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Title Robust Small Area Estimation

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Author Sebastian Warnholz [aut, cre]

Maintainer Sebastian Warnholz <wahani@gmail.com>

Description Methods to fit robust alternatives to commonly used models used in Small Area Estimation. The methods here used are based on best linear unbiased predictions and linear mixed models. At this time available models include area level models incorporating spatial and temporal correlation in the random effects.

BugReports https://github.com/wahani/saeRobust/issues

Depends R (>= 3.3.0), methods, aoos

Imports assertthat, ggplot2, Matrix, magrittr, MASS, modules, memoise, pbapply, Rcpp, spdep

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`bootstrap` *Fit model on Bootstrap sample*

Description

These functions help to repeatedly fit a rfh model on bootstrap samples. Use `bootstrap` as a user interface. `boot` can be used to extend the framework but is not meant to be used interactively. If you are interested in the parameteric bootstrap for a 'rfh' model you can use the implementation in mse.

Usage

```
bootstrap(object, matV = variance(object), B = NULL, ...)

boot(object, matV, B, ...)

## S4 method for signature 'ANY,ANY,integerORnumeric'
boot(object, matV, B, filter = NULL, postProcessing = identity, ...)

## S4 method for signature 'rfh,rfhVariance,`NULL`'
boot(object, matV, B, ...)
```

Arguments

object	a fitted object
matV	the variance of a fitted object used to draw samples. In most cases this is object. Alternatively it may be useful to use a non-robust model.
B	the number of repetitions
...	arguments passed down to methods
filter	a vector indicating which elements in the fittedd object to keep in each repetition.
postProcessing	a function to process the results. Is applied before the filter.

Examples

```
data(milk, package = "sae")
milk$samplingVar <- milk$SD^2
modelFit <- rfh(yi ~ as.factor(MajorArea), milk, "samplingVar")
bootstrapCoefs <- bootstrap(modelFit, B = 2, filter = "coefficients")
do.call(rbind, unlist(bootstrapCoefs, FALSE))
```

---

corSAR1-class *Correlation Structure*

Description

Various correlation structures. They can be used inside the rfh function to supply an alterantive variance structure to be fitted. For examples see the documentation of rfh.

Usage

```
corSAR1(W)

corAR1(nTime)

corSAR1AR1(nTime, W)
```

Arguments

W	the row-standardised proximity matrix
nTime	(numeric) number of time periods

Details

corSAR1 can be used to model a simultanous autoregressive process of order one: spatial correlation.

corAR1 can be used to model a autoregressive process of order one: temporal correlation.

corSAR1AR1 can be used to model to model spatial and temporal correlation

Slots

`W` the row-standardised proximity matrix

`nTime` (numeric) number of time periods

`fitrfh` *Fitting Precedures*

Description

Several fitting procedures. The arguments can be passed to these functions using the interface in rfh. The functions here listed are the low level implementations and are not intended for interactive use.

Usage

```
fitrfh(y, x, samplingVar, ...)

fitrsfh(y, x, samplingVar, W, x0Var = c(0.01, 1), ...)

fitrtfh(y, x, samplingVar, nTime, x0Var = c(0.01, 1, 1), ...)

fitrstfh(y, x, samplingVar, W, nTime, x0Var = c(0.01, 0.01, 1, 1), ...)

fitGenericModel(
  y,
  x,
  matVFun,
  fixedPointParam,
  k = 1.345,
  K = getK(k),
  x0Coef = NULL,
  x0Var = 1,
  x0Re = NULL,
  tol = 1e-06,
  maxIter = 100,
  maxIterParam = 10,
  maxIterRe = 100,
  convCrit = convCritRelative(tol),
  ...
)

## S4 method for signature 'numeric,matrixORMatrix,numeric,`NULL`'
rfh(formula, data, samplingVar, correlation = NULL, ...)

## S4 method for signature 'numeric,matrixORMatrix,numeric,corSAR1'
rfh(formula, data, samplingVar, correlation = NULL, ...)
```

```
## S4 method for signature 'numeric,matrixORMatrix,numeric,corAR1'
rfh(formula, data, samplingVar, correlation = NULL, ...)

## S4 method for signature 'numeric,matrixORMatrix,numeric,corSAR1AR1'
rfh(formula, data, samplingVar, correlation = NULL, ...)
```

