage observed outcome category  $Y^* \in \{1, 2\}$ . The fourth column, `Ytilde`, represents a second-stage observed outcome category  $\tilde{Y} \in \{1, 2\}$ . The last column, `Probability`, is the value of the equation  $\frac{\exp\{\tilde{\delta}_{\ell k j 0} + \tilde{\delta}_{\ell k j V} V_i\}}{1 + \exp\{\tilde{\delta}_{\ell k j 0} + \tilde{\delta}_{\ell k j V} V_i\}}$  computed for each subject,

first-stage observed outcome category, second-stage observed outcome category, and true, latent outcome category.

### Examples

```
set.seed(123)
sample_size <- 1000
cov1 <- rnorm(sample_size)
cov2 <- rnorm(sample_size, 1, 2)
v_matrix <- matrix(c(cov1, cov2), nrow = sample_size, byrow = FALSE)
estimated_deltas <- array(c(1, -1, .5, .2, -.6, 1.5,
                           -1, .5, -1, -.5, -1, -.5), dim = c(3,2,2))
P_Ytilde_Ystar_Y <- misclassification_prob2(estimated_deltas, v_matrix)
head(P_Ytilde_Ystar_Y)
```

---

model\_picker

*Select a Binary Outcome Misclassification Model for a Given Prior*

---

### Description

Select a Binary Outcome Misclassification Model for a Given Prior

### Usage

```
model_picker(prior)
```

### Arguments

**prior** A character string specifying the prior distribution for the  $\beta$  and  $\gamma$  parameters. Options are "t", "uniform", "normal", or "dexp" (double Exponential, or Weibull).

### Value

model\_picker returns a character string specifying the binary outcome misclassification model to be turned into a .BUG file and used for MCMC estimation with rjags.

---

model_picker_2stage	<i>Select a Two-Stage Binary Outcome Misclassification Model for a Given Prior</i>
---------------------	--

---

**Description**

Select a Two-Stage Binary Outcome Misclassification Model for a Given Prior

**Usage**

```
model_picker_2stage(prior)
```

**Arguments**

prior	A character string specifying the prior distribution for the $\beta$ , $\gamma$ , and $\delta$ parameters. Options are "t", "uniform", "normal", or "dexp" (double Exponential, or Weibull).
-------	--

**Value**

model\_picker returns a character string specifying the two-stage binary outcome misclassification model to be turned into a .BUG file and used for MCMC estimation with rjags.

---

naive_jags_picker	<i>Set up a Naive Logistic Regression jags.model Object for a Given Prior</i>
-------------------	---

---

**Description**

Set up a Naive Logistic Regression jags.model Object for a Given Prior

**Usage**

```
naive_jags_picker(
  prior,
  sample_size,
  dim_x,
  n_cat,
  Ystar,
  X,
  beta_prior_parameters,
  number_MCMC_chains,
  naive_model_file,
  display_progress = TRUE
)
```

**Arguments**

prior	character string specifying the prior distribution for the naive $\beta$ parameters. Options are "t", "uniform", "normal", or "dexp" (double Exponential, or Weibull).
sample_size	An integer value specifying the number of observations in the sample.
dim_x	An integer specifying the number of columns of the design matrix of the true outcome mechanism, $X$ .
n_cat	An integer specifying the number of categorical values that the true outcome, $Y$ , and the observed outcome, $Y^*$ can take.
Ystar	A numeric vector of indicator variables (1, 2) for the observed outcome $Y^*$ . The reference category is 2.
X	A numeric design matrix for the true outcome mechanism.
beta_prior_parameters	A numeric list of prior distribution parameters for the $\beta$ terms. For prior distributions "t", "uniform", "normal", or "dexp", the first element of the list should contain a matrix of location, lower bound, mean, or shape parameters, respectively, for $\beta$ terms. For prior distributions "t", "uniform", "normal", or "dexp", the second element of the list should contain a matrix of shape, upper bound, standard deviation, or scale parameters, respectively, for $\beta$ terms. For prior distribution "t", the third element of the list should contain a matrix of the degrees of freedom for $\beta$ terms. The third list element should be empty for all other prior distributions. All matrices in the list should have dimensions $\text{dim}_x \times n\_cat$ , and all elements in the $n\_cat$ column should be set to NA.
number_MCMC_chains	An integer specifying the number of MCMC chains to compute.
naive_model_file	A .BUG file and used for MCMC estimation with rjags.
display_progress	A logical value specifying whether messages should be displayed during model compilation. The default is TRUE.

**Value**

naive\_jags\_picker returns a `jags.model` object for a naive logistic regression model predicting the potentially misclassified  $Y^*$  from the predictor matrix  $x$ . The object includes the specified prior distribution, model, number of chains, and data.

