

# Package ‘sae2’

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**Title** Small Area Estimation: Time-Series Models

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**Description** Time series area-level models for small area estimation.

The package supplements the functionality of the sae package. Specifically, it includes EBLUP fitting of the Rao-Yu model in the original form without a spatial component. The package also offers a modified (“dynamic”) version of the Rao-Yu model, replacing the assumption of stationarity. Both univariate and multivariate applications are supported. Of particular note is the allowance for covariance of the area-level sample estimates over time, as encountered in rotating panel designs such as the U.S. National Crime Victimization Survey or present in a time-series of 5-year estimates from the American Community Survey. Key references to the methods include J.N.K. Rao and I. Molina (2015, ISBN:9781118735787), J.N.K. Rao and M. Yu (1994) <doi:10.2307/3315407>, and R.E. Fay and R.A. Herriot (1979) <doi:10.1080/01621459.1979.10482505>.

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`sae2-package`*Small Area Estimation: Time-Series Models.*

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## Description

Time series area-level models for small area estimation. The package supplements the functionality of the package `sae`. Specifically, it includes EBLUP fitting of the Rao-Yu model in the original form without a spatial component. It also offers a modified ("dynamic") version of the Rao-Yu model, replacing the assumption of stationarity. Both univariate and multivariate applications are supported. Of particular note is the allowance for covariance of the area-level sample estimates over time, as encountered in rotating panel designs such as the U.S. National Crime Victimization Survey or present in a time-series of 5-year estimates from the American Community Survey.

## Details

Package: `sae2`  
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The package provides two primary functions, `eblupRY` and `eblupDyn`, to fit non-spatial time-series small area models to area-level data. Each acts as an interface to `dynRYfit`, which offers a number of output options and parameters governing convergence. The function `mvrnormSeries` provides simulated data under either model. Functions `geo_ratios` and `vcovgen` can assist in preparing the input to `eblupRY` and `eblupDyn`.

## Author(s)

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## References

- Fay, R.E. and Herriot, R.A. (1979). Estimation of income from small places: An application of James-Stein procedures to census data. *Journal of the American Statistical Association* 74, 269-277.
- Fay, R.E., Planty, M. and Diallo, M.S. (2013). Small area estimates from the National Crime Victimization Survey. *Proceedings of the Joint Statistical Meetings*. American Statistical Association, pp. 1544-1557.
- Rao, J.N.K. and Molina, I. (2015). *Small Area Estimation*, 2nd ed. Wiley, Hoboken, NJ.
- Rao, J.N.K. and Yu, M. (1994). Small area estimation by combining time series and cross-sectional data. *Canadian Journal of Statistics* 22, 511-528.

**Description**

Function designed to be called by either eblupDyn or eblupRY to produce EBLUP small area estimates of the dynamic or Rao-Yu time series models through either ML or REML estimation of the variance components. For completeness and as a reference to several optional parameters, the function is documented here, but users are encouraged to base applications on calls to the more convenient eblupDyn or eblupRY.

**Usage**

```
dynRYfit(y, X, M, TI, NV=1, vcov_e, maxiter=100,
         iter.tol=.1e-5, ncolx=NULL, sig2_u=1, sig2_v=1,
         rho=.8, rho_u=.4, delta=NULL, rho.fixed=NULL,
         y.include=NULL, ids=NULL, contrast.matrix=NULL,
         baby.steps=TRUE, dampening=NULL, iter.history=NULL,
         sig2.min.factor=.0001, max.rho_u=.98, max.rho=NULL,
         tol=.Machine$double.eps, y.rescale=NULL,
         llike.only=FALSE, method=c("REML", "ML"),
         model=c("dyn", "RY"))
```

**Arguments**

y	For a univariate model, the dependent variable sorted in ascending order by time within domain. For a multivariate model, the dependent variables sorted in ascending order by time within variable within domain.
X	A matrix of independent variables with the same number of rows as the length of y.
M	The total number of domains, equivalent to D in eblupDyn and eblupRY.
TI	If TI is of length 1, it should specify the number of equally spaced time instances, nt; for example, the number of years in an unbroken sequence of years. If some of the time instances in the time interval are to be omitted from the model, the first element of TI should be 1, the last element should be the ending instance, and the elements in between should indicate the other instances to include. For example, over a period of 6 years, TI=c(1, 2, 4:6) omits the 3rd year from the model, giving nt=5.
NV	The number of dependent variables.
vcov_e	For the univariate model, the sampling covariance matrix for the direct estimates of the M*nt elements of the dependent variable, where nt is based on TI. The covariance matrix should be in the form of a square matrix with M*nt rows and columns. Non-zero covariances between domains are not allowed, so the matrix must have block diagonal form with M blocks, each of which is a square matrix with nt rows and columns. Note that within domain, non-zero covariances are allowed over time.