Arguments

y	(numeric) response vector
x	([ml|M]atrix) the design matrix
samplingVar	(numeric) vector with sampling variances
...	arguments passed to `fitGenericModel`
W	(matrix) proximity matrix
x0Var	(numeric) starting values for variance parameters
nTime	(integer) number of time periods
matVFun	(function) a function with one argument - the variance parameters - constructing something like variance
fixedPointParam	(function) a function with one argument. The vector of model parameters. Returns a list of results of the next iteration in the overall algorithm.
k	(numeric) tuning constant
K	(numeric) scaling constant
x0Coef	(numeric) starting values for regression coefficients
x0Re	(numeric) starting values for random effects
tol	(numeric) numerical toloerance to be used during optimisation
maxIter	(integer) the maximum number of iterations for model parameters.
maxIterParam	(integer) the maximum number of iterations for each parameter in each overall iteration
maxIterRe	(integer) the maximum number of iterations for fitting the random effects
convCrit	(function) a function defining the stopping rule
formula	(formula) a formula specifying the fixed effects part of the model.
data	(data.frame) a data set.
correlation	an optional correlation structure, e.g. corSAR1, for the random effects part of the model. Default is no correlation, i.e. a random intercept.

Details

`fitrfh` implements the robust Fay-Herriot model; `fitrsfh` the spatial, `fitrtfh` the temporal, and `fitrstfh` the spatio-temporal extension to this model type. See rfh how to fit such models. `fitGenericModel` is used by all these implementations and can be used for possible extensions of the framework.

Examples

```
data(milk, package = "sae")
x <- matrix(1, nrow = NROW(milk))
y <- milk$yi
samplingVar <- milk$SD^2
fitrfh(y, x, samplingVar)
```

`fixedPoint` *Fixed Point Algorithm Infrastructure*

Description

A fixed-point function supplied by the user is iteratively evaluated. `addAverageDamp` can be used to add average damping to the function - this may have a positive effect on the speed of convergence.

Usage

```
fixedPoint(fun, x0, convCrit)

addAverageDamp(fun)

addConstraintMin(fun, value)

addConstraintMax(fun, value)

convCritAbsolute(tolerance = 1e-06)

convCritRelative(tolerance = 1e-06)

addMaxIter(fun, maxIter)

addCounter(fun)

addHistory(fun)

addStorage(fun)

newtonRaphson(funList, ...)

newtonRaphsonFunction(funList)
```

Arguments

`fun`	the function to be evaluated in the algorithm
`x0`	starting value
`convCrit`	a function returning a logical scalar. Is called with two arguments; the first is the value from iteration n; the second is the value from iteration n-1

value	(numeric)
tolerance	a numeric value > 0
maxIter	maximum number of iterations
funList	(list) the functions to be evaluated in the algorithm. First element is typically the score function, second is the derivative of the score.
...	arguments passed to fixedPoint

Details

addAverageDamp adds average damping to an arbitrary fixed point function.

addConstraintMin takes care that values are not below a minimum value.

addConstraintMax takes care that values are not larger than maximum value.

convCritAbsolute absolute difference as convergence criterion.

convCritRelative relative (to previous iteration) absolute difference as convergence criterion. If value is smaller than 1, absolute difference is used.

addMaxIter can be used to modify convergence criterion functions.

addCounter can be used to count the number of calls of a function.

addHistory can be used to save a history of results of a function. The history is stored as a matrix, so this works best if the return value of fun is numeric.

addStorage will add a storage to a function. The storage is a list in which each result is stored. The function will coerce the return value into a numeric.

newtonRaphson finds zeroes of a function. The user can supply the function and its first derivative. Note that the Newton Raphson Algorithm is a special case of a fixed point algorithm thus it is implemented using fixedPoint and is only a convenience.

Examples

```
## Not run:
vignette("fixedPoint", "saeRobust")

## End(Not run)
```

---

makeXY *makeXY*

Description

Extract respone vector and design matrix from data with given formula.

Usage

```
makeXY(.formula, .data)
```

Arguments

.formula	(formula)
.data	(data.frame) data from which design matrix and response to extract from

Examples

```
set.seed(1)
makeXY(y ~ I(x^2), data.frame(x = rnorm(10), y = rnorm(10)))
```

---

matU *Matrix constructor functions*

Description

These functions construct different parts of matrix components. They are used internally. If you are interested in the weights of a model fitted using rfh please try to use weights.fitrfh on that object.

