

Package ‘MSGARCH’

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Description The MSGARCH package offers methods to fit (by Maximum Likelihood or Bayesian), simulate, and forecast various Markov-Switching GARCH processes.

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Imports Rcpp, adaptMCMC, DEoptim, nloptr, methods, stringr, ggplot2, reshape2, zoo, expm, fanplot

LinkingTo Rcpp, RcppArmadillo

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MSGARCH-package	<i>The R package MSGARCH</i>
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Description

The R package MSGARCH aims to provide a comprehensive set of functionalities for Markov-switching GARCH processes (Haas et al. 2004), including fitting, filtering, forecasting, and simulating. Other functions related to Value-at-Risk, Expected-Shortfall, and conditional distributions are also available. The main functions of the package are coded in C++ with Rcpp (Eddelbuettel and Francois, 2011) and RcppArmadillo (Eddelbuettel and Sanderson, 2014). In the R package MSGARCH there is no equation for the mean as in the R package rugarch (Ghalanos, 2015). This means that we assume that before modeling, the user has filtered the mean from their time series.

We provide a variety of single-regime GARCH processes and regime-switching allowing for many conditional distributions. This allows for a rich modeling environment for Markov-switching GARCH models. Each single-regime process is a one-lag process (e.g., GARCH(1,1)). Allowing for only one-lag has proved to be sufficient in many cases and it reduces models complexity which can become a problem during the optimization procedure. When optimization is taking place, we ensure that each regime is covariance-stationary and strictly positive (see details in [kernel](#) for more information) which makes the entire process also covariance-stationary and strictly positive. We also set a condition that each unique single-regime models type in a multiple-regime framework are in order of unconditional volatility. This means that is if a three regimes specification with two sGARCH regimes and one gjrGARCH regime is constructed with `create.spec`, the first sGARCH regime will have a lower unconditional volatility than the second sGARCH regime while the gjrGARCH regime can have any unconditional volatility since it is the only regime with this model.

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References

- Eddelbuettel, D. & Francois, R. (2011). Rcpp: Seamless R and C++ Integration. *Journal of Statistical Software*, 40, pp. 1-18, <http://www.jstatsoft.org/v40/i08/>.
- Eddelbuettel, D. & Sanderson, C. (2014). RcppArmadillo: Accelerating R with High-Performance C++ Linear Algebra. *Computational Statistics & Data Analysis*, 71, pp. 1054-1063, <http://dx.doi.org/10.1016/j.csda.2013.02.005>.
- Haas, M. Mittnik, S. Paoletta, MS. (2004). A New Approach to Markov-Switching GARCH Models. *Journal of Financial Econometrics*, 2, pp. 493-530, <http://doi.org/10.1093/jjfinec/nbh020>
- Ghalanos, A. (2015). rugarch: Univariate GARCH Models. <https://cran.r-project.org/package=rugarch>.

AIC

Compute Akaike information criterion (AIC).

Description

Compute Akaike information criterion (AIC).

Usage

```
AIC(fit)
```

Arguments

fit	Fit object of type MSGARCH_MLE_FIT created with <code>fit.mle</code> or MSGARCH_BAY_FIT created with <code>fit.bayes</code> .
-----	---

Details

If a matrix of MCMC posterior draws estimates is given, the AIC on the posterior mean is calculated.

Value

AIC value.

References

Akaike, H. (1974). A New Look at the Statistical Model Identification. *IEEE Transactions on Automatic Control*, 19, pp. 716-723.

