Package 'garchx'

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Type Package

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Description Flexible and robust estimation and inference of Generalised Autoregressive Conditional Heteroscedasticity (GARCH) models with covariates ('X') based on the results by Francq and Thieu (2019) <doi:10.1017/S0266466617000512>. Coefficients can straightforwardly be set to zero by omission, and quasi maximum likelihood methods ensure estimates are generally consistent and inference valid, even when the standardised innovations are non-normal and/or dependent over time. See <doi:10.32614/RJ-2021-057> for an overview of the package.

License GPL (>= 2)

Depends R (>= 3.4.0), methods, zoo

Suggests tvgarch, lgarch

BugReports https://github.com/gsucarrat/garchx/issues

URL https://www.sucarrat.net/

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Contents

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garchx-package *Flexible and Robust GARCH-X Modelling*

Description

Flexible and robust estimation and inference of GARCH(q,p,r)-X models, where q is the GARCH order, p is the ARCH order, r is the asymmetry or leverage order, and 'X' indicates that covariates can be included. Suitable subsets of the coefficients can be restriced to zero by omission, and Quasi Maximum Likelihood (QML) methods ensure estimates are generally consistent, even when the standardised innovations are non-normal and/or dependent.

Details

Package:	garchx
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Author(s)

Genaro Sucarrat, https://www.sucarrat.net/

Maintainer: Genaro Sucarrat

See Also

garchxSim, coef, fitted, logLik, print, residuals, vcov

Examples

```
##simulate from a garch(1,1):
set.seed(123)
y <- garchxSim(1000)

##estimate garch(1,1) model:
mymod <- garchx(y)
mymod
```

---

coef.garchx *Extraction functions for 'garchx' objects*

Description

Extraction functions for objects of class 'garchx'

Usage

```
  ## S3 method for class 'garchx'
coef(object, ...)
  ## S3 method for class 'garchx'
confint(object, parm, level = 0.95, ...)
  ## S3 method for class 'garchx'
fitted(object, as.zoo = TRUE, ...)
  ## S3 method for class 'garchx'
logLik(object, ...)
  ## S3 method for class 'garchx'
nobs(object, ...)
  ## S3 method for class 'garchx'
predict(object, n.ahead = 10, newxreg = NULL,
    newindex = NULL, n.sim = NULL, verbose = FALSE, ...)
  ## S3 method for class 'garchx'
print(x, ...)
  ## S3 method for class 'garchx'
quantile(x, probs=0.025, names = TRUE, type = 7, as.zoo = TRUE, ...)
  ## S3 method for class 'garchx'
residuals(object, as.zoo = TRUE, ...)
  ## S3 method for class 'garchx'
toLatex(object, digits = 4, ...)
  ## S3 method for class 'garchx'
vcov(object, vcov.type = NULL, ...)
```

Arguments

object	an object of class 'garchx'
x	an object of class 'garchx'

parm	a specification of which parameters are to be given confidence intervals, either a vector of numbers or a vector of names. If missing, all parameters are considered
level	numeric value between 0 and 1 (the confidence level required)
as.zoo	logical. If TRUE, then the returned result is of class zoo
n.ahead	integer that determines how many steps ahead predictions should be generated
newxreg	vector or matrix with the out-of-sample regressor values
newindex	zoo-index for the out-of-sample predictions. If NULL (default), then 1:n.ahead is used
n.sim	NULL or an integer, the number of simulations
verbose	logical. If TRUE, then the simulations - in addition to the predictions - are returned
probs	vector of probabilities
names	logical, whether to return names or not
type	integer that determines the algorithm used to compute the quantile, see quantile
digits	integer, the number of digits in the printed LaTeX code
vcov.type	NULL or character that is (partially) matched to "ordinary", "robust" or "hac". The robust coefficient-covariance ("robust") is that of Francq and Thieu (2019). The Heteroscedasticity and Autocorrelation Consistent ("hac") variance-covariance estimates the variance of the score (the 'meat') based on Theorem 2.2 in De Jong and Davidson (2000). For the details of the kernel weights (Bartlett) and bandwidth, see the code in the vcov.garchx function
...	additional arguments