Usage

```
matU(.V)

matTrace(x)

matB(y, X, beta, re, matV, psi)

matBConst(y, X, beta, matV, psi)

matA(y, X, beta, matV, psi)

matAConst(y, X, matV, psi)

matW(y, X, beta, re, matV, psi)

matWbc(y, reblup, W, samplingVar, c = 1)

matTZ(.nDomains, .nTime)

matTZ1(.nDomains = 10, .nTime = 10)
```

Arguments

.V	(Matrix) variance matrix
x	([m|M]atrix) a matrix
y	(numeric) response
X	(Matrix) design matrix

beta	(numeric) vector of regression coefficients
re	(numeric) vector of random effects
matV	(list of functions) see matVFH for an example
psi	(function) the influence function
reblup	(numeric) vector with robust best linear unbiased predictions
W	(Matrix) the weighting matrix
samplingVar	(numeric) the vector of sampling variances
c	(numeric) scalar
.nDomains	(integer) number of domains
.nTime	(integer) number of time periods

Details

matU computes U. U is the matrix containing only the diagonal elements of V. This function returns a list of functions which can be called to compute specific transformations of U.

matTrace computes the trace of a matrix.

matB computes the matrix B which is used to compute the weights in the pseudo linearised representation of the REBLUP.

matBConst returns a function with one argument, u, to compute the matrix B. This function is used internally to compute B in the fixed point algorithm.

matA computes the matrix A which is used to compute the weights in the pseudo linearized representation of the REBLUP.

matAConst returns a function with one argument, beta, to compute the matrix A. This function is used internally to compute A in the fixed point algorithm for beta.

matW returns a matrix containing the weights as they are defined for the pseudo linear form, such that matW %*% y is the REBLUP.

matWbc returns a matrix containing the weights as they are defined for the pseudo linear form, such that matWbc %*% y is the bias-corrected REBLUP. c is a multiplyer for the standard deviation.

matTZ constructs the Z matrix in a linear mixed model with autocorrelated random effects.

matTZ1 constructs the Z1 matrix in a linear mixed model with autocorrelated random effects.

References

Warnholz, S. (2016): "Small Area Estimaiton Using Robust Extension to Area Level Models". Not published (yet).

Examples

```
data("grapes", package = "sae")
data("grapesprox", package = "sae")

fitRFH <- rfh(
  grapehect ~ area + workdays - 1,
  data = grapes,
```

```
  samplingVar = "var"
)

matV <- variance(fitRFH)

# matU:
matU(matV$V())$U()
matU(matV$V())$sqrt()
matU(matV$V())$sqrtInv()

# matB (and matA + matW accordingly):
matB(
  fitRFH$y,
  fitRFH$x,
  fitRFH$coefficients,
  fitRFH$re,
  matV,
  function(x) psiOne(x, k = fitRFH$k)
)

matBConst(
  fitRFH$y,
  fitRFH$x,
  fitRFH$coefficients,
  matV,
  function(x) psiOne(x, k = fitRFH$k)
)(fitRFH$re)

# construcors for 'Z' in linear mixed models
matTZ(2, 3)
matTZ1(2, 3)
```

`mse` *Compute the Mean Squared Error of an Estimator*

Description

A generic function to compute the mean squared error of the predicted values under the estimated model. See also rfh for examples.

Usage

```
mse(object, ...)

## S3 method for class 'fitrfh'
mse(object, type = "pseudo", predType = "reblupbc", B = 100, ...)
```

Arguments

object	(see methods) an object containing the estimation result, e.g. rfh
...	arguments passed to methods
type	(character) the type of the MSE. Available are 'pseudo' and 'boot'
predType	(character) the type of prediction: c("reblup","reblupbc")
B	(numeric) number of bootstrap repetitions

Details

Type pseudo is an approximation of the MSE based on a pseudo linearisation approach by Chambers, et. al. (2011). The specifics can be found in Warnholz (2016). Type boot implements a parameteric bootstrap for these methods.

References

Chambers, R., H. Chandra and N. Tzavidis (2011). "On bias-robust mean squared error estimation for pseudo-linear small area estimators". In: Survey Methodology 37 (2), pp. 153–170.

Warnholz, S. (2016): "Small Area Estimaiton Using Robust Extension to Area Level Models". Not published (yet).

Examples

```
data("grapes", package = "sae")
data("grapesprox", package = "sae")

fitRFH <- rfh(
  grapehect ~ area + workdays - 1,
  data = grapes,
  samplingVar = "var"
)

mseRFH <- mse(fitRFH)
plot(mseRFH)
```

---

plot.rfh *Plots*

Description

Various implementations of diagnostic plots. They are linked together using the plot generic function.