Examples

```
## Not run:
# load data
data("sp500")
sp500 = sp500[1:1000]

# create model specification
spec = MSGARCH::create.spec()

# fit the model by MLE
fit = MSGARCH::fit.mle(spec = spec, y = sp500, ctr = list(do.init = FALSE))

# compute AIC
AIC = MSGARCH::AIC(fit)

## End(Not run)
```

AMZN	<i>Log return of Amazon inc. closing Value</i>		
Description <p>The Amazon inc. closing value log return from 1998-01-01 to 2015-12-31 from Yahoo Finance https://finance.yahoo.com/.</p>			
Usage <pre>data("AMZN")</pre>			
Format <p>Matrix containing 4529 observations.</p>			
Source <p>Yahoo Finance https://finance.yahoo.com/</p>			
BIC	<i>Compute Bayesian information criterion (BIC).</i>		
Description <p>Compute Bayesian information criterion (BIC).</p>			
Usage <pre>BIC(fit)</pre>			
Arguments <table> <tr> <td>fit</td><td>Fit object of type MSGARCH_MLE_FIT created with fit.mle or MSGARCH_BAY_FIT created with fit.bayes</td></tr> </table>		fit	Fit object of type MSGARCH_MLE_FIT created with fit.mle or MSGARCH_BAY_FIT created with fit.bayes
fit	Fit object of type MSGARCH_MLE_FIT created with fit.mle or MSGARCH_BAY_FIT created with fit.bayes		
Details <p>If a matrix of MCMC posterior draws estimates is given, the BIC on the posterior mean is calculated.</p>			
Value <p>BIC value.</p>			
References <p>Schwarz, G. (1978). Estimating the dimension of a model. <i>Annals of Statistics</i>, 6, pp. 461-464.</p>			

Examples

```
## Not run:
# load data
data("sp500")
sp500 = sp500[1:1000]

# create model specification
spec = MSGARCH::create.spec()

# fit the model by MLE
fit = MSGARCH::fit.mle(spec = spec, y = sp500, ctr = list(do.init = FALSE))

# compute BIC
BIC = MSGARCH::BIC(fit)

## End(Not run)
```

cdf	<i>Cumulative function.</i>
-----	-----------------------------

Description

Method returning the cumulative function in-sample or of a vector of points at $t = T + 1$.

Usage

```
cdf(object, x, theta, y, log = FALSE, do.its = FALSE)
```

Arguments

object	Model specification of class MSGARCH_SPEC created with create.spec or fit object of type MSGARCH_MLE_FIT created with fit.mle or MSGARCH_BAY_FIT created with fit.bayes .
x	Vector (of size N) of point at $t = T + 1$ to be evaluated (used when <code>do.its = FALSE</code>).
theta	Vector (of size d) or matrix (of size M x d) of parameter estimates (not require when using a fit object).
y	Vector (of size T) of observations (not require when using a fit object).
log	Boolean indicating if the log cumulative is returned. (Default: <code>log = FALSE</code>)
do.its	Boolean indicating if the in-sample cdf is returned. (Default: <code>do.its = FALSE</code>)

Details

If a matrix of parameter estimates is given, each parameter estimates is evaluated individually. If `do.its = FALSE`, the points `x` are evaluated as $t = T + 1$ realization and the method uses the variance estimate at $t = T + 1$. If `do.its = TRUE`, `y` is evaluated using their respective variance estimate at each time `t`.

Value

A list of class MSGARCH_CDF containing two components:

- cdf:
 - If `do.its = FALSE`: (Log-)Cumulative of the points x at $t = T + 1$ (vector of size N or matrix of size $M \times N$).
 - If `do.its = TRUE`: In-sample (Log-)Cumulative of y (vector of size T or matrix of size $M \times T$).
- x:
 - If `do.its = FALSE`: Vector (of size N) of point at $t = T + 1$ evaluated.
 - If `do.its = TRUE`: Vector (of size T) of observations.

The class MSGARCH_CDF contains the `plot` method only if `do.its = FALSE`.

Examples

```
## Not run:
# load data
data("sp500")
sp500 = sp500[1:1000]

# create model specification
spec = MSGARCH::create.spec()

# fit the model on the data with ML estimation using DEoptim initialization
set.seed(123)
fit = MSGARCH::fit.mle(spec = spec, y = sp500, ctr = list(do.init = FALSE))

# run pdf method in-sample
cdf.its = MSGARCH::cdf(object = fit, log = FALSE, do.its = TRUE)

# create mesh
x = seq(-3, 3, 0.01)

# run cdf method on mesh at T + 1
cdf = MSGARCH::cdf(object = fit, x = x, log = FALSE, do.its = FALSE)

plot(cdf)

## End(Not run)
```

create.spec

Model specification

Description

Function for creating a model specification before fitting and using the R package MSGARCH functionalities.