Value

coef:	numeric vector containing parameter estimates
confint:	A matrix lower and upper confidence limits for each parameter
fitted:	fitted conditional variance
logLik:	log-likelihood (normal density)
nobs:	the number of observations used in the estimation
predict:	a vector with the predictions (verbose=FALSE), or a matrix with both the predictions and the simulations (verbose=TRUE)
print:	print of the estimation results
quantile:	the fitted quantiles, i.e. the conditional standard deviation times the empirical quantile of the standardised innovations
residuals:	standardised residuals
vcov:	coefficient variance-covariance matrix

Author(s)

Genaro Sucarrat, https://www.sucarrat.net/

References

Christian Francq and Le Quien Thieu (2019): 'QML inference for volatility models with covariates', Econometric Theory 35, pp. 37-72, doi:10.1017/S0266466617000512 Robert M. de Jong and James Davidson (2000): 'Consistency of Kernel Estimators of Heteroscedastic and Autocorrelated Covariance Matrices', Econometrica 68, pp. 407-423

See Also

garchx, garchxSim, zoo

Examples

```
##simulate from a garch(1,1):
set.seed(123)
y <- garchxSim(1000)

##estimate garch(1,1) model:
mymod <- garchx(y)

##print estimation results:
print(mymod)

##extract coefficients:
coef(mymod)

##extract and store conditional variances:
sigma2hat <- fitted(mymod)

##extract log-likelihood:
logLik(mymod)

##extract and store standardised residuals:
etahat <- residuals(mymod)

##extract coefficient variance-covariance matrix:
vcov(mymod)

##generate predictions:
predict(mymod)
```

---

garchx *Estimate a GARCH-X model*

Description

Quasi Maximum Likelihood (ML) estimation of a GARCH(q,p,r)-X model, where q is the GARCH order, p is the ARCH order, r is the asymmetry (or leverage) order and 'X' indicates that covariates

can be included. Note that the underlying estimation theory assumes the covariates are stochastic. The estimation procedure will, in general, provide consistent estimates when the standardised innovations are not normal or independent (or both), see Francq and Thieu (2018).

Usage

```
garchx(y, order = c(1,1), arch = NULL, garch = NULL, asym = NULL,
  xreg = NULL, vcov.type = c("ordinary", "robust", "hac"),
  initial.values = NULL, backcast.values = NULL, lower = 0,
  upper = +Inf, control = list(), hessian.control = list(),
  solve.tol = .Machine$double.eps, estimate = TRUE, c.code = TRUE,
  penalty.value = NULL, sigma2.min = .Machine$double.eps,
  objective.fun = 1, turbo = FALSE)
```

Arguments

y	numeric vector, time-series or zoo object. Missing values in the beginning and at the end of the series is allowed, as they are removed with the na.trimcommand
order	integer vector of length 1, 2 or 3, for example c(1,1,1). The first entry controls the GARCH order, the second the ARCH order and the third the ASYM (asymmetry/leverage) order
arch	NULL or numeric vector containing the ARCH-terms to include. Note: If not NULL, then the value of the ARCH argument overrides the value of the first entry in the order argument
garch	NULL or numeric vector containing the GARCH-terms to include. Note: If not NULL, then the value of the GARCH argument overrides the value of the second entry in the order argument
asym	NULL or numeric vector containing the ASYM-terms (asymmetry/leverage terms) to include. Note: If not NULL, then the value of the ASYM argument overrides the value of the third entry in the order argument
xreg	numeric vector, time-series or zoo object. Missing values in the beginning and at the end of the series is allowed, as they are removed with the na.trim command
vcov.type	character, either "ordinary", "robust" or "hac". The robust coefficient-covariance ("robust") is that of Francq and Thieu (2019). The Heteroscedasticity and Autocorrelation Consistent ("hac") variance-covariance estimates the variance of the score (the 'meat') based on Theorem 2.2 in De Jong and Davidson (2000). For the details of the kernel weights (Bartlett) and bandwidth, see the code in the vcov.garchx function
initial.values	NULL or a numeric vector with the initial parameter values passed on to the optimisation routine, nlminb. If NULL, the default, then the values are chosen automatically
backcast.values	NULL or a non-negative numeric. The backcast value is used to initiate the forward recursion of the conditional variance. If NULL (default), then the value is chosen automatically (currently the average of y squared is used). If backcast.values is a non-negative numeric, then the initial recursion values are all set to this value

