

Package ‘msae’

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Title Multivariate Fay Herriot Models for Small Area Estimation

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Description Implements multivariate Fay-Herriot models for small area estimation. It uses empirical best linear unbiased prediction (EBLUP) estimator. Multivariate models consider the correlation of several target variables and borrow strength from auxiliary variables to improve the effectiveness of a domain sample size. Models which accommodated by this package are univariate model with several target variables (model 0), multivariate model (model 1), autoregressive multivariate model (model 2), and heteroscedastic autoregressive multivariate model (model 3). Functions provide EBLUP estimators and mean squared error (MSE) estimator for each model. These models were developed by Roberto Benavent and Domingo Morales (2015) <[doi:10.1016/j.csda.2015.07.013](https://doi.org/10.1016/j.csda.2015.07.013)>.

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datasae1	<i>Data generated based on Multivariate Fay Herriot Model (Model 1)</i>
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Description

This data is generated based on multivariate Fay-Herriot model (model 1) by these following steps:

1. Generate sampling error e , random effect u , and auxiliary variables $X1$ $X2$.
 - For sampling error e , we set $e_d \sim N_3(0, V_{ed})$, where $V_{ed} = (\sigma_{dij})_{i,j=1,2,3}$, with $\sigma_{11} \sim InvGamma(11, 1)$, $\sigma_{22} \sim InvGamma(11, 2)$, $\sigma_{33} \sim InvGamma(11, 3)$, and $\rho_e = 0.5$.
 - For random effect u , we set $u \sim N_3(0, V_u)$, where $\sigma_{u11} = 0.2$, $\sigma_{u22} = 0.4$, and $\sigma_{u33} = 1.2$.
 - For auxiliary variables $X1$ and $X2$, we set $X1 \sim N(5, 0.1)$ and $X2 \sim N(10, 0.2)$.
2. Calculate direct estimation $Y1$ $Y2$ and $Y3$, where $Y_i = X * \beta + u_i + e_i$. We take $\beta_1 = 5$ and $\beta_2 = 10$.

Auxiliary variables $X1$ $X2$, direct estimation $Y1$ $Y2$ $Y3$, and sampling variance-covariance $v1$ $v2$ $v3$ $v12$ $v13$ $v23$ are combined into a dataframe called `datasae1`.

Usage

```
datasae1
```

Format

A data frame with 50 rows and 11 variables:

- X1** Auxiliary variable of $X1$
- X2** Auxiliary variable of $X2$
- Y1** Direct Estimation of $Y1$
- Y2** Direct Estimation of $Y2$
- Y3** Direct Estimation of $Y3$
- v1** Sampling Variance of $Y1$
- v12** Sampling Covariance of $Y1$ and $Y2$
- v13** Sampling Covariance of $Y1$ and $Y3$
- v2** Sampling Variance of $Y2$
- v23** Sampling Covariance of $Y2$ and $Y3$
- v3** Sampling Variance of $Y3$

Reference

Benavent, Roberto & Morales, Domingo. (2015). Multivariate Fay-Herriot models for small area estimation. *Computational Statistics & Data Analysis*. 100. 372-390. DOI: 10.1016/j.csda.2015.07.013.

datasae2	<i>Data generated based on Autoregressive Multivariate Fay Herriot Model (Model 2)</i>
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Description

This data is generated based on autoregressive multivariate Fay-Herriot model (model 2) by following these steps:

1. Generate sampling error e , random effect u , and auxiliary variables $X1$ $X2$.
 - For sampling error e , we set $e \sim N_3(0, V_e)$, where $V_e = (\sigma_{ij})_{i,j=1,2,3}$, with $\sigma_{11} = 0.1$, $\sigma_{22} = 0.2$, $\sigma_{33} = 0.3$, and $\rho_e = 0.5$.
 - For random effect u , we set $u \sim N_3(0, V_u)$, where $\sigma_u = 0.4$, and $\rho_u = 0.8$.
 - For auxiliary variables $X1$ and $X2$, we set $X1 \sim N(5, 0.1)$ and $X2 \sim N(10, 0.2)$.
2. Calculate direct estimation $Y1$ $Y2$ and $Y3$, where $Y_i = X * \beta + u_i + e_i$. We take $\beta_1 = 5$ and $\beta_2 = 10$.