For the multivariate model, the square covariance matrix for the  $M \times NV \times nt$  elements of the dependent variables. The matrix should be in the form of a square matrix with  $M \times NV \times nt$  rows and columns. Time should vary within variable, which should vary within domain. Non-zero covariances between domains are not allowed, but non-zero covariances may be present across time and between variables within each domain.

maxiter	The maximum number of iterations allowed for the Fisher-scoring algorithm, with a default value of 100.
iter.tol	The convergence tolerance limit for the Fisher-scoring algorithm, with a default value of .000001.
ncolx	For a univariate model, the number of columns of X. For a multivariate model, a vector of length NV must be specified giving the number of columns of X used for each dependent variable.
sig2_u	An initial starting value or values for the variance of the random increments.
sig2_v	An initial starting value or values for a domain level random effect. In the Rao-Yu model, the random effect is constant over time, whereas in the dynamic model it is an initial effect subject to dampening over time.
rho	The correlation across time. This correlation is assumed to be the same for the dependent variables in the multivariate model.
rho_u	For $NV > 1$ only, the $(NV \times (NV - 1)) / 2$ starting values for the correlations between the random effects of the different dependent variables. If a single value is given, it will be used for the $(NV \times (NV - 1)) / 2$ components. The sort order corresponds to a lower triangle of the covariance matrix.
delta	The random effect components in the preferred internal order. Specification of delta will override any specification of sig2_u, sig2_v, rho, or rho_u. In the univariate case, delta should contain sig2_u, sig2_v, and rho. In the bivariate case, delta should be of length 6 with sig2_u and sig2_v each of length 2, then rho, and rho_u. Similarly, for 3 dependent variables, the length of delta is 10, with the last 3 elements rho_u in lower triangular form.
rho.fixed	If TRUE, the value of rho imbedded in delta, if specified, or else given by rho, will remain fixed during the iterations. Among other features, this allows the likelihood function for trial values of rho to be computed at the maximum over the other random effect parameters.
y.include	If specified, vector of length M to indicate which domains to include in the estimation, with 1 signalling inclusion and 0 exclusion. Estimates for the excluded domains will be based on the fixed effects model only.
ids	A data frame with M rows giving ids for each of the domains. The data frame is copied into the returned object.
contrast.matrix	A matrix of coefficients of contrasts. The matrix must have $nt \times NV$ rows, but it can contain an arbitrary number of columns. Within each domain, the coefficients are applied to the $nt \times NV$ EBLUP estimates.
baby.steps	Unless specified as FALSE, the first five iterations of the Fisher scoring algorithm are dampened by factors of $c(.0625, .125, .25, .5, .75)$ . These heuristically derived factors appear to lessen drastic overshooting of the true maximum in the initial iterations.

dampening	A factor used to dampen the changes in the random effect parameters. Unlike <code>baby.steps</code> , its effect persists during all of the iterations until convergence. Note that the "factory setting" of this parameter is 1 for the dynamic model but .9 for the Rao-Yu model.
iter.history	If TRUE, key values are saved during each iteration and included as additional items, described below, in the returned list: <ul style="list-style-type: none"> <li>• <code>delta.hist</code>,</li> <li>• <code>llikelihood.hist</code>,</li> <li>• <code>adj.hist</code>,</li> <li>• <code>s.hist</code>,</li> <li>• <code>ix.hist</code>,</li> <li>• <code>adj.factor.hist</code>, and</li> <li>• <code>warning.hist</code>.</li> </ul> <p>If <code>iter.history</code> is not specified, these items will be returned only if the calculations are begun but not successfully completed.</p>
sig2.min.factor	A factor to multiply the minimum direct variance to use as a minimum value for any of the variance components. The iterations will be constrained not to go below the resulting bounds.
max.rho_u	A maximum allowed value for the estimated <code>rho_u</code> . The default value is .98.
max.rho	A maximum allowed value for <code>rho</code> . By default, <code>eblupRY</code> sets this value to .98.
tol	A tolerance value used by matrix routines to prevent numerical instability. The value may be set to a lower value to encourage convergence, but appropriate caution should be applied.
y.rescale	In the univariate case, a scalar multiplier for all of the <code>y</code> values. If the <code>y</code> values are either too small or too large, the information matrix may become unstable. Setting this value to 1 has no effect; setting it to 10 or 100 rescales very small <code>y</code> values to a more appropriate range. Similarly, positive values less than 1 may be used to rescale large <code>y</code> values. The effect of rescaling is removed before normal return from the function, within the limits of normal precision. In the multivariate case, <code>y.rescale</code> may be a vector of length <code>NV</code> to rescale each component separately.
llike.only	Compute the log-likelihood (ML) or restricted log-likelihood (REML) without further iteration, typically from values specified by <code>delta</code> .
method	Use restricted maximum likelihood ("REML") or maximum likelihood ("ML").
model	Dynamic ("dyn") or Rao-Yu ("RY").