---

naive\_jags\_picker\_2stage

*Set up a Naive Two-Stage Regression jags.model Object for a Given Prior*

---

**Description**

Set up a Naive Two-Stage Regression `jags.model` Object for a Given Prior

**Usage**

```
naive_jags_picker_2stage(
  prior,
  sample_size,
  dim_x,
  dim_v,
  n_cat,
  Ystar,
  Ytilde,
  X,
  V,
  beta_prior_parameters,
  delta_prior_parameters,
  number_MCMC_chains,
  naive_model_file,
  display_progress = TRUE
)
```

**Arguments**

prior	character string specifying the prior distribution for the naive $\beta$ parameters. Options are "t", "uniform", "normal", or "dexp" (double Exponential, or Weibull).
sample_size	An integer value specifying the number of observations in the sample.
dim_x	An integer specifying the number of columns of the design matrix of the first-stage outcome mechanism, X.
dim_v	An integer specifying the number of columns of the design matrix of the second-stage outcome mechanism, V.
n_cat	An integer specifying the number of categorical values that the observed outcomes can take.
Ystar	A numeric vector of indicator variables (1, 2) for the first-stage observed outcome $Y^*$ . The reference category is 2.
Ytilde	A numeric vector of indicator variables (1, 2) for the second-stage observed outcome $\tilde{Y}$ . The reference category is 2.
X	A numeric design matrix for the true outcome mechanism.
V	A numeric design matrix for the second-stage outcome mechanism.
beta_prior_parameters	A numeric list of prior distribution parameters for the $\beta$ terms. For prior distributions "t", "uniform", "normal", or "dexp", the first element of the list should contain a matrix of location, lower bound, mean, or shape parameters, respectively, for $\beta$ terms. For prior distributions "t", "uniform", "normal", or "dexp", the second element of the list should contain a matrix of shape, upper bound, standard deviation, or scale parameters, respectively, for $\beta$ terms. For prior distribution "t", the third element of the list should contain a matrix of the degrees of freedom for $\beta$ terms. The third list element should be empty for all

other prior distributions. All matrices in the list should have dimensions  $\text{dim}_x \times n_{\text{cat}}$ , and all elements in the  $n_{\text{cat}}$  column should be set to NA.

`delta_prior_parameters`

A numeric list of prior distribution parameters for the naive  $\delta$  terms. For prior distributions "t", "uniform", "normal", or "dexp", the first element of the list should contain an array of location, lower bound, mean, or shape parameters, respectively, for  $\delta$  terms. For prior distributions "t", "uniform", "normal", or "dexp", the second element of the list should contain an array of shape, upper bound, standard deviation, or scale parameters, respectively, for  $\delta$  terms. For prior distribution "t", the third element of the list should contain an array of the degrees of freedom for  $\delta$  terms. The third list element should be empty for all other prior distributions. All arrays in the list should have dimensions  $n_{\text{cat}} \times n_{\text{cat}} \times \text{dim}_v$ , and all elements in the  $n_{\text{cat}}$  row should be set to NA.

`number_MCMC_chains`

An integer specifying the number of MCMC chains to compute.

`naive_model_file`

A .BUG file and used for MCMC estimation with rjags.

`display_progress`

A logical value specifying whether messages should be displayed during model compilation. The default is TRUE.

## Value

`naive_jags_picker_2stage` returns a `jags.model` object for a naive two-stage regression model predicting the potentially misclassified  $Y^*$  from the predictor matrix  $x$  and the potentially misclassified  $\tilde{Y}|Y^*$  from the predictor matrix  $v$ . The object includes the specified prior distribution, model, number of chains, and data.

---

<code>naive_loglik_2stage</code>	<i>Observed Data Log-Likelihood Function for Estimation of the Naive Two-Stage Misclassification Model</i>
----------------------------------	--

---

## Description

Observed Data Log-Likelihood Function for Estimation of the Naive Two-Stage Misclassification Model

## Usage

```
naive_loglik_2stage(
  param_current,
  X,
  V,
  obs_Ystar_matrix,
  obs_Ytilde_matrix,
  sample_size,
  n_cat
)
```