Auxiliary variables $X1$ $X2$, direct estimation $Y1$ $Y2$ $Y3$, and sampling variance-covariance $v1$ $v2$ $v3$ $v12$ $v13$ $v23$ are combined into a dataframe called `datasae2`.

Usage

```
datasae2
```

Format

A data frame with 50 rows and 11 variables:

X1 Auxiliary variable of $X1$

X2 Auxiliary variable of $X2$

Y1 Direct Estimation of $Y1$

Y2 Direct Estimation of $Y2$

Y3 Direct Estimation of $Y3$

v1 Sampling Variance of $Y1$

v12 Sampling Covariance of $Y1$ and $Y2$

v13 Sampling Covariance of $Y1$ and $Y3$

v2 Sampling Variance of $Y2$

v23 Sampling Covariance of $Y2$ and $Y3$

v3 Sampling Variance of $Y3$

Reference

Benavent, Roberto & Morales, Domingo. (2015). Multivariate Fay-Herriot models for small area estimation. *Computational Statistics & Data Analysis*. 100. 372-390. DOI: 10.1016/j.csda.2015.07.013.

datasae3	<i>Data generated based on Heteroscedastic Autoregressive Multivariate Fay Herriot Model (Model 3)</i>
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Description

This data is generated based on heteroscedastic autoregressive multivariate Fay-Herriot model (model 3) by following these steps:

1. Generate sampling error e , random effect u , and auxiliary variables $X1$ $X2$.
 - For sampling error e , we set $e \sim N_3(0, V_e)$, where $V_e = (\sigma_{ij})_{i,j=1,2,3}$, with $\sigma_{11} = 0.1$, $\sigma_{22} = 0.2$, $\sigma_{33} = 0.3$, and $\rho_e = 0.5$.
 - For random effect u , we set $u \sim N_3(0, V_u)$, where $\sigma_{u11} = 0.2$, $\sigma_{u22} = 0.4$, $\sigma_{u33} = 1.2$, and $\rho_u = 0.8$.
 - For auxiliary variables $X1$ and $X2$, we set $X1 \sim N(5, 0.1)$ and $X2 \sim N(10, 0.2)$.
2. Calculate direct estimation $Y1$ $Y2$ and $Y3$, where $Y_i = X * \beta + u_i + e_i$. We take $\beta_1 = 5$ and $\beta_2 = 10$.

Auxiliary variables $X1$ $X2$, direct estimation $Y1$ $Y2$ $Y3$, and sampling variance-covariance $v1$ $v2$ $v3$ $v12$ $v13$ $v23$ are combined into a dataframe called `datasae3`.

Usage

```
datasae3
```

Format

A data frame with 50 rows and 11 variables:

- X1** Auxiliary variable of $X1$
- X2** Auxiliary variable of $X2$
- Y1** Direct Estimation of $Y1$
- Y2** Direct Estimation of $Y2$
- Y3** Direct Estimation of $Y3$
- v1** Sampling Variance of $Y1$
- v12** Sampling Covariance of $Y1$ and $Y2$
- v13** Sampling Covariance of $Y1$ and $Y3$
- v2** Sampling Variance of $Y2$
- v23** Sampling Covariance of $Y2$ and $Y3$
- v3** Sampling Variance of $Y3$

Reference

Benavent, Roberto & Morales, Domingo. (2015). Multivariate Fay-Herriot models for small area estimation. *Computational Statistics & Data Analysis*. 100. 372-390. DOI: 10.1016/j.csda.2015.07.013.

df2matR	<i>Transform Dataframe to Matrix R</i>
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Description

This function transforms dataframe contains sampling variance to block diagonal matrix R

Usage

```
df2matR(var.df, r)
```

Arguments

var.df	dataframe of sampling variances of direct estimators.
r	number of variables

Value

Block diagonal matrix R

Examples

```
NULL
```

eblupMFH1	<i>EBLUPs based on a Multivariate Fay Herriot (Model 1)</i>
-----------	---

Description

This function gives the EBLUP and MSE based on a multivariate Fay-Herriot model (model 1)

Usage

```
eblupMFH1(
  formula,
  vardir,
  samevar = FALSE,
  MAXITER = 100,
  PRECISION = 1e-04,
  data
)
```