lower	numeric vector, either of length 1 or the number of parameters to be estimated, see nlminb
upper	numeric vector, either of length 1 or the number of parameters to be estimated, see nlminb
control	a list passed on to the control argument of nlminb
hessian.control	a list passed on to the control argument of optimHess
solve.tol	numeric value passed on to the tol argument of solve, which is called whenever the coefficient variance-coariance matrix is computed. The value controls the toleranse for detecting linear dependence between columns when inverting a matrix
estimate	logical, if TRUE then estimation is carried out. If FALSE, then the initial.values are used
c.code	logical, if TRUE then compiled C code is used in the forward recursion
penalty.value	NULL (default) or a numeric value. If NULL, then the log-likelihood value associated with the initial values is used. Sometimes estimation can result in NA and/or +/-Inf values. The penalty.value is the value returned by the objective function garchxObjective in the presence of NA or +/-Inf values
sigma2.min	numeric with default .Machine$double.eps. To avoid taking taking the log of a very small value when computing the log-likelihood, sigma2.min is used as the lower bound of the fitted conditional variances, see the code of garchxObjective
objective.fun	numeric, either 1 or 0
turbo	logical. If FALSE (default), then the coefficient variance-covariance is computed during estimation, and the fitted values and residuals are attached to the returned object. If TRUE, then these operations are skipped, and hence estimation is faster. Note, however, that if turbo is set to TRUE, then the coefficient-covariance, fitted values and residuals can still be extracted subsequent to estimation with vcov.garchx, fitted.garchx and residuals.garchx, respectively

Value

A list of class 'garchx'

Author(s)

Genaro Sucarrat, https://www.sucarrat.net/

References

Christian Francq and Le Quien Thieu (2019): 'QML inference for volatility models with covariates', Econometric Theory 35, pp. 37-72, doi:10.1017/S0266466617000512 Christian Francq and Jean-Michel Zakoian (2019): 'GARCH Models', 2nd Edition, Wiley Robert M. de Jong and James Davidson (2000): 'Consistency of Kernel Estimators of Heteroscedastic and Autocorrelated Covariance Matrices', Econometrica 68, pp. 407-423

See Also

garchxSim, nlminb, optimHess, coef.garchx

Examples

```
##simulate from a garch(1,1):
set.seed(123)
y <- garchxSim(1000)

##estimate garch(1,1) model:
mymod <- garchx(y)

##print estimation results:
print(mymod)

##extract coefficients:
coef(mymod)

##extract and store conditional variances:
sigma2hat <- fitted(mymod)

##extract log-likelihood:
logLik(mymod)

##extract and store standardised residuals:
etahat <- residuals(mymod)

##extract variance-covariance matrix:
vcov(mymod)

##generate predictions:
predict(mymod)
```

---

garchxAvar *Asymptotic Coefficient Covariance*

Description

Compute the asymptotic coefficient-covariance of a GARCH(q,p,r)-X model by simulation. Note that the principles of how to use the arch, garch, asym and xreg arguments are the same as those of garchx

Usage

```
garchxAvar(pars, arch = NULL, garch = NULL, asym = NULL,
  xreg = NULL, vcov.type = c("ordinary", "robust", "hac"),
  innovations = NULL, Eeta4 = NULL, n = 1e+06, objective.fun = 1,
  seed = NULL)
```