**Arguments**

- `param_current` A numeric vector of regression parameters, in the order  $\beta, \delta$ . The  $\delta$  vector is obtained from the matrix form. In matrix form, the gamma parameter matrix rows correspond to parameters for the  $\tilde{Y} = 1$  observed outcome, with the dimensions of  $V$ . In matrix form, the gamma parameter matrix columns correspond to the true outcome categories  $j = 1, \dots, n\_cat$ . The numeric vector `delta_v` is obtained by concatenating the delta matrix, i.e. `delta_v <- c(delta_matrix)`.
- `X` A numeric design matrix for the first-stage observed mechanism.
- `V` A numeric design matrix for the second-stage observed mechanism.
- `obs_Ystar_matrix` A numeric matrix of indicator variables (0, 1) for the first-stage observed outcome  $Y^*$ . Rows of the matrix correspond to each subject. Columns of the matrix correspond to each observed outcome category. Each row should contain exactly one 0 entry and exactly one 1 entry.
- `obs_Ytilde_matrix` A numeric matrix of indicator variables (0, 1) for the second-stage observed outcome  $\tilde{Y}$ . Rows of the matrix correspond to each subject. Columns of the matrix correspond to each observed outcome category. Each row should contain exactly one 0 entry and exactly one 1 entry.
- `sample_size` Integer value specifying the number of observations in the sample. This value should be equal to the number of rows of the design matrix, `X` or `V`.
- `n_cat` The number of categorical values that the first- and second-stage outcomes,  $Y^*$  and  $\tilde{Y}$ , can take.

**Value**

`naive_loglik_2stage` returns the negative value of the observed data log-likelihood function,  $\sum_{i=1}^N \left[ \sum_{k=1}^2 \sum_{k=1}^2 \sum_{\ell=1}^2 y_{ik}^* \tilde{y}_i \log\{P(\tilde{Y}_i = \ell, Y_i^* = k | x_i, v_i)\} \right]$ , at the provided inputs.

---

`naive_model_picker`      *Select a Logistic Regression Model for a Given Prior*

---

**Description**

Select a Logistic Regression Model for a Given Prior

**Usage**

```
naive_model_picker(prior)
```

**Arguments**

- `prior` A character string specifying the prior distribution for the naive  $\beta$  parameters. Options are "t", "uniform", "normal", or "dexp" (double Exponential, or Weibull).

**Value**

naive\_model\_picker returns a character string specifying the logistic regression model to be turned into a .BUG file and used for MCMC estimation with rjags.

---

naive\_model\_picker\_2stage

*Select a Naive Two-Stage Regression Model for a Given Prior*

---

**Description**

Select a Naive Two-Stage Regression Model for a Given Prior

**Usage**

```
naive_model_picker_2stage(prior)
```

**Arguments**

prior            A character string specifying the prior distribution for the naive  $\beta$  parameters. Options are "t", "uniform", "normal", or "dexp" (double Exponential, or Weibull).

**Value**

naive\_model\_picker\_2stage returns a character string specifying the logistic regression model to be turned into a .BUG file and used for MCMC estimation with rjags.

---

perfect\_sensitivity\_EM

*EM-Algorithm Estimation of the Binary Outcome Misclassification Model while Assuming Perfect Sensitivity*

---

**Description**

Code is adapted by the SAMBA R package from Lauren Beesley and Bhramar Mukherjee.

**Usage**

```
perfect_sensitivity_EM(
  Ystar,
  Z,
  X,
  start,
  beta0_fixed = NULL,
  weights = NULL,
```



```

    expected = TRUE,
    tolerance = 1e-07,
    max_em_iterations = 1500
  )

```

## Arguments

Ystar	A numeric vector of indicator variables (1, 0) for the observed outcome $Y^*$ . The reference category is 0.
Z	A numeric matrix of covariates in the true outcome mechanism. Z should not contain an intercept.
X	A numeric matrix of covariates in the observation mechanism. X should not contain an intercept.
start	Numeric vector of starting values for parameters in the true outcome mechanism ( $\theta$ ) and the observation mechanism ( $\beta$ ), respectively.
beta0_fixed	Optional numeric vector of values of the observation mechanism intercept to profile over. If a single value is entered, this corresponds to fixing the intercept at the specified value. The default is NULL.
weights	Optional vector of row-specific weights used for selection bias adjustment. The default is NULL.
expected	A logical value indicating whether or not to calculate the covariance matrix via the expected Fisher information matrix. The default is TRUE.
tolerance	A numeric value specifying when to stop estimation, based on the difference of subsequent log-likelihood estimates. The default is $1e-7$ .
max_em_iterations	An integer specifying the maximum number of iterations of the EM algorithm. The default is 1500.

## Value

perfect\_sensitivity\_EM returns a list containing nine elements. The elements are detailed in `?SAMBA::obsloglikEM` documentation. Code is adapted from the `SAMBA::obsloglikEM` function.

## References

Beesley, L. and Mukherjee, B. (2020). Statistical inference for association studies using electronic health records: Handling both selection bias and outcome misclassification. *Biometrics*, 78, 214-226.