Usage

```
## S3 method for class 'rfh'
plot(x, y, ...)

## S3 method for class 'prediction.fitrfh'
plot(x, y, alpha = 0.05, ...)

## S3 method for class 'mse.fitrfh'
plot(x, y = "pseudo", xlim = NULL, ylim = NULL, ...)

qqPlot(sample)

blandAltmanPlot(x, y, alpha = 0.05)
```

Arguments

x	an object
y	for mse estimates a filter for the predictors; otherwise ignored
...	ignored
alpha	(numeric) between 0 and 1 - used in computation of confidence interval
xlim, ylim	arguments are passed to coord_cartesian and coord_flip.
sample	(numeric) a vector

Details

`qqPlot` a QQ-Plot using ggplot2

`blandAltmanPlot` a Bland-Altman plot. Solid line is the mean. Dashed lines are the upper and lower bound of the limits-of-aggreements: z-quantile * sd(x - y) – not the standard error. The alpha level can be set using `alpha`. This plot is otherwise known as Tukey's mean-difference plot.

Examples

```
qqPlot(rnorm(10))
blandAltmanPlot(rnorm(10), rnorm(10))
```

`psiOne` *psiOne*

Description

`psiOne` is a Huber influence function. `getK` function to compute capital K – used internally.

Usage

```
psiOne(u, k = 1.345, deriv = FALSE)

getK(k)
```

Arguments

u	standardized residuals
k	tuning constant
deriv	if TRUE returns the derivative

Examples

```
set.seed(1)
u <- rnorm(10)
psiOne(u, k = 1.345, deriv = FALSE)
```

---

rfh *Robust Fay Herriot Model*

Description

User interface to fit robust Fay-Herriot type models. These models are here framed as linear mixed models. The parameter estimation is robust against outliers. Available models are the standard FH model, a spatial extension, a temporal extension and a spatio-temporal extension.

Usage

```
rfh(formula, data, samplingVar, correlation = NULL, ...)

## S4 method for signature 'formula,data.frame,character,ANY'
rfh(formula, data,
  samplingVar, correlation, ...)

## S3 method for class 'fitrfh'
predict(object, type = "reblup", c = 1, ...)
```

Arguments

formula	(formula) a formula specifying the fixed effects part of the model.
data	(data.frame) a data set.
samplingVar	(character) the name of the variable in data containing the sampling variances.
correlation	an optional correlation structure, e.g. corSAR1, for the random effects part of the model. Default is no correlation, i.e. a random intercept.
...	arguments passed fitGenericModel
object	(rfh) an object of class rfh
type	(character) one or more in c("linear", "reblup", "reblupbc")
c	(numeric) scalar; a multiplyer constant used in the bias correction. Default is to make no correction for realisations of direct estimator within c = 1 times the standard deviation of direct estimator.

Details

To trigger the spatial and temporal extensions you can supply an argument `correlation`. When `corSAR1` is used the model of Petrucci and Salvati (2006); for `corAR1` the model of Rao and Yu (1994) is used; and for `corSAR1AR1` the model of Marhuenda et al. (2013).

The methods introducing the robust framework underpinning this implementation can be found in Warnholz (2016). They are based on the results by Sinha and Rao (2009) and Richardson and Welsh (1995).

Value

A list with the following elements:

- `call` (language) the call generating the value
- `formula` (formula) the formula passed as argument
- `samplingVar` (numeric) the vector of sampling variances
- `coefficients` (numeric) the vector of regression coefficients
- `variance` (numeric) the vector of fitted variance parameter(s)
- `iterations` (list) reporting each step in the optimisation
- `tol` (numeric) the tolerance level used
- `maxIter` (numeric) maximum overall allowed iterations
- `maxIterParam` (numeric) maximum allowed iterations for model parameters in each overall iteration
- `maxIterRe` (numeric) maximum allowed iterations for fitting the random effects
- `k` (numeric) tuning constant in influence function
- `K` (numeric) additional tuning constant; often derived from `k` to scale down the residual variance
- `y` (numeric) the response vector
- `x` (Matrix) the design matrix
- `re` (numeric) the fitted random effects. Can be c(re1, re2)
- `reblup` (numeric) the robust best linear unbiased prediction under the fitted model
- `residuals` (numeric) the realised sampling errors
- `fitted` (numeric) the fitted values using only the fixed effects part

References

Marhuenda, Y., I. Molina and D. Morales (2013). "Small area estimation with spatio-temporal Fay-Herriot models". In: Computational Statistics and Data Analysis 58, pp. 308–325.

Pratesi, M. and N. Salvati (2008). "Small area estimation: the EBLUP estimator based on spatially correlated random area effects". In: Statistical Methods & Applications 17, pp. 113–141.

Rao, J. N. K. and M. Yu (1994). "Small-Area Estimation by Combining Time-Series and Cross-Sectional Data". In: Canadian Journal of Statistics 22.4, pp. 511–528.