Usage

```
create.spec(model = c("sGARCH", "sGARCH"), distribution = c("norm", "norm"),
  do.skew = c(FALSE, FALSE), do.mix = FALSE, do.shape.ind = FALSE)
```

Arguments

<code>model</code>	Vector (of size K) containing the variance model specifications. Valid models are "sGARCH", "eGARCH", "gjrGARCH", "tGARCH", and "GAS". (Default: <code>model = c("sGARCH", "sGARCH")</code>)
<code>distribution</code>	Vector (of size K) of conditional densities. Valid distribution are "norm", "std", and "ged". The vector must be of the same length as the models vector. (Default: <code>distribution = c("norm", "norm")</code>)
<code>do.skew</code>	Vector (of size K) of boolean indicating if the conditional density is skewed. The vector must be of the same length as the distributions vector. (Default: <code>do.skew = c(FALSE, FALSE)</code>)
<code>do.mix</code>	Boolean indicating if the specification is a mixture type. If the argument is TRUE, a Mixture of GARCH is created, while if the argument is FALSE, a Markov-Switching GARCH is created (see details). (Default: <code>do.mix = FALSE</code>)
<code>do.shape.ind</code>	Boolean indicating if the distribution are Regime-Independent. If the argument is TRUE, all distributions are the same and the distribution parameters does not dependent on the regime in which the distribution is attributed to. If the argument is TRUE, all distributions in the distribution argument and all skew argument must be the same. (Default: <code>do.shape.ind = FALSE</code>)

Details

The Markov-Switching specification created is based on the Haas et al. (2004a) MSGARCH specification. It is a MSGARCH model that is separated in K single-regimes specifications which are updated in parallel. Under this specification, the conditional variance is a function of the past data and the current state. The Mixture of GARCH option is based on the Haas et al. (2004b). A Mixture of GARCH is a mixture of distribution where the variance process of each distribution is a single-regime process. Every single-regime specification is a one-lag process (e.g., GARCH(1,1)) since it has proved to be sufficient in financial econometrics and it reduces models complexity which can become a problem during the optimization procedure

Value

A list of class MSGARCH_SPEC containing variables related to the created specification.
The list contains:

- `theta0` : Vector (of size d) of default parameters.
- `is.mix` : Boolean indicating if the specification is a mixture.
- `is.shape.ind` : Boolean indicating if the distribution parameters are regime-independent.
- `K` : Number of regimes.
- `sigma0` : Default variance-covariance matrix (of size K x K) used for the Bayesian estimation.
- `lower` : Vector (of size d) of lower parameters bound.
- `upper` : Vector (of size d) of upper parameters bound.
- `ineqlb` : Vector (of size d) of lower inequality bound.
- `inequb` : Vector (of size d) of upper inequality bound.
- `n.params` : Vector (of size K) of the total number of parameters by regime including distribution parameters.
- `n.params.vol` : Vector (of size K) of the total number of parameters by regime excluding distribution parameters.

- `do.init` : Boolean indicating the default `do.init` argument.
- `label` : Vector (of size `d`) of parameters label.
- `name` : Vector (of size `K`) of model specification name.
- `func` : List of `R` functions internally used.
- `rcpp.func` : List of `Rcpp` functions internally used.

The MSGARCH_SPEC class possesses these methods:

- `sim` : Simulation method.
- `simahead` : Step ahead simulation method.
- `ht` : Conditional volatility in each regime.
- `kernel` : Kernel method.
- `unc.vol` : Unconditional volatility in each regime.
- `pred` : Predictive method.
- `pit` : Probability Integral Transform.
- `risk` : Value-at-Risk And Expected-Shortfall methods.
- `pdf` : Probability density function.
- `cdf` : Cumulative function.
- `Pstate` : State probabilities filtering method.
- `fit.mle` : Maximum Likelihood estimation.
- `fit.bayes` : Bayesian estimation.
- `print` and `summary` : Summary of the created specification.