---

pistar_by_chain	<i>Compute the Mean Conditional Probability of Correct Classification, by True Outcome Across all Subjects for each MCMC Chain</i>
-----------------	--

---

**Description**

Compute the Mean Conditional Probability of Correct Classification, by True Outcome Across all Subjects for each MCMC Chain

**Usage**

```
pistar_by_chain(n_chains, chains_list, Z, n, n_cat)
```

**Arguments**

n_chains	An integer specifying the number of MCMC chains to compute over.
chains_list	A numeric list containing the samples from n_chains MCMC chains.
Z	A numeric design matrix.
n	An integer value specifying the number of observations in the sample. This value should be equal to the number of rows of the design matrix, Z.
n_cat	The number of categorical values that the true outcome, Y, and the observed outcome, Y* can take.

**Value**

pistar\_by\_chain returns a numeric matrix of the average conditional probability  $P(Y^* = j|Y = j, Z)$  across all subjects for each MCMC chain. Rows of the matrix correspond to MCMC chains, up to n\_chains. The first column contains the conditional probability  $P(Y^* = 1|Y = 1, Z)$ . The second column contains the conditional probability  $P(Y^* = 2|Y = 2, Z)$ .

---

pistar_compute	<i>Compute Conditional Probability of Each Observed Outcome Given Each True Outcome, for Every Subject</i>
----------------	--

---

**Description**

Compute Conditional Probability of Each Observed Outcome Given Each True Outcome, for Every Subject

**Usage**

```
pistar_compute(gamma, Z, n, n_cat)
```

**Arguments**

gamma	A numeric matrix of regression parameters for the observed outcome mechanism, $Y^*   Y$ (observed outcome, given the true outcome) $\sim Z$ (misclassification predictor matrix). Rows of the matrix correspond to parameters for the $Y^* = 1$ observed outcome, with the dimensions of $Z$ . Columns of the matrix correspond to the true outcome categories $j = 1, \dots, n\_cat$ .
Z	A numeric design matrix.
n	An integer value specifying the number of observations in the sample. This value should be equal to the number of rows of the design matrix, $Z$ .
n_cat	The number of categorical values that the true outcome, $Y$ , and the observed outcome, $Y^*$ can take.

**Value**

pistar\_compute returns a matrix of conditional probabilities,  $P(Y_i^* = k | Y_i = j, Z_i) = \frac{\exp\{\gamma_{k,j0} + \gamma_{k,j} Z_i\}}{1 + \exp\{\gamma_{k,j0} + \gamma_{k,j} Z_i\}}$  for each of the  $i = 1, \dots, n$  subjects. Rows of the matrix correspond to each subject and observed outcome. Specifically, the probability for subject  $i$  and observed category  $1$  occurs at row  $i$ . The probability for subject  $i$  and observed category  $2$  occurs at row  $i + n$ . Columns of the matrix correspond to the true outcome categories  $j = 1, \dots, n\_cat$ .

---

pistar\_compute\_for\_chains

*Compute Conditional Probability of Each Observed Outcome Given Each True Outcome for a given MCMC Chain, for Every Subject*

---

**Description**

Compute Conditional Probability of Each Observed Outcome Given Each True Outcome for a given MCMC Chain, for Every Subject

**Usage**

```
pistar_compute_for_chains(chain_colMeans, Z, n, n_cat)
```

**Arguments**

chain_colMeans	A numeric vector containing the posterior means for all sampled parameters in a given MCMC chain. chain_colMeans must be a named object (i.e. each parameter must be named as gamma[k, j, p]).
Z	A numeric design matrix.
n	An integer value specifying the number of observations in the sample. This value should be equal to the number of rows of the design matrix, $Z$ .
n_cat	The number of categorical values that the true outcome, $Y$ , and the observed outcome, $Y^*$ can take.

**Value**

`pitilde_compute_for_chains` returns a matrix of conditional probabilities,  $P(Y_i^* = k | Y_i = j, Z_i) = \frac{\exp\{\gamma_{k,j0} + \gamma_{k,j} Z_i\}}{1 + \exp\{\gamma_{k,j0} + \gamma_{k,j} Z_i\}}$  for each of the  $i = 1, \dots, n$  subjects. Rows of the matrix correspond to each subject and observed outcome. Specifically, the probability for subject  $i$  and observed category 0 occurs at row  $i$ . The probability for subject  $i$  and observed category 1 occurs at row  $i + n$ . Columns of the matrix correspond to the true outcome categories  $j = 1, \dots, n\_cat$ .