Richardson, A. M. and A. H. Welsh (1995). "Robust Restricted Maximum Likelihood in Mixed Linear Models". In: Biometrics 51 (4), pp. 1429–1439.

Sinha, S. K. and J. N. K. Rao (2009). "Robust Small Area Estimation". In: The Canadian Journal of Statistics 37 (3), pp. 381–399.

Warnholz, S. (2016): "Small Area Estimaiton Using Robust Extension to Area Level Models". Dissertation. https://refubium.fu-berlin.de/handle/fub188/9706.

Examples

```
# Non-temporal models:
data("grapes", package = "sae")
data("grapesprox", package = "sae")

fitRFH <- rfh(
  grapehect ~ area + workdays - 1,
  data = grapes,
  samplingVar = "var"
)

fitRFH
summary(fitRFH)

plot(fitRFH)
plot(predict(fitRFH))
plot(mse(fitRFH))

## Not run:
# And the same including a spatial structure:
fitRSFH <- rfh(
  grapehect ~ area + workdays - 1,
  data = grapes,
  samplingVar = "var",
  corSAR1(as.matrix(grapesprox))
)

# Use the same methods, e.g. plot, for all these implementations:
data("spacetime", package = "sae")
data("spacetimeprox", package = "sae")
nTime <- length(unique(spacetime$Time))

fitRTFH <- rfh(
  Y ~ X1 + X2,
  spacetime,
  "Var",
  corAR1(nTime = nTime)
)

fitRSTFH <- rfh(
  Y ~ X1 + X2,
  spacetime,
  "Var",
  corSAR1AR1(W = as.matrix(spacetimeprox), nTime = nTime)
```

```
)

## End(Not run)
```

---

score *Compute values of robust score functions*

Description

Can be used to compute the values of the robust estimation equations at their 'solution'.

Usage

```
score(object, filter, ...)
```

Arguments

object	a fitted object
filter	(character) a selection of values to be computed
...	arguments passed to methods

Examples

```
data("grapes", package = "sae")

fitRFH <- rfh(
  grapehect ~ area + workdays - 1,
  data = grapes,
  samplingVar = "var"
)

score(fitRFH)
```

---

testMatX *Construction of test data*

Description

Construction of test data

Usage

```
testMatX(...)

testResponse0(x, beta = rep(1, ncol(x)))

testResponse(y0, k = 1:4, .sd = sd(y0))

testRook(n)
```

Arguments

...	matrices
x	a matrix
beta	a vector with parameters
y0	a response vector (numeric)
k	values in 1 to 4 (integer)
.sd	the standard deviation used for random numbers
n	dimension

References

Weihs / Mersmann / Ligges (2014): Foundations of Statistical Algorithms: With References to R Packages

Examples

```
## Examples from Weihs et. al. (2014) p. 108
library("Matrix")
testMatX(Matrix(998), Matrix(998))
Z <- Matrix(c(998, 0, 0, 0), 2, 2)
testMatX(Z, Z)
testResponse0(testMatX(Matrix(1)))
library("magrittr")
Matrix(1) %>% testMatX %>% testResponse0 %>% testResponse
```

---

update,rfh-method *Update a fitted object*

Description

This is a method which can be used to update a rfh result object and refit it. The fitted parameter values from the current object are used as starting values, then update.default is called.

Usage

```
## S4 method for signature 'rfh'
update(object, formula, ..., where = parent.frame(2))

## S4 method for signature 'fitrfh'
update(object, ...)
```

Arguments

object	(rfh) an object fitted by rfh
formula	see update.formula
...	arguments passed to update.default
where	(environment) should not be specified by the user

variance *Construct variance*

Description

A generic function to construct the different variance components of an object. You may want to use this in conjunction with bootstrap.

Usage

```
variance(.object, ...)

## S3 method for class 'fitrfh'
variance(.object, ...)

## S3 method for class 'fitrsfh'
variance(.object, ...)

## S3 method for class 'fitrtfh'
variance(.object, ...)

## S3 method for class 'fitrstfh'
variance(.object, ...)

## S3 method for class 'fitrfh'
weights(object, c = 1, ...)
```

Arguments

.object, object	an object
...	arguments passed to method
c	(numeric) scalar

Examples

```
data("grapes", package = "sae")
data("grapesprox", package = "sae")

fitRFH <- rfh(
  grapehect ~ area + workdays - 1,
  data = grapes,
  samplingVar = "var"
)

# The variance component of a mixed linear model:
matV <- variance(fitRFH)
# The full variance matrix:
matV$V()
```

```
# The sampling error component
matV$Ve()

# the random effects component
matV$Vu()
```

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