## Details

Many of arguments can be used to control the iterations if the defaults lead to convergence difficulties.

`llike.only` in combination with `delta` permits a point-by-point investigation of the likelihood surface.

The primary functions `eblupDyn` and `eblupRY` determine `X`, `NV`, `colx`, and `model`, but the remaining parameters can be passed to `dynRYfit` through `eblupDyn` or `eblupRY`.

**Value**

eblup	In the univariate case, a vector of length $M \times nt$ with the eblup estimates in the same sort order as $y$ . In the multivariate case, a matrix of $M \times nt$ rows and $NV$ columns.
fit	A list summarizing the fit of the model with the following: <ul style="list-style-type: none"> <li>• <code>model</code>: form of the model: T - Dynamic or RaoYu; REML or ML.</li> <li>• <code>convergence</code>: a logical value indicating whether the convergence criterion was met.</li> </ul>
parm	A labelled vector with the estimated variance components, correlations, and number of iterations.
coef	A labelled vector of coefficients for the fixed effects of the model or models.
ids	A data frame with $D$ rows and one or more columns of numeric or character domain identifiers.
delta	An ordered vector of the variance components (see above). It may be used as starting values for additional iterations.
eblup.mse	MSE estimates for eblup.
eblup.g1	The $g_1$ term of the MSE estimate.
eblup.g2	The $g_2$ term of the MSE estimate.
eblup.g3	The $g_3$ term of the MSE estimate.
est.fixed	Estimates based on fixed effects only.
est.fixed.var	The variance-covariance matrix for the estimates in <code>coef</code> .
eblup.wt1	Weights given to the direct estimate in forming eblup.
eblup.wt2	Weights given to the direct estimate, including effects through estimating the fixed effect coefficients.
contrast.est	Estimates requested by the specified contrasts.
contrast.mse	MSE estimates for <code>contrast.est</code> .
contrast.g1	The $g_1$ term in the estimation of <code>contrast.mse</code> .
contrast.g2	The $g_2$ term in the estimation of <code>contrast.mse</code> .
contrast.g3	The $g_3$ term in the estimation of <code>contrast.mse</code> .
contrast.fixed.est	Contrast estimates based on the fixed effect model.
contrast.fixed.var	Variance estimates for the fixed effect model.
contrast.wt1	Weight $wt_1$ given to the direct estimate in estimating the contrasts.
contrast.wt2	Weight $wt_2$ in estimating the contrasts.
inf.mat	Information matrix for the components of <code>delta</code> .
var.coef	Variance covariance matrix for <code>coef</code> .
delta.hist	Values of <code>delta</code> at each iteration.
llikelihood.hist	Values of the log-likelihood (ML) or restricted log-likelihood (REML) at each iteration.

adj.hist	Number of cycles in the internal loop to determine adj.factor within each iteration.
inf.mat.hist	Values of inf.mat at each iteration.
s.hist	Vector to be multiplied by the inverse information matrix to determine the change in the parameters.
ix.hist	List of parameters eligible for change at each iteration. Parameters with estimated changes out of bounds will not be eligible.
adj.factor.hist	Adjustment to the vector change in the parameters at each iteration.
warning.hist	A 4-row matrix of warnings at each iteration, where warning 1 is set to 1 for the iteration if the algorithm has not found an increase in the restricted log likelihood or log likelihood, warning 2 is set to 1 if the maximum number of iterations is reached, warning 3 is set to 1 if the estimated variance-covariance matrix becomes singular, and warning 4 is set to 1 if the coefficients of the fixed effects cannot be estimated.