---

<code>pitilde_by_chain</code>	<i>Compute the Mean Conditional Probability of Second-Stage Correct Classification, by First-Stage and True Outcome Across all Subjects for each MCMC Chain</i>
-------------------------------	---

---

**Description**

Compute the Mean Conditional Probability of Second-Stage Correct Classification, by First-Stage and True Outcome Across all Subjects for each MCMC Chain

**Usage**

```
pitilde_by_chain(n_chains, chains_list, V, n, n_cat)
```

**Arguments**

<code>n_chains</code>	An integer specifying the number of MCMC chains to compute over.
<code>chains_list</code>	A numeric list containing the samples from <code>n_chains</code> MCMC chains.
<code>V</code>	A numeric design matrix.
<code>n</code>	An integer value specifying the number of observations in the sample. This value should be equal to the number of rows of the design matrix, <code>V</code> .
<code>n_cat</code>	The number of categorical values that the true outcome, $Y$ , the first-stage observed outcome, $Y^*$ , and the second-stage observed outcome, $\tilde{Y}$ , can take.

**Value**

`pitilde_by_chain` returns a numeric matrix of the average conditional probability  $P(\tilde{Y} = j | Y^* = j, Y = j, V)$  across all subjects for each MCMC chain. Rows of the matrix correspond to MCMC chains, up to `n_chains`. The first column contains the conditional probability  $P(\tilde{Y} = 1 | Y^* = 1, Y = 1, V)$ . The second column contains the conditional probability  $P(\tilde{Y} = 2 | Y^* = 2, Y = 2, V)$ .

---

pitilde_compute	<i>Compute Conditional Probability of Each Second-Stage Observed Outcome Given Each True Outcome and First-Stage Observed Outcome, for Every Subject</i>
-----------------	--

---

## Description

Compute Conditional Probability of Each Second-Stage Observed Outcome Given Each True Outcome and First-Stage Observed Outcome, for Every Subject

## Usage

```
pitilde_compute(delta, V, n, n_cat)
```

## Arguments

delta	A numeric array of regression parameters for the second-stage observed outcome mechanism, $\tilde{Y} Y^*, Y$ (second-stage observed outcome, given the first-stage observed outcome and the true outcome) $\sim V$ (misclassification predictor matrix). Rows of the matrix correspond to parameters for the $\tilde{Y} = 1$ observed outcome, with the dimensions of $V$ . Columns of the matrix correspond to the first-stage observed outcome categories $k = 1, \dots, n\_cat$ . The third dimension of the array corresponds to the true outcome categories $j = 1, \dots, n\_cat$
V	A numeric design matrix.
n	An integer value specifying the number of observations in the sample. This value should be equal to the number of rows of the design matrix, $V$ .
n_cat	The number of categorical values that the true outcome, $Y$ , and the observed outcomes can take.

## Value

pitilde\_compute returns an array of conditional probabilities,  $P(\tilde{Y}_i = \ell | Y_i^* = k, Y_i = j, V_i) = \frac{\exp\{\delta_{\ell k j 0} + \delta_{\ell k j V} V_i\}}{1 + \exp\{\delta_{\ell k j 0} + \delta_{\ell k j V} V_i\}}$  for each of the  $i = 1, \dots, n$  subjects. Rows of the matrix correspond to each subject and second-stage observed outcome. Specifically, the probability for subject  $i$  and observed category  $\$1\$$  occurs at row  $i$ . The probability for subject  $i$  and observed category  $\$2\$$  occurs at row  $i + n$ . Columns of the matrix correspond to the first-stage outcome categories,  $k = 1, \dots, n\_cat$ . The third dimension of the array corresponds to the true outcome categories,  $j = 1, \dots, n\_cat$ .

---

pitilde\_compute\_for\_chains

*Compute Conditional Probability of Each Observed Outcome Given Each True Outcome for a given MCMC Chain, for Every Subject*

---

### Description

Compute Conditional Probability of Each Observed Outcome Given Each True Outcome for a given MCMC Chain, for Every Subject

### Usage

```
pitilde_compute_for_chains(chain_colMeans, V, n, n_cat)
```

### Arguments

`chain_colMeans` A numeric vector containing the posterior means for all sampled parameters in a given MCMC chain. `chain_colMeans` must be a named object (i.e. each parameter must be named as `delta[l, k, j, p]`).

`V` A numeric design matrix.

`n` An integer value specifying the number of observations in the sample. This value should be equal to the number of rows of the design matrix, `V`.

`n_cat` The number of categorical values that the true outcome,  $Y$ , the first-stage observed outcome,  $Y^*$ , and the second-stage observed outcome,  $\tilde{Y}$ , can take.

### Value

`pitilde_compute_for_chains` returns a matrix of conditional probabilities,  $P(\tilde{Y}_i = \ell | Y_i^* = k, Y_i = j, V_i) = \frac{\exp\{\delta_{\ell k j 0} + \delta_{\ell k j V} V_i\}}{1 + \exp\{\delta_{\ell k j 0} + \delta_{\ell k j V} V_i\}}$  corresponding to each subject and observed outcome. Specifically, the probability for subject  $i$  and second-stage observed category  $1$  occurs at row  $i$ . The probability for subject  $i$  and second-stage observed category  $2$  occurs at row  $i + n$ . Columns of the matrix correspond to the first-stage outcome categories  $j = 1, \dots, n\_cat$ . The third dimension of the array corresponds to the true outcome categories,  $j = 1, \dots, n\_cat$ .