References

- Bollerslev, T. (1986). Generalized Autoregressive Conditional Heteroskedasticity. *Journal of Econometrics*, 31, pp. 307-327.
- Creal, D. Koopman, S. J. & Lucas, A. (2013). Generalized Autoregressive Score Models with Applications. *Journal of Applied Econometrics*, 28, pp. 777-795.
- Fernandez, C. & Steel, M. F. (1998). On Bayesian Modeling of Fat Tails and Skewness. *Journal of the American Statistical Association*, 93, pp. 359-371.
- Glosten, L. R. Jagannathan, R. & Runkle, D. E. (1993). On the Relation Between the Expected Value and the Volatility of the Nominal Excess Return on Stocks. *Journal of Finance*, 48, pp. 1779-1801.
- Haas, M. Mittnik, S. & Paoletta, M. S. (2004a). A New Approach to Markov-Switching GARCH Models. *Journal of Financial Econometrics*, 2, pp. 493-530.
- Haas, M. Mittnik, S. & Paoletta, M. S. (2004b). Mixed Normal Conditional Heteroskedasticity. *Journal of Financial Econometrics*, 2, pp. 211-250.
- Nelson, D. B. (1991). Conditional Heteroskedasticity in Asset Returns: A New Approach. *Econometrica*, 59, pp. 347-370.
- Zakoian, J.-M. (1994). Threshold Heteroskedastic Models. *Journal of Economic Dynamics and Control*, 18, pp. 931-955.

Examples

```
# create model specification
spec = MSGARCH::create.spec(model = c("sGARCH", "gjrGARCH"), distribution = c("norm", "std"),
                             do.skew = c(TRUE, FALSE), do.mix = FALSE, do.shape.ind = FALSE)
print(spec)
```

DIC

Compute Deviance Information Criterion (DIC).

Description

Compute Deviance Information Criterion (DIC).

Usage

`DIC(fit)`

Arguments

`fit` Fit object of type MSGARCH_BAY_FIT created with `fit.bayes`.

Details

We define the deviance as:

$$D(\theta) = -2LLH(\mathbf{y}|\theta),$$

where \mathbf{y} are the data, θ are the parameters, and $LLH()$ is the log-likelihood function. The expectation

$$\bar{D} = \mathbf{E}^\theta[D(\theta)]$$

, where \mathbf{E}^θ is the expectation over all theta in the chain, is a measure of how well the model fits the data. The larger this is, the worse the fit. The effective number of parameters of the model can be define as

$$p_V = \frac{1}{2} \widehat{var}(D(\theta))$$

, where \widehat{var} is the the standard empirical variance estimator. The larger the effective number of parameters is, the easier it is for the model to fit the data, and so the deviance needs to be penalized. Finally DIC is defined as:

$$DIC = p_V + \bar{D}.$$

Value

A list containing four variables:

- DIC : Deviance Information Criterion.
- IC : Bayesian Predictive Information Criterion ($IC = 2 * p_V + D.bar$).
- p_V : Effective number of parameters ($p_V = var(D)/2$)
- $D.bar$: Expected value of the deviance over the posterior

References

Gelman, A. Carlin, J. B. Stern, H. S. & Rubin, D. B. (2003). Bayesian Data Analysis. *Chapman and Hall/CRC*

Examples

```
## Not run:
# load data
data("sp500")
sp500 = sp500[1:1000]

# create model specification
spec = MSGARCH::create.spec()

# fit the model by Bayesian estimation
set.seed(123)
fit = MSGARCH::fit.bayes(spec = spec, y = sp500)

# compute DIC
DIC = MSGARCH::DIC(fit)

## End(Not run)
```

fit.bayes	<i>Bayesian estimation.</i>
-----------	-----------------------------

Description

Method that performs Bayesian estimation of a MSGARCH_SPEC object on a set of observations.