**Author(s)**

Robert E. Fay, Mamadou Diallo

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eblupDyn

*EBLUP Fit of the Dynamic and Rao-Yu Time Series Models*

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**Description**

Functions for producing EBLUP small area estimates of the dynamic or Rao-Yu time series models through either ML or REML estimation of the variance components. The functions can fit univariate or multivariate models.

**Usage**

```
eblupDyn(formula, D, TI, vardir, method = c("REML", "ML"),
          MAXITER = 1000, PRECISION = .1e-05, data,
          max.rho = NULL, dampening = 1, ...)
```

```
eblupRY(formula, D, TI, vardir, method = c("REML", "ML"),
         MAXITER = 1000, PRECISION = .1e-05, data,
         max.rho = .98, dampening = 0.9, ...)
```

**Arguments**

formula For a univariate model, a formula for the linear regression relationship between the dependent variable and the independent variable(s). The variables included in formula must have length equal to  $D \times n_t$  and be sorted in ascending order by

time within each domain, where  $nt$  is the number of time instances specified by `TI`.

For a multivariate model, a list of formulas, one for each dependent variable. The number of dependent variables,  $NV$ , is determined by the length of the list. The dependent variables included in the formulas must each have length equal to  $D*nt$  and be sorted in ascending order by time within each component within each domain, where  $nt$  is the number of time instances specified by `TI`. The sorting requirement is an extension of the sorting requirement for the univariate model. Further details of the model specification are given under Details.

<code>D</code>	The total number of domains.
<code>TI</code>	<p>If <code>TI</code> is of length 1, it should specify the number of equally spaced time instances, <math>nt</math>. For example, <code>TI</code> can be the number of years in an unbroken sequence of years.</p> <p>If some of the time instances in the time interval are to be omitted from the model, the first element of <code>TI</code> should be 1, the last element should be the ending instance, and the elements in between should indicate the other instances to include. For example, over a period of 6 years, <code>TI=c(1, 2, 4:6)</code> omits the 3rd year from the model, giving <math>nt=5</math>.</p>
<code>vardir</code>	<p>For the univariate model, the sampling covariance matrix for the direct estimates of the <math>D*nt</math> elements of the dependent variable, where <math>nt</math> is the number of instances specified by <code>TI</code>. The covariance matrix should be in the form of a square matrix with <math>D*nt</math> rows and columns. Non-zero covariances between domains are not allowed, so the matrix must have a block diagonal form with <math>D</math> blocks, each of which is a square matrix with <math>nt</math> rows and columns. Note that within domain, non-zero covariances are allowed over time.</p> <p>Alternatively, <code>vardir</code> can be a list of <math>D</math> covariance matrices, each with <math>nt</math> rows and columns.</p> <p>For the multivariate model, the square covariance matrix for the <math>D*NV*nt</math> elements of the dependent variables. The matrix must be in the form of a square matrix with <math>D*NV*nt</math> rows and columns. The variances and covariances should be in the sort order of time within dependent variable within domain. Non-zero covariances between domains are not allowed, but non-zero covariances may be present across time and between components within a domain.</p> <p>Alternatively, <code>vardir</code> can be a list of <math>D</math> covariance matrices, each with <math>NV*nt</math> rows and columns.</p>
<code>method</code>	Whether restricted maximum likelihood REML or maximum likelihood ML should be used.
<code>MAXITER</code>	The maximum number of iterations allowed for the Fisher-scoring algorithm.
<code>PRECISION</code>	The convergence tolerance limit for the Fisher-scoring algorithm.
<code>data</code>	An optional data frame containing the variables named in <code>formula</code> . By default the variables are taken from the environment from which <code>eblupDyn</code> is called. Because <code>vardir</code> will be of a different size than the variables in <code>formula</code> , <code>data</code> will not be searched for <code>vardir</code> .
<code>max.rho</code>	If not <code>NULL</code> , the maximum value allowed for <code>rho</code> . Note the different defaults for <code>eblupDyn</code> and <code>eblupRY</code> .

dampening	A multiplier of the computed update to parameters after iteration 5. A value less than 1 may slow the iterations but lessens the chance of overshooting the optimum choice. The default values were determined experimentally, but may be modified.
...	Other parameters passed to <code>dynRYfit</code> that affect convergence, provide starting values, or request specific results. The exceptions are <code>y</code> , <code>X</code> , <code>NV</code> , <code>M</code> , <code>ncolx</code> , and <code>model</code> , which will be determined by <code>eblupDyn</code> or <code>eblupRY</code> .