Arguments

formula	an object of class list of formula, describe the model to be fitted
vardir	if data is available, it is vector containing name of sampling variances of direct estimators. if not, it is data frame of sampling variances of direct estimators. The order is : var1, var2, . . . , var(k) , cov12, . . . cov1k, cov23, . . . , cov(k-1)(k)
samevar	logical input, true if variances of the data are same, Default: FALSE
MAXITER	maximum number of iterations allowed in the Fisher-scoring algorithm, Default: 100
PRECISION	convergence tolerance limit for the Fisher-scoring algorithm, Default: 1e-4
data	dataframe containing the variables named in formula and vardir

Value

The function returns a list with the following objects:

eblup a dataframe with the values of the EBLUP estimators

MSE a dataframe with the estimated mean squared errors of the EBLUPs for the small domains

randomEffect a dataframe with the values of the random effect estimators

Rmatrix a block diagonal matrix composed of sampling errors

fit a list containing the following objects:

- method : type of fitting method, named "REML"
- convergence : a logical value of convergence of Fisher Scoring algorithm
- iterations : number of iterations performed by Fisher-Scoring algorithm
- estcoef : a dataframe with the estimated model coefficient in the first column, their standard error in the second column, the t statistics in the third column, and the p-values of the significance of each coefficient in the last column
- refvar : a dataframe with the estimated random effect variance
- informationFisher : a matrix of information Fisher of Fisher-Scoring algorithm

Examples

```
## Load dataset
data(datasae1)

# Compute EBLUP and MSE of Y1 Y2 and Y3 based on Model 1
# using auxiliary variables X1 and X2 for each dependent variable

## Using parameter 'data'
Fo <- list(f1=Y1~X1+X2,
           f2=Y2~X1+X2,
           f3=Y3~X1+X2)
vardir <- c("v1", "v2", "v3", "v12", "v13", "v23")
m1 <- eblupMFH1(Fo, vardir, data=datasae1)

## Without parameter 'data'
Fo <- list(f1=datasae1$Y1~datasae1$X1+datasae1$X2,
```

```

      f2=datasae1$Y2~datasae1$X1+datasae1$X2,
      f3=datasae1$Y3~datasae1$X1+datasae1$X2)
varidir <- datasae1[,c("v1", "v2", "v3", "v12", "v13", "v23")]
m1 <- eblupMFH1(Fo, varidir)

m1$eblup # see the EBLUP estimators
m1$MSE # see MSE of EBLUP estimators

```

eblupMFH2	<i>EBLUPs based on a Autoregressive Multivariate Fay Herriot (Model 2)</i>
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Description

This function gives the EBLUP and MSE based on a autoregressive multivariate Fay-Herriot model (model 2).

Usage

```
eblupMFH2(formula, varidir, MAXITER = 100, PRECISION = 1e-04, data)
```

Arguments

formula	an object of class list of formula, describe the model to be fitted
varidir	if data is available, it is vector containing name of sampling variances of direct estimators. if not, it is data frame of sampling variances of direct estimators. The order is : var1, var2, . . . , var(k) , cov12, . . . cov1k, cov23, . . . , cov(k-1)(k)
MAXITER	maximum number of iterations allowed in the Fisher-scoring algorithm, Default: 100
PRECISION	convergence tolerance limit for the Fisher-scoring algorithm, Default: 1e-4
data	dataframe containing the variables named in formula and varidir

Value

The function returns a list with the following objects:

eblup a dataframe with the values of the EBLUP estimators

MSE a dataframe with the estimated mean squared errors of the EBLUPs for the small domains

randomEffect a dataframe with the values of the random effect estimators

Rmatrix a block diagonal matrix composed of sampling errors

fit a list containing the following objects:

- method : type of fitting method, named "REML"
- convergence : a logical value of convergence of Fisher Scoring algorithm
- iterations : number of iterations performed by Fisher-Scoring algorithm

- `estcoef` : a dataframe with the estimated model coefficient in the first column, their standard error in the second column, the t statistics in the third column, and the p-values of the significance of each coefficient in the last column
- `refvar` : a dataframe with the estimated random effect variance
- `rho` : a dataframe with the estimated rho of random effect variance and their rho parameter test based on Model 2
- `informationFisher` : a matrix of information Fisher of Fisher-Scoring algorithm