Arguments

pars	vector of parameters of length 1 or more. The first component contains the coefficient-value of the intercept, the next component(s) the ARCH-coefficient(s), and so on.
arch	NULL or integer vector with the lags of the ARCH-terms to include. Works in the same way as the arch argument in the garchx function
garch	NULL or integer vector with the lags of the GARCH-terms. Works in the same way as the garch argument in the garchx function
asym	NULL or integer vector with the lags of the asymmetry terms to include. Works in the same way as the asym argument in the garchx function
xreg	NULL, or a vector or matrix with the covariates of the model. Works in the same way as the xreg argument in the garchx function
vcov.type	character that determines the type of coefficient-covariance
innovations	NULL or a vector with the standardised innovations to use. If NULL, then the innovations are standard normal
Eeta4	numeric, the fourth moment of the innovations. If NULL, then the value is estimated internally. Note: The value of Eeta4 is only used if vcov.type = "ordinary", otherwise it is ignored
n	integer, the number of observations to use in the simulations
objective.fun	integer equal to 1 or 0 that determines the type of objective function to use, see the code of garchxObjective
seed	NULL or an integer that sets the seed (the value is passed on to set.seed. Useful for reproducibility

Value

A matrix

Author(s)

Genaro Sucarrat, https://www.sucarrat.net/

References

Christian Francq and Le Quien Thieu (2018): 'QML inference for volatility models with covariates', Econometric Theory, doi:10.1017/S0266466617000512 Christian Francq and Jean-Michel Zakoian (2019): 'GARCH Models', 2nd Edition, Wiley

See Also

garchx, garchxSim, vcov.garchx

Examples

```
##asymptotic coefficient-covariance of a garch(1,1)
##note: the estimate is rough, since n is small
intercept <- 0.2
alpha <- 0.1
beta <- 0.8
pars <- c(intercept, alpha, beta)
seed <- 123 #for reproducibility
garchxAvar(pars, arch=1, garch=1, n=10000, seed=seed)
```

`garchxObjective` *Auxiliary functions*

Description

Auxiliary functions used in estimation. Not intended for the average user

Usage

```
garchxObjective(pars, aux)
garchxRecursion(pars, aux)
```

Arguments

`pars`	numeric vector of parameters
`aux`	`list` created by `garchx`

Value

`garchxObjective`:
: value of the objective function

`garchxRecursion`:
: fitted conditional variance

Author(s)

Genaro Sucarrat, https://www.sucarrat.net/

See Also

`garchx`, `fitted.garchx`, `residuals.garchx`

garchxSim *Simulate from a GARCH-X model*

Description

Simulate from a GARCH(q,p,r)-X model. Optionally, if verbose=TRUE, the conditional variance and innovations are also returned.

Usage

```
garchxSim(n, intercept = 0.2, arch = 0.1, garch = 0.8, asym = NULL, xreg = NULL,
  innovations = NULL, backcast.values = list(), verbose = FALSE, as.zoo = TRUE,
  c.code = TRUE)
```

Arguments

n	integer
intercept	numeric
arch	NULL or numeric vector with the values of the ARCH-coefficients
garch	NULL or numeric vector with the values of the GARCH-coefficients
asym	NULL or numeric vector with the values of the asymmetry-coefficients
xreg	NULL or numeric vector with the values of the X-term
innovations	NULL or numeric vector with the innovations. If NULL, then standard normal innovations are generated with rnorm
backcast.values	list with backcast values
verbose	logical
as.zoo	logical. If TRUE (default), then the returned object is of class zoo
c.code	logical. If TRUE (default), then compiled C code is used for the recursion (faster). Otherwise R code is used (slower)

Value

a numeric vector or matrix with the simulated values.