## Details

A typical model has the form  $\text{response} \sim \text{terms}$  where `response` is the (numeric) response vector and `terms` is a series of terms that specifies a linear predictor for response.

A formula has an implied intercept term. To remove this use either  $y \sim x - 1$  or  $y \sim 0 + x$ . See `link{formula}` for more details of allowed formulae.

`eblupDyn` and `eblupRY` parse `formula` by calling core R functions to determine `X`, then calling `dynRYfit`. Factors appearing in `terms` will be converted to indicator variables in forming `X` before calling `dynRYfit`.

As a last step, `eblupDyn` or `eblupRY` finalize the list that they return.

The additional parameters passed to `dynRYfit` may include `contrast.matrix`, which specifies linear combinations of estimates within domains, such as the sum over dependent variables or moving averages across time. Corresponding MSE estimates are provided for the contrasts.

The argument `ids` accepts a data frame with `D` rows of domain identifiers. These `ids` are returned in the list from `eblupDyn` or `eblupRY`.

If `iter.history` is set to `TRUE`, the returned object will include additional items with values of statistics at each step of the iteration; see `dynRYfit` for details on

- `delta.hist`,
- `llikelihood.hist`,
- `adj.hist`,
- `s.hist`,
- `ix.hist`,
- `adj.factor.hist`, and
- `warning.hist`.

The default action is to include the history only if the iterations fail, in which case the history might suggest what went wrong. In the case of convergence, the history is usually not of interest, in which case omitting it reduces the size of the returned object.

MSE estimation for REML for both the Rao-Yu and dynamic models follows the results summarized in Rao and Molina (2015, pp. 98-111). The MSE estimates incorporate  $g_1$ ,  $g_2$ , and  $g_3$  terms. Our simulations show that the REML estimates have somewhat smaller MSEs than the ML estimates, but this is not reflected in the comparison of the estimated MSEs returned by the functions. The MSE estimates under REML perform quite well on average. The MSE estimates for ML use the same estimator as for REML, but they are modest underestimates of the true MSE in the same simulations.

**Value**

eblup	In the univariate case, a vector of length $D \times nt$ with the eblup estimates. In the multivariate case, a data frame of $D \times nt$ rows and $NV$ columns.
fit	A list summarizing the fit of the model with the following: <ul style="list-style-type: none"> <li>• <code>model</code>: form of the model: T - Dynamic or Rao-Yu; REML or ML.</li> <li>• <code>convergence</code>: a logical value indicating whether the convergence criterion was met.</li> <li>• <code>TI</code>: specified TI for model (see above).</li> <li>• <code>estcoef</code>: a data frame with the estimated model coefficients (<code>beta</code>) in the first column, their asymptotic standard errors (<code>std.error</code>) in the second column, the t statistics (<code>tvalue</code>) in the third column, and the p-values (<code>pvalue</code>) of the significance of each coefficient in last column.</li> <li>• <code>estvarcomp</code>: a data frame with the estimated values of the variances and correlation coefficients in the first column (<code>estimate</code>) and their asymptotic standard errors in the second column (<code>std.error</code>).</li> <li>• <code>iterations</code>: number of iterations performed by the Fisher-scoring algorithm.</li> <li>• <code>goodness</code>: the log-likelihood and, if REML, the restricted log-likelihood.</li> </ul>
parm	A labelled vector with the estimated variance components, correlations, and number of iterations.
coef	A labelled vector of coefficients of the model or models.
ids	A data frame with $D$ rows and one or more columns of numeric or character domain identifiers.
delta	An ordered vector of the variance components, which may be used as starting values for additional iterations, see <code>dynRYfit</code> .
eblup.mse	MSE estimates for eblup.
eblup.g1	The <code>g1</code> term of the MSE estimate.
eblup.g2	The <code>g2</code> term of the MSE estimate.
eblup.g3	The <code>g3</code> term of the MSE estimate.
est.fixed	Estimates based on fixed effects only.
est.fixed.var	The variance-covariance matrix for the estimates in <code>coef</code> .
eblup.wt1	Weights given to the direct estimate in forming eblup.
eblup.wt2	Weights given to the direct estimate, including effects through estimating the fixed effect coefficients.
contrast.est	Estimates requested by the specified contrasts.
contrast.mse	MSE estimates for <code>contrast.est</code> .
contrast.g1	The <code>g1</code> term in the estimation of <code>contrast.mse</code> .
contrast.g2	The <code>g2</code> term in the estimation of <code>contrast.mse</code> .
contrast.g3	The <code>g3</code> term in the estimation of <code>contrast.mse</code> .
contrast.fixed.est	Contrast estimates based on the fixed effect model.