Usage

```
fit.bayes(spec, y, ctr = list())
```

Arguments

spec	Model specification of class MSGARCH_SPEC created with create.spec .
y	Vector (of size T) of observations.
ctr	A list of control parameters. The control parameters have three components: <ul style="list-style-type: none"> • N.burn (integer ≥ 0): Number of discarded draws. (Default: N.burn = 5000) • N.mcmc (integer > 0): Number of draws. (Default: N.mcmc = 10000) • N.thin (integer > 0): Thinning factor (every N.thin draws are kept). (Default: N.thin = 10) • theta0 : Starting value for the chain (if empty the specification default value are used). • do.enhance.theta0 : Boolean indicating if the default parameters value are enhance using y variance. (Default: do.enhance.theta0 = FALSE)

Details

The total number of draws is equal to $N.mcmc / N.thin$. The Bayesian estimation uses the R package adaptMCMC (Andreas, 2012) which implements the adaptive sampler of Vihola (2012). The starting parameters are the specification default parameters. The argument do.enhance.theta0 uses the volatilities of rolling windows of y and adjust the default parameter of the specification so that the unconditional volatility of each regime is set to different quantiles of the volatilities of the rolling windows of y.

Value

A list of class MSGARCH_BAY_FIT containing four components:

- `theta` : The MCMC chain (matrix from the R package coda (Plummer et al., 2006) of size `N.mcmc / N.thin`).
- `accept` : Acceptation rate of the sampler.
- `y` : Vector (of size T) of observations.
- `spec` : Model specification of class MSGARCH_SPEC created with `create.spec`.

The MSGARCH_BAY_FIT contains these methods:

- `AIC` : Compute Akaike information criterion (AIC).
- `BIC` : Compute Bayesian information criterion (BIC).
- `DIC` : Compute Deviance Information Criterion (DIC).
- `ht` : Conditional volatility in each regime.
- `kernel` : Kernel method.
- `unc.vol` : Unconditional volatility in each regime.
- `pred` : Predictive method.
- `pit` : Probability Integral Transform.
- `risk` : Value-at-Risk And Expected-Shortfall methods.
- `simahead` : Step ahead simulation method.
- `sim` : Simulation method.
- `pdf` : Probability density function.
- `cdf` : Cumulative function.
- `Pstate` : State probabilities filtering method.
- `summary` : Summary of the fit.

References

- Andreas, S. (2012). adaptMCMC: Implementation of a Generic Adaptive Monte Carlo Markov Chain Sampler. <https://cran.r-project.org/package=adaptMCMC>.
- Metropolis, N.; Rosenbluth, A. W.; Rosenbluth, M. N.; Teller, A. H. & Teller, E. (1953). Equation of State Calculations by Fast Computing Machines. *Journal of Chemical Physics*, 21, pp. 1087-1092.
- Plummer, M. Best, N. Cowles, K. & Vines, K. (2006). CODA: Convergence Diagnosis and Output Analysis for MCMC. *R News*, 6, pp.7-11. <https://cran.r-project.org/package=coda>.
- Vihola, M. (2012). Robust Adaptive Metropolis Algorithm with Coerced Acceptance Rate. *Statistics and Computing*, 22, pp. 997-1008.

Examples

```
## Not run:
# load data
data("sp500")
sp500 = sp500[1:1000]

# create model specification
spec = MSGARCH::create.spec()
```

```
# fit the model on the data with Bayesian estimation
set.seed(123)
fit = MSGARCH::fit.bayes(spec = spec, y = sp500,
                        ctr = list(N.burn = 5000, N.mcmc = 10000, N.thin = 1))

summary(fit)

## End(Not run)
```

fit.mle

ML estimation.

Description

Method that performs Maximum Likelihood estimation of a MSGARCH_SPEC object on a set of observations.