Author(s)

Genaro Sucarrat, https://www.sucarrat.net/

See Also

garchx, zoo

Examples

```
##simulate from a garch(1,1):
y <- garchxSim(1000)

##simulate from a garch(1,1) with asymmetry/leverage:
yy <- garchxSim(1000, asym=0.1)

##simulate from a garch(1,1) w/user-provided backcast values:
yyy <- garchxSim(1000, backcast.values=list(z2=1, sigma2=0.5))
```

---

gdiff *Difference a vector or a matrix, with special treatment of* zoo *objects*

Description

Similar to the diff function from the base package, but gdiff enables padding (e.g. NAs or 0s) of the lost entries. Contrary to the diff function in the base package, however, the default in gdiff is to pad (with NAs). The gdiff function is particularly suited for zoo objects, since their indexing is retained

Usage

```
gdiff(x, lag = 1, pad = TRUE, pad.value = NA)
```

Arguments

x	a numeric vector or matrix
lag	integer equal to the difference-length (the default is 1)
pad	logical. If TRUE (default), then the lost entries are padded with pad.value. If FALSE, then no padding is undertaken
pad.value	numeric, the pad-value

Value

A vector or matrix with the differenced values

Note

Empty

Author(s)

Genaro Sucarrat, https://www.sucarrat.net/

See Also

diff, glag, lag

Examples

```
##1st difference of a series:
x <- rnorm(5)
gdiff(x)

##1st difference with no padding:
gdiff(x, pad=FALSE)

##1st difference retaining the original zoo-index ordering:
gdiff(as.zoo(x))

##1st difference of a matrix:
y <- matrix(rnorm(8),4,2)
gdiff(y)

##2nd difference of the same matrix:
gdiff(y, lag=2)
```

`glag` *Lag a vector or a matrix, with special treatment of* zoo *objects*

Description

Similar to the lag function from the `stats` package, but `glag` enables padding (e.g. NAs or 0s) of the lost entries. Contrary to the lag function in the stats package, however, the default in `glag` is to pad (with NAs). The `glag` is particularly suited for zoo objects, since their indexing is retained

Usage

```
glag(x, k = 1, pad = TRUE, pad.value = NA)
```

Arguments

x	a numeric vector or matrix
k	integer equal to the lag (the default is 1)
pad	logical. If TRUE (default), then the lost entries are padded with pad.value. If FALSE, then no padding is undertaken
pad.value	the pad-value

Value

A vector or matrix with the lagged values

Note

Empty

Author(s)

Genaro Sucarrat, https://www.sucarrat.net/

See Also

lag, gdiff, diff

Examples

```
##lag series with NA for the missing entries:
x <- rnorm(5)
glag(x)

##lag series with no padding:
x <- rnorm(5)
glag(x, pad=FALSE)

##lag series and retain the original zoo-index ordering:
x <- as.zoo(rnorm(5))
glag(x)

##lag two periods:
glag(x, k=2)
```

---

refit *Refit a model to new data*

Description

Refit a model to new data, typically for cross-validation purposes. Re-estimation (reestimate) is optional (the default is FALSE).

Usage

```
##generic:
refit(object, ...)

##S3 method for 'garchx' objects:
## S3 method for class 'garchx'
refit(object, newy = NULL, newxreg = NULL,
  backcast.value = NULL, reestimate = FALSE, ...)
```

Arguments

object	an object of class garchx
newy	vector, the new 'y' data, see garchx
newxreg	the new 'xreg' data, if any, see garchx
backcast.value	NULL or a non-negative numeric, see garchx
reestimate	logical. If FALSE (default), then the estimates from object are used on the new data. If TRUE, then the model is re-estimated using the new data
...	further arguments passed to or from other methods

Details

refit.garchx is a convenience function to facilitate cross-validation and related analyses.