contrast.fixed.var	Variance estimates for the fixed effect model.
contrast.wt1	Weight wt1 given to the direct estimate in estimating the contrasts.
contrast.wt2	Weight wt2 in estimating the contrasts.
inf.mat	Information matrix for the components of delta.
var.coef	Variance covariance matrix for coef.
model	The formula or list of formulas implemented.

### Author(s)

Robert E. Fay, Mamadou Diallo

### References

- Fay, R.E. and Herriot, R.A. (1979). Estimation of income from small places: An application of James-Stein procedures to census data. *Journal of the American Statistical Association* 74, 269-277.
- Fay, R.E., Planty, M. and Diallo, M.S. (2013). Small area estimates from the National Crime Victimization Survey. *Proceedings of the Joint Statistical Meetings*. American Statistical Association, pp. 1544-1557.
- Rao, J.N.K. and Molina, I. (2015). *Small Area Estimation*, 2nd ed. Wiley, Hoboken, NJ.
- Rao, J.N.K. and Yu, M. (1994). Small area estimation by combining time series and cross-sectional data. *Canadian Journal of Statistics* 22, 511-528.

### Examples

```

D <- 20 # number of domains
TI <- 5 # number of years
set.seed(1)
data <- data.frame(Y= mvrnormSeries(D=D, TI=TI, rho.dyn=.9, sigma.v.dyn=1,
  sigma.u.dyn=.19, sigma.e=diag(5)), X=rep(1:TI, times=D))
result.dyn <- eblupDyn(Y ~ X, D, TI, vardir = diag(100), data=data)
result.dyn$fit

## Not run:
require(sae)
data(spacetime) # Load data set from sae package
data(spacetimeprox) # Load proximity matrix

D <- nrow(spacetimeprox) # number of domains
TI <- length(unique(spacetime$Time)) # number of time instants
# Fit model ST with AR(1) time effects for each domain
resultST <- eblupSTFH(Y ~ X1 + X2, D, TI, Var, spacetimeprox,
  data=spacetime)
resultT <- eblupDyn(Y ~ X1 + X2, D, TI, vardir = diag(spacetime$Var),
  data=spacetime, ids=spacetime$Area)
resultT.RY <- eblupRY(Y ~ X1 + X2, D, TI, vardir = diag(spacetime$Var),
  data=spacetime, ids=spacetime$Area)

resultST$fit
resultT$fit

```

```

resultT.RY$fit
rowsT <- seq(TI, TI*D, by=TI)
data.frame(Domain=spacetime$Area[rowsT], Y=spacetime$Y[rowsT],
           EBLUP_ST=resultST$eblup[rowsT],
           EBLUB_Dyn=resultT$eblup[rowsT],
           EBLUP_RY=resultT.RY$eblup[rowsT])

## End(Not run)

```

---

geo_ratios	<i>Compute rates or ratios for a set of geographic entities over a set of years</i>
------------	---

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### Description

The function computes rates or ratios by a geographic code and the variable Year. If designvars is specified, the function also returns a data frame with linear substitutes to compute Taylor series variances.

### Usage

```

geo_ratios(data, geocode, numerators, denominators, geonames,
           new.names, designvars)

```

### Arguments

data	A data frame with the required variables, including a variable named Year.
geocode	A character variable with the name of the geographic variable for which separate estimates are of interest.
numerators	A character vector listing the names in data of the numerators of the ratios.
denominators	A character vector listing the names in data of the denominators of the ratios. If a single value is given, it will be used for all of the ratios.
geonames	An optional data frame containing geocode and one or more geographic variables, such as names, that will be merged into the results. There should be only one row for each value of geocode.
new.names	An optional character vector of the same length as numerators naming the resulting ratios. If new.names is not specified, the output ratios will have the same names as numerators.
designvars	Optional. If given, a character vector naming one or more survey design variables in data to use in forming linear substitutes for variance calculation of the ratios cross-classified by Year and the variable named by geocode. The vector should not include the geocode variable or Year.