Examples

```
## Load dataset
data(datasae2)

# Compute EBLUP and MSE of Y1 Y2 and Y3 based on Model 2
# using auxiliary variables X1 and X2 for each dependent variable

## Without parameter 'data'
Fo <- list(f1=Y1~X1+X2,
           f2=Y2~X1+X2,
           f3=Y3~X1+X2)
vardir <- c("v1", "v2", "v3", "v12", "v13", "v23")
m2 <- eblupMFH2(Fo, vardir, data=datasae2)

## Without parameter 'data'
Fo <- list(f1=datasae2$Y1~datasae2$X1+datasae2$X2,
           f2=datasae2$Y2~datasae2$X1+datasae2$X2,
           f3=datasae2$Y3~datasae2$X1+datasae2$X2)
vardir <- datasae2[,c("v1", "v2", "v3", "v12", "v13", "v23")]
m2 <- eblupMFH2(Fo, vardir)

m2$eblup # see the EBLUP estimators
m2$MSE # see MSE of EBLUP estimators
```

eblupMFH3

EBLUPs based on a Heteroscedastic Autoregressive Multivariate Fay Herriot (Model 3)

Description

This function gives the EBLUP and MSE based on a heteroscedastic autoregressive multivariate Fay-Herriot model (model 3).

Usage

```
eblupMFH3(formula, vardir, MAXITER = 100, PRECISION = 1e-04, data)
```


Arguments

formula	an object of class list of formula, describe the model to be fitted
vardir	if data is available, it is vector containing name of sampling variances of direct estimators. if not, it is data frame of sampling variances of direct estimators. The order is : var1 , var2 , . , var(k) , cov12 , . . cov1k , cov23 , . . , cov(k-1) (k)
MAXITER	maximum number of iterations allowed in the Fisher-scoring algorithm, Default: 100
PRECISION	convergence tolerance limit for the Fisher-scoring algorithm, Default: 1e-4
data	dataframe containing the variables named in formula and vardir

Value

The function returns a list with the following objects:

eblup a dataframe with the values of the EBLUP estimators

MSE a dataframe with the estimated mean squared errors of the EBLUPs for the small domains

randomEffect a dataframe with the values of the random effect estimators

Rmatrix a block diagonal matrix composed of sampling errors

fit a list containing the following objects:

- method : type of fitting method, named "REML"
- convergence : a logical value of convergence of Fisher Scoring algorithm
- iterations : number of iterations performed by Fisher-Scoring algorithm
- estcoef : a dataframe with the estimated model coefficient in the first column, their standard error in the second column, the t statistics in the third column, and the p-values of the significance of each coefficient in the last column
- refvar : a dataframe with the estimated random effect variance
- refvarTest : homogeneity of random effect variance test based on Model 3
- rho : a dataframe with the estimated rho of random effect variance and their rho parameter test based on Model 2
- informationFisher : a matrix of information Fisher of Fisher-Scoring algorithm

Examples

```
## Load dataset
data(datasae3)

# Compute EBLUP and MSE of Y1 Y2 and Y3 based on Model 3
# using auxiliary variables X1 and X2 for each dependent variable

## Using parameter 'data'
Fo <- list(f1=Y1~X1+X2,
           f2=Y2~X1+X2,
           f3=Y3~X1+X2)
vardir <- c("v1", "v2", "v3", "v12", "v13", "v23")
m3 <- eblupMFH3(Fo, vardir, data=datasae3)
```

```
## Without parameter 'data'
Fo <- list(f1=datasae3$Y1~datasae3$X1+datasae3$X2,
          f2=datasae3$Y2~datasae3$X1+datasae3$X2,
          f3=datasae3$Y3~datasae3$X1+datasae3$X2)
vardir <- datasae3[,c("v1", "v2", "v3", "v12", "v13", "v23")]
m3 <- eblupMFH3(Fo, vardir)

m3$eblup # see the EBLUP estimators
m3$MSE # see MSE of EBLUP estimators
```

eblupUFH

EBLUPs based on a Univariate Fay Herriot (Model 0)

Description

This function gives the EBLUP and MSE based on a univariate Fay Herriot model (model 0)

Usage

```
eblupUFH(
  formula,
  vardir,
  samevar = FALSE,
  MAXITER = 100,
  PRECISION = 1e-04,
  data
)
```