---

pi\_compute

*Compute Probability of Each True Outcome, for Every Subject*

---

### Description

Compute Probability of Each True Outcome, for Every Subject

### Usage

```
pi_compute(beta, X, n, n_cat)
```

**Arguments**

beta	A numeric column matrix of regression parameters for the $Y$ (true outcome) $\sim X$ (predictor matrix of interest).
X	A numeric design matrix.
n	An integer value specifying the number of observations in the sample. This value should be equal to the number of rows of the design matrix, $X$ .
n_cat	The number of categorical values that the true outcome, $Y$ , can take.

**Value**

pi\_compute returns a matrix of probabilities,  $P(Y_i = j|X_i) = \frac{\exp(X_i\beta)}{1+\exp(X_i\beta)}$  for each of the  $i = 1, \dots, n$  subjects. Rows of the matrix correspond to each subject. Columns of the matrix correspond to the true outcome categories  $j = 1, \dots, n\_cat$ .

q\_beta\_f

*M-Step Expected Log-Likelihood with respect to Beta***Description**

Objective function of the form:  $Q_\beta = \sum_{i=1}^N \left[ \sum_{j=0}^1 w_{ij} \log\{\pi_{ij}\} \right]$ . Used to obtain estimates of  $\beta$  parameters.

**Usage**

```
q_beta_f(beta, X, w_mat, sample_size, n_cat)
```

**Arguments**

beta	A numeric vector of regression parameters for the $Y$ (true outcome) $\sim X$ (predictor matrix of interest).
X	A numeric design matrix.
w_mat	Matrix of E-step weights obtained from w_j.
sample_size	An integer value specifying the number of observations in the sample. This value should be equal to the number of rows of the design matrix, $X$ .
n_cat	The number of categorical values that the true outcome, $Y$ , can take.

**Value**

q\_beta\_f returns the negative value of the expected log-likelihood function,  $Q_\beta = \sum_{i=1}^N \left[ \sum_{j=1}^2 w_{ij} \log\{\pi_{ij}\} \right]$ , at the provided inputs.

q\_delta\_f

*M-Step Expected Log-Likelihood with respect to Delta***Description**

Objective function of the form:  $Q_\delta = \sum_{i=1}^N \left[ \sum_{j=1}^2 \sum_{k=1}^2 \sum_{\ell=1}^2 w_{ij} y_{ik}^* \tilde{y}_{i\ell} \log\{\tilde{\pi}_{i\ell k j}\} \right]$ . Used to obtain estimates of  $\delta$  parameters.

**Usage**

```
q_delta_f(
  delta_v,
  V,
  obs_Ystar_matrix,
  obs_Ytilde_matrix,
  w_mat,
  sample_size,
  n_cat
)
```

**Arguments**

delta_v	A numeric array of regression parameters for the second-stage observed outcome mechanism, $\tilde{Y} Y^*, Y$ (second-stage observed outcome, given the first-stage observed outcome and the true outcome) $\sim V$ (misclassification predictor matrix). The $\delta$ vector is obtained from the array form. In array form, the first dimension (matrix rows) of delta corresponds to parameters for the $\tilde{Y} = 1$ second-stage observed outcome, with the dimensions of the $V$ . The second dimension (matrix columns) correspond to the first-stage observed outcome categories $Y^* \in \{1, 2\}$ . The third dimension of delta_start corresponds to the true outcome categories $Y \in \{1, 2\}$ . The numeric vector $\delta$ is obtained by concatenating the delta array, i.e. <code>delta_v &lt;- c(delta_array)</code> .
V	A numeric design matrix.
obs_Ystar_matrix	A numeric matrix of indicator variables (0, 1) for the observed outcome $Y^*$ . Rows of the matrix correspond to each subject. Columns of the matrix correspond to each observed outcome category. Each row should contain exactly one 0 entry and exactly one 1 entry.
obs_Ytilde_matrix	A numeric matrix of indicator variables (0, 1) for the observed outcome $\tilde{Y}$ . Rows of the matrix correspond to each subject. Columns of the matrix correspond to each observed outcome category. Each row should contain exactly one 0 entry and exactly one 1 entry.
w_mat	Matrix of E-step weights obtained from <code>w_j_2stage</code> .
sample_size	An integer value specifying the number of observations in the sample. This value should be equal to the number of rows of the design matrix, $V$ .



n\_cat            The number of categorical values that the true outcome, Y, and the observed outcomes can take.