## Details

For programming simplicity, the function enforces the requirement that names should not be repeated in either numerators or new.names. Names may be repeated in denominators.

Rather than a typical survey file, the function expects the data frame data to contain weighted estimates for each analytic variable. As a simple example, to find the variance of the weighted mean of  $y$  with weights  $w$ , data should contain  $w$  and  $y * w$ . For convenience, the weighted estimates can still be assigned their original names in data, such as  $y$ . In this case,

```
numerators = y, denominators=w
```

would create the appropriate linear substitutes for the variance of the weighted mean.

This design of the function allows complex possibilities, such as estimating the variance of a rate where the numerator is based on one weight and the denominator is based on another. For example, estimation for the National Crime Victimization Survey requires this capability.

## Value

If designvars is not specified, a named list with one element, a data frame containing the ratios sorted by geocode and Year.

If designvars is specified, a second element is added to the list, a data frame giving the totals of the linear substitutes by Year, geocode, and designvars. The elements of the list are named estimates and linear.subs.

## Author(s)

Robert E. Fay

## References

- Woodruff, R.S. (1971). A simple method for approximating the variance of a complex estimate. *Journal of the American Statistical Association* 66, 411-414.

## See Also

vcovgen

## Examples

```
require(survey)
require(MASS)
D <- 20 # number of domains
T <- 5 # number of years
samp <- 16 # number of sample cases per domain
set.seed(1)
# use conditional.mean=TRUE to generate true small area values
# without sampling error
Y.list <- mvrnormSeries(D=D, T=T, rho.dyn=.9, sigma.v.dyn=1,
  sigma.u.dyn=.19, sigma.e=diag(5), conditional.mean=TRUE)
# generate sampling errors
e <- rnorm(samp * T * D, mean=0, sd=4)
```

```

Y <- Y.list[[2]] + tapply(e, rep(1:100, each=16), mean)
data <- data.frame(Y=Y, X=rep(1:T, times=D))
# model fit with the true sampling variances
result.dyn <- eblupDyn(Y ~ X, D, T, vardir = diag(100), data=data)
# individual level observations consistent with Y
Y2 <- rep(Y.list[[2]], each=16) + e
data2 <- data.frame(Y=Y2, X=rep(rep(1:T, each=samp), times=D),
                    Year=rep(rep(1:T, each=samp), times=D),
                    weight=rep(1, times=samp*T*D),
                    d=rep(1:D, each=samp*T),
                    strata=rep(1:(D*T), each=samp),
                    ids=1:(D*T*samp))
# geo_ratios with designvars specified
geo.results <- geo_ratios(data2, geocode="d", numerators="Y",
                          denominators="weight",
                          designvars=c("strata", "ids"))
# illustrative check
max(abs(geo.results[[1]]$Y - Y))
vcov.list <- vcovgen(geo.results[[2]], year.list=1:5, geocode="d",
                    designvars=c("strata", "ids"))
vcov.list[[1]]
# model fitted with directly estimated variance-covariances
result2.dyn <- eblupDyn(Y ~ X, D, T, vardir=vcov.list, data=data)
cor(result.dyn$eblup, result2.dyn$eblup)

```

---

mvrnormSeries

*Generate data under the Dynamic or Rao-Yu Time Series Models*


---

## Description

Function to generate data under a Rao-Yu time series model, a dynamic model, or a mixture of both. The function can produce either univariate or multivariate observations. All components of the returned random variable have unconditional mean zero. The function calls `mvrnorm` in **MASS**.

## Usage

```

mvrnormSeries(NV=1, D, TI, sigma.e,
              rho.dyn, sigma.v.dyn, sigma.u.dyn, rho.u.dyn,
              rho.RY, sigma.v.RY, sigma.u.RY, rho.u.RY, tol=1e-6,
              conditional.mean=FALSE)

```

## Arguments

NV	The number of variables.
D	The number of domains.
TI	The number of time instances (constant for all domains).