Value

A list of class 'garchx'

Author(s)

Genaro Sucarrat, https://www.sucarrat.net/

See Also

garchx

Examples

```
##simulate from a garch(1,1):
set.seed(123)
y <- garchxSim(1000)

##estimate garch(1,1) model:
mymod <- garchx(y)

##new data (e.g. 'out-of-sample' or 'test' data):
yy <- garchxSim(100)

##apply the estimates of 'mymod' on yy data:
refit(mymod, newy=yy)
```

rmnorm *Random number generation from the multivariate normal distribution*

Description

This function is a speed-optimised version of the rmnorm function from the mnormt package of Adelchi Azzalini (2013).

Usage

```
rmnorm(n, mean = NULL, vcov = 1)
```

Arguments

n	integer, the number of observations to generate
mean	numeric vector, i.e. the mean values
vcov	numeric matrix, i.e. the variance-covariance matrix

Value

A matrix of n rows

Author(s)

Genaro Sucarrat, https://www.sucarrat.net/

References

Adelchi Azzalini (2013): 'mnormt: The multivariate normal and t distributions', R package version 1.4-7, https://CRAN.R-project.org/package=mnormt

Examples

```
##generate from univariate standardised normal:
z1 <- rmnorm(100)

##generate from bivariate, independent standardised normal:
z2 <- rmnorm(100, vcov=diag(c(1,1)))

##generate from bivariate, dependent standardised normal:
z3 <- rmnorm(100, vcov=cbind(c(1,0.3),c(0.3,1)))
```

ttest0 *T-tests and Wald-tests under nullity*

Description

The permissible parameter-space of GARCH-models is bounded from below by 0. This means non-standard inference is required when one or more parameters are 0 under the null hypothesis, a frequent situation in empirical applications. The functions `ttest0` and `waldtest0` perform t-tests and Wald-tests when one or more parameters is 0. In the latter test, the Wald-test, the critical values are obtained by simulation, see Francq and Thieu (2018).

Usage

```
ttest0(x, k = NULL)
waldtest0(x, r = 0, R = NULL, level = c(0.1,0.05,0.01),
  vcov.type = NULL, quantile.type = 7, n = 20000)
```

Arguments

`x`	an object of class 'garchx'
`k`	`NULL` (default) or a vector of integers with the coefficients to test. If `NULL`, then all coefficients apart from the intercepts are tested
`r`	`vector` with restrictions
`R`	`NULL` (default) or a full-rank `matrix`. If `NULL`, then `R` is specified such that a test of all coefficients - apart from the intercept - is equal to the restriction `r`. If `length(r)==1`, then it is recycled so that its dimension match that of `R`
`level`	`vector` of significance levels whose critical values should be computed
`vcov.type`	`NULL` or a `character` that determines the type of coefficient-covariance to use, see `vcov.garchx`
`quantile.type`	integer, the algorithm used to compute the quantile, see `quantile`
`n`	`integer`, the numer of simulations used to estimate the critical values

Details

The `ttest0` function performs a t-test of coefficient `k` with 0 as null. Under this null the parameter is on the boundary of the admissible parameter space, and so the distribution is non-standard under the null. The function `ttest0` returns the result(s) of these non-standard t-test(s), see Francq and Thieu (2018). If `k=NULL`, the default, then a test for each coefficient apart from the intercept is undertaken.

The `waldtest0` function performs a Wald-test of the restrictions in `r`, when one or more of its elements are 0, see Francq and Thieu (2018).

Value

`ttest0:`	a `matrix` with the t-tests
`waldtest0:`	a `list` with the test-statistic and the critical values

Author(s)

Genaro Sucarrat, https://www.sucarrat.net/

References

Christian Francq and Le Quien Thieu (2018): 'QML inference for volatility models with covariates', Econometric Theory, doi:10.1017/S0266466617000512

See Also

garchx, quantile, vcov.garchx, rmnorm

Examples

```
##simulate and estimate a garch(1,1):
set.seed(123)
y <- garchxSim(1000)
mymod <- garchx(y)

##t-tests:
ttest0(mymod)

##wald-test:
waldtest0(mymod)
```

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