### Value

q\_beta\_f returns the negative value of the expected log-likelihood function,  $Q_\delta = \sum_{i=1}^N \left[ \sum_{j=1}^2 \sum_{k=1}^2 \sum_{\ell=1}^2 w_{ij} y_{ik}^* \tilde{y}_{i\ell} \log\{\tilde{\pi}_{ikj}\} \right]$  at the provided inputs.

---

q\_gamma\_f

*M-Step Expected Log-Likelihood with respect to Gamma*

---

### Description

Objective function of the form:  $Q_\gamma = \sum_{i=1}^N \left[ \sum_{j=1}^2 \sum_{k=1}^2 w_{ij} y_{ik}^* \log\{\pi_{ikj}^*\} \right]$ . Used to obtain estimates of  $\gamma$  parameters.

### Usage

```
q_gamma_f(gamma_v, Z, obs_Y_matrix, w_mat, sample_size, n_cat)
```

### Arguments

gamma\_v            A numeric vector of regression parameters for the observed outcome mechanism,  $Y^* | Y$  (observed outcome, given the true outcome)  $\sim Z$  (misclassification predictor matrix). In matrix form, the gamma parameter matrix rows correspond to parameters for the  $Y^* = 0$  observed outcome, with the dimensions of Z. In matrix form, the gamma parameter matrix columns correspond to the true outcome categories  $j = 1, \dots, n\_cat$ . The numeric vector gamma\_v is obtained by concatenating the gamma matrix, i.e. `gamma_v <- c(gamma_matrix)`.

Z                    A numeric design matrix.

obs\_Y\_matrix        A numeric matrix of indicator variables (0, 1) for the observed outcome  $Y^*$ . Rows of the matrix correspond to each subject. Columns of the matrix correspond to each observed outcome category. Each row should contain exactly one 0 entry and exactly one 1 entry.

w\_mat                Matrix of E-step weights obtained from `w_j`.

sample\_size        An integer value specifying the number of observations in the sample. This value should be equal to the number of rows of the design matrix, Z.

n\_cat                The number of categorical values that the true outcome, Y, and the observed outcome,  $Y^*$  can take.

### Value

q\_beta\_f returns the negative value of the expected log-likelihood function,  $Q_\gamma = \sum_{i=1}^N \left[ \sum_{j=1}^2 \sum_{k=1}^2 w_{ij} y_{ik}^* \log\{\pi_{ikj}^*\} \right]$ , at the provided inputs.

---

sum_every_n	<i>Sum Every "n"th Element</i>
-------------	--------------------------------

---

**Description**

Sum Every "n"th Element

**Usage**

sum\_every\_n(x, n)

**Arguments**

x	A numeric vector to sum over
n	A numeric value specifying the distance between the reference index and the next index to be summed

**Value**

sum\_every\_n returns a vector of sums of every  $n^{\text{th}}$  element of the vector x.

---

sum_every_n1	<i>Sum Every "n"th Element, then add 1</i>
--------------	--

---

**Description**

Sum Every "n"th Element, then add 1

**Usage**

sum\_every\_n1(x, n)

**Arguments**

x	A numeric vector to sum over
n	A numeric value specifying the distance between the reference index and the next index to be summed

**Value**

sum\_every\_n1 returns a vector of sums of every  $n^{\text{th}}$  element of the vector x, plus 1.

---

true\_classification\_prob

*Compute Probability of Each True Outcome, for Every Subject*

---

### Description

Compute the probability of the latent true outcome  $Y \in \{1, 2\}$  as  $P(Y_i = j|X_i) = \frac{\exp(X_i\beta)}{1+\exp(X_i\beta)}$  for each of the  $i = 1, \dots, n$  subjects.

### Usage

```
true_classification_prob(beta_matrix, x_matrix)
```

### Arguments

beta_matrix	A numeric column matrix of estimated regression parameters for the true outcome mechanism, $Y$ (true outcome) $\sim X$ (predictor matrix of interest), obtained from COMBO_EM or COMBO_MCMC.
x_matrix	A numeric matrix of covariates in the true outcome mechanism. x_matrix should not contain an intercept.

### Value

true\_classification\_prob returns a dataframe containing three columns. The first column, Subject, represents the subject ID, from 1 to n, where n is the sample size, or equivalently, the number of rows in x\_matrix. The second column, Y, represents a true, latent outcome category  $Y \in \{1, 2\}$ . The last column, Probability, is the value of the equation  $P(Y_i = j|X_i) = \frac{\exp(X_i\beta)}{1+\exp(X_i\beta)}$  computed for each subject and true, latent outcome category.