Arguments

formula	an object of class list of formula, describe the model to be fitted
vardir	if data is available, it is vector containing name of sampling variances of direct estimators. if not, it is data frame of sampling variances of direct estimators. The order is : var1, var2, . . , var(k) , cov12, . . cov1k, cov23, . . , cov(k-1)(k)
samevar	logical input, true if variance of the data is same, Default: FALSE
MAXITER	maximum number of iterations allowed in the Fisher-scoring algorithm, Default: 100
PRECISION	convergence tolerance limit for the Fisher-scoring algorithm, Default: 1e-4
data	dataframe containing the variables named in formula and vardir

Value

The function returns a list with the following objects:

eblup a dataframe with the values of the EBLUP estimators

MSE a dataframe with the estimated mean squared errors of the EBLUPs for the small domains

randomEffect a dataframe with the values of the random effect estimators

Rmatrix a block diagonal matrix composed of sampling errors

fit a list containing the following objects:

- **method** : type of fitting method, named "REML"
- **convergence** : a logical value of convergence of Fisher Scoring algorithm
- **iterations** : number of iterations performed by Fisher-Scoring algorithm
- **estcoef** : a dataframe with the estimated model coefficient in the first column, their standard error in the second column, the t statistics in the third column, and the p-values of the significance of each coefficient in the last column
- **refvar** : a dataframe with the estimated random effect variance
- **informationFisher** : a matrix of information Fisher of Fisher-Scoring algorithm

Examples

```
## Load dataset
data(datasae1)

# Compute EBLUP and MSE of Y1 Y2 and Y3 based on Model 0
# using auxiliary variables X1 and X2 for each dependent variable

## Using parameter 'data'
Fo <- list(f1=Y1~X1+X2,
           f2=Y2~X1+X2,
           f3=Y3~X1+X2)
varDir <- c("v1", "v2", "v3", "v12", "v13", "v23")
un <- eblupUFH(Fo, varDir, data=datasae1)

## Without parameter 'data'
Fo <- list(f1=datasae1$Y1~datasae1$X1+datasae1$X2,
           f2=datasae1$Y2~datasae1$X1+datasae1$X2,
           f3=datasae1$Y3~datasae1$X1+datasae1$X2)
varDir <- datasae1[,c("v1", "v2", "v3", "v12", "v13", "v23")]
un <- eblupUFH(Fo, varDir)

un$eblup # see the EBLUP estimators
un$MSE # see MSE of EBLUP estimators
```

Description

Implements multivariate Fay-Herriot models for small area estimation. It uses empirical best linear unbiased prediction (EBLUP) estimator. Multivariate models consider the correlation of several target variable and borrow strength from auxiliary variables to improve the effectiveness of a domain sample size. Models which accommodated by this package are univariate model with several target

variables (model 0), multivariate model (model 1), autoregressive multivariate model (model 2), and heteroscedastic autoregressive multivariate model (model 3). Functions provide EBLUP estimators and mean squared error (MSE) estimator for each model. These models were developed by Roberto Benavent and Domingo Morales (2015) <doi:10.1016/j.csda.2015.07.013>.

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Functions

[eblupUFH](#) Gives the EBLUPs and MSE of Univariate SAE (Model 0)

[eblupMFH1](#) Gives the EBLUPs and MSE of Multivariate SAE (Model 1)

[eblupMFH2](#) Gives the EBLUPs and MSE of Autoregressive Multivariate SAE (Model 2)

[eblupMFH3](#) Gives the EBLUPs and MSE of Heteroscedastics Autoregressive Multivariate SAE (Model 3)

Reference

- Benavent, Roberto & Morales, Domingo. (2015). Multivariate Fay-Herriot models for small area estimation. *Computational Statistics & Data Analysis*. 100. 372-390. DOI: 10.1016/j.csda.2015.07.013.
- Rao, J.N.K & Molina. (2015). *Small Area Estimation 2nd Edition*. New York: John Wiley and Sons, Inc.
- Ubaidillah, Azka et al. (2019). Multivariate Fay-Herriot models for small area estimation with application to household consumption per capita expenditure in Indonesia. *Journal of Applied Statistics*. 46:15. 2845-2861. DOI: 10.1080/02664763.2019.1615420.

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