<code>sigma.e</code>	The covariance matrix for the variation due to sampling, specified either as a single square matrix with $NV \times TI$ rows and columns, or as a list of $D$ matrices, each with $NV \times TI$ rows and columns. The rows should vary over $TI$ more quickly than over $NV$ . Sampling covariances between domains are assumed to be zero.
<code>rho.dyn</code>	The temporal correlation parameter in the dynamic model. This parameter is not a true correlation, however, and it may exceed 1.
<code>sigma.v.dyn</code>	A vector of length $NV$ with the $v$ (nu) component of the variance under the dynamic model. This component measures the variance of the random effect at the beginning of the series.
<code>sigma.u.dyn</code>	A vector of length $NV$ with the $u$ component of the variance under the dynamic model.
<code>rho.u.dyn</code>	For $NV > 1$ , the cross-sectional correlation(s) under the model. The vector should specify $(NV \times (NV - 1)) / 2$ correlations, in lower triangular form. For example, for $NV = 3$ , the correlations should be specified in the order (2,1), (3,1), (3,2).
<code>rho.RY</code>	The temporal correlation parameter in the Rao-Yu model. This is a true correlation, unlike the parameter in the dynamic model.
<code>sigma.v.RY</code>	A vector of length $NV$ with the $v$ (nu) component of the variance under the Rao-Yu model. This component reflects a constant random effect for each domain unchanging over time.
<code>sigma.u.RY</code>	A vector of length $NV$ with the $u$ component of the variance under the Rao-Yu model.
<code>rho.u.RY</code>	For $NV > 1$ , the cross-sectional correlation under the model. The vector should specify $(NV \times (NV - 1)) / 2$ correlations, in lower triangular form. For example, for $NV = 3$ , the correlations should be specified in the order (2,1), (3,1), (3,2).
<code>tol</code>	A tolerance parameter used by <code>mvrnorm</code> in <b>MASS</b> to determine if the covariance matrix is non-singular.
<code>conditional.mean</code>	If true, the function will also return the generated values of the random effects.

## Details

The function assembles the covariance matrix from the covariance matrix under the dynamic model (if specified), the Rao-Yu model (if specified) and a required sampling covariance matrix.

## Value

If `conditional.mean=FALSE`, then for  $NV=1$ , a multivariate normal random vector with mean zero and length  $D \times TI$ . For  $NV > 1$ , a matrix with  $D \times TI$  rows and  $NV$  columns.

If `conditional.mean=TRUE`, a list with the first element as above and a second element that is the sum of the random effects without the sampling error. Simulation studies can evaluate the small area estimates using the first element of the list as input against the second element of the list, which is the target of the small area estimation.

## Author(s)

Robert E. Fay

**Examples**

```
set.seed(7)
mvrnormSeries(D=2, TI=5, sigma.e=diag(5), rho.dyn=.8,
  sigma.v.dyn=2, sigma.u.dyn=.72, conditional.mean=TRUE)
mvrnormSeries(NV=2, D=2, TI=5, sigma.e=diag(10), rho.dyn=.8,
  sigma.v.dyn=2, sigma.u.dyn=.72, rho.u.dyn=.8)
```

vcovgen

*Estimate variance/covariance matrices using linear substitutes***Description**

The function computes estimates of variance/covariance matrices for sampling with replacement at the first stage from a stratified sample, using the linear substitutes produced by [geo\\_ratios](#). The function produces a list of estimated covariance matrices corresponding the geographic areas identified by geocode.

**Usage**

```
vcovgen(linear.subs, year.list, geocode, designvars)
```

**Arguments**

linear.subs	A data frame with linear substitutes for each Y variable, Year, and the variables with the names given by geocode and designvars.
year.list	A character or numeric vector of the years to include.
geocode	A character variable with the name of the geographic variable for which separate estimates are of interest.
designvars	A character vector of length 2, naming the strata and first-stage units.

**Details**

The function reformats the second element of the list output from [geo\\_ratios](#) in order to estimate covariances across time for each separate geographic area identified by the variable with the name indicated by geocode. It then calls functions from the **survey** package to estimate covariances.

See the example in [geo\\_ratios](#).

**Value**

A list of estimated covariance matrices, sorted by the geographic names. The list may be used by `eblupDyn` or `eblupRY`, although many applications require the estimated variance/covariance matrices to be smoothed.

**Author(s)**

Robert E. Fay

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