### Examples

```
set.seed(123)
sample_size <- 1000
cov1 <- rnorm(sample_size)
cov2 <- rnorm(sample_size, 1, 2)
x_matrix <- matrix(c(cov1, cov2), nrow = sample_size, byrow = FALSE)
estimated_betas <- matrix(c(1, -1, .5), ncol = 1)
P_Y <- true_classification_prob(estimated_betas, x_matrix)
head(P_Y)
```

---

w_j	<i>Compute E-step for Binary Outcome Misclassification Model Estimated With the EM-Algorithm</i>
-----	--

---

### Description

Compute E-step for Binary Outcome Misclassification Model Estimated With the EM-Algorithm

### Usage

```
w_j(ystar_matrix, pistar_matrix, pi_matrix, sample_size, n_cat)
```

### Arguments

- |               |  |
|---------------|--|
| ystar_matrix  | A numeric matrix of indicator variables (0, 1) for the observed outcome $Y^*$ . Rows of the matrix correspond to each subject. Columns of the matrix correspond to each observed outcome category. Each row should contain exactly one 0 entry and exactly one 1 entry.      |
| pistar_matrix | A numeric matrix of conditional probabilities obtained from the internal function <code>pistar_compute</code> . Rows of the matrix correspond to each subject and to each observed outcome category. Columns of the matrix correspond to each true, latent outcome category. |
| pi_matrix     | A numeric matrix of probabilities obtained from the internal function <code>pi_compute</code> . Rows of the matrix correspond to each subject. Columns of the matrix correspond to each true, latent outcome category.   |
| sample_size   | An integer value specifying the number of observations in the sample. This value should be equal to the number of rows of the observed outcome matrix, <code>ystar_matrix</code> .   |
| n_cat         | The number of categorical values that the true outcome, $Y$ , and the observed outcome, $Y^*$ , can take.  |

### Value

`w_j` returns a matrix of E-step weights for the EM-algorithm, computed as follows:  $\sum_{k=1}^2 \frac{y_{ik}^* \pi_{ikj}^* \pi_{ij}}{\sum_{\ell=1}^2 \pi_{ik\ell}^* \pi_{i\ell}}$ . Rows of the matrix correspond to each subject. Columns of the matrix correspond to the true outcome categories  $j = 1, \dots, n\_cat$ .

---

w_j_2stage	<i>Compute E-step for Two-Stage Binary Outcome Misclassification Model Estimated With the EM-Algorithm</i>
------------	--

---

**Description**

Compute E-step for Two-Stage Binary Outcome Misclassification Model Estimated With the EM-Algorithm

**Usage**

```
w_j_2stage(
  ystar_matrix,
  ytilde_matrix,
  pitilde_array,
  pistar_matrix,
  pi_matrix,
  sample_size,
  n_cat
)
```

**Arguments**

ystar_matrix	A numeric matrix of indicator variables (0, 1) for the observed outcome $Y^*$ . Rows of the matrix correspond to each subject. Columns of the matrix correspond to each observed outcome category. Each row should contain exactly one 0 entry and exactly one 1 entry.
ytilde_matrix	A numeric matrix of indicator variables (0, 1) for the observed outcome $\tilde{Y}$ . Rows of the matrix correspond to each subject. Columns of the matrix correspond to each observed outcome category. Each row should contain exactly one 0 entry and exactly one 1 entry.
pitilde_array	A numeric array of conditional probabilities obtained from the internal function <code>pitilde_compute</code> . Rows of the matrices correspond to each subject and to each second-stage observed outcome category. Columns of the matrix correspond to each first-stage observed outcome category. The third dimension of the array corresponds to each true, latent outcome category.
pistar_matrix	A numeric matrix of conditional probabilities obtained from the internal function <code>pistar_compute</code> . Rows of the matrix correspond to each subject and to each first-stage observed outcome category. Columns of the matrix correspond to each true, latent outcome category.
pi_matrix	A numeric matrix of probabilities obtained from the internal function <code>pi_compute</code> . Rows of the matrix correspond to each subject. Columns of the matrix correspond to each true, latent outcome category.
sample_size	An integer value specifying the number of observations in the sample. This value should be equal to the number of rows of the observed outcome matrices, <code>ystar_matrix</code> and <code>ytilde_matrix</code> .

n\_cat            The number of categorical values that the true outcome,  $Y$ , and the observed outcomes can take.

**Value**

w\_j returns a matrix of E-step weights for the EM-algorithm, computed as follows:  $\sum_{k=1}^2 \sum_{\ell=1}^2 \frac{y_{ik}^* \tilde{y}_{i\ell} \tilde{\pi}_{i\ell k j} \pi_{ikj}^* \pi_{ij}}{\sum_{h=1}^2 \tilde{\pi}_{i\ell k h} \pi_{ikh}^* \pi_{ih}}$ . Rows of the matrix correspond to each subject. Columns of the matrix correspond to the true outcome categories  $j = 1, \dots, n\_cat$ .

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