Usage

```
fit.mle(spec, y, ctr = list())
```

Arguments

spec	Model specification created with create.spec .
y	Vector (of size T) of observations.
ctr	List of control parameters. The control parameters have two components to it: <ul style="list-style-type: none"> • <code>do.init</code> : Boolean indicating if there is a pre-optimization with the R package DEoptim (Ardia et al., 2011). (Default: <code>do.init = TRUE</code>) • <code>NP</code> : Number of parameter vectors in the population in DEoptim optimization. (Default: <code>NP = 200</code>) • <code>itermax</code> : Maximum iteration (population generation) allowed in DEoptim optimization. (Default: <code>maxit = 200</code>) • <code>do.enhance.theta0</code> : Boolean indicating if the default parameters value are enhance using y variance. (Default: <code>do.enhance.theta0 = TRUE</code>)

Details

The Maximum likelihood estimation uses the R package nloptr (Johnson, 2014) for main optimizer while it uses the R package DEoptim when `do.init = TRUE` as an initialization for nloptr. The starting parameters are the specification default parameters. The argument `do.enhance.theta0` uses the volatilities of rolling windows of y and adjust the starting parameters of the specification so that the unconditional volatility of each regime is set to different quantiles of the volatilities of the rolling windows of y.

Value

A list of class MSGARCH_MLE_FIT containing five components:

- `theta` : Optimal parameters (vector of size d).
- `log_kernel` : log-kernel of y given the optimal parameters.

- `spec` : Model specification of class MSGARCH_SPEC created with `create.spec`.
- `is.init` : Indicating if estimation was made with `do.init` option.
- `y` : Vector (of size T) of observations.

The MSGARCH_MLE_FIT contains these methods:

- `AIC` : Compute Akaike information criterion (AIC).
- `BIC` : Compute Bayesian information criterion (BIC).
- `ht` : Conditional volatility in each regime.
- `kernel` : Kernel method.
- `unc.vol` : Unconditional volatility in each regime.
- `pred` : Predictive method.
- `pit` : Probability Integral Transform.
- `risk` : Value-at-Risk And Expected-Shortfall methods.
- `simahead` : Step ahead simulation method.
- `sim` : Simulation method.
- `pdf` : Probability density function.
- `cdf` : Cumulative function.
- `Pstate` : State probabilities filtering method.
- `summary` : Summary of the fit.

References

- Ardia, D. Boudt, K. Carl, P. Mullen, K. M. & Peterson, B. G. (2011). Differential Evolution with DEoptim. *R Journal*, 3, pp. 27-34
- Ardia, D. Mullen, K. M. Peterson, B. G. & Ulrich, J. (2015). DEoptim: Differential Evolution in R. <https://cran.r-project.org/package=DEoptim>
- Mullen, K. M. Ardia, D. Gil, D. L. Windover, D. Cline, J.(2011) DEoptim: An R Package for Global Optimization by Differential Evolution. *Journal of Statistical Software*, 40, pp. 1-26, DOI: <http://dx.doi.org/10.18637/jss.v040.i06>
- Johnson, S. G. (2014). The NLOpt Nonlinear-Optimization. <https://cran.r-project.org/package=nloptr>.

Examples

```
## Not run:
# load data
data("sp500")
sp500 = sp500[1:1000]

# create model specification
spec = MSGARCH::create.spec()

# fit the model on the data with ML estimation using DEoptim initialization
set.seed(123)
fit = MSGARCH::fit.mle(spec = spec, y = sp500,
                      ctr = list(do.init = TRUE, NP = 500, itermax = 500))
summary(fit)

## End(Not run)
```

ht	<i>Conditional volatility in each regime.</i>
----	---

Description

Method returning the conditional volatility of each regime.

Usage

```
ht(object, theta, y)
```

Arguments

object	Model specification of class MSGARCH_SPEC created with create.spec or fit object of type MSGARCH_MLE_FIT created with fit.mle or MSGARCH_BAY_FIT created with fit.bayes .
theta	Vector (of size d) or matrix (of size M x d) of parameter estimates (not require when using a fit object).
y	Vector (of size T) of observations (not require when using a fit object).

Details

If a matrix of parameter estimates is given, each parameter estimates is evaluated individually.

Value

Conditional volatility (array of size (T + 1) x M x K) in each regime.

Examples

```
## Not run:
# load data
data("sp500")
sp500 = sp500[1:1000]

# create model specification
spec = MSGARCH::create.spec()

# fit the model on the data with ML estimation using DEoptim initialization
set.seed(123)
fit = MSGARCH::fit.mle(spec = spec, y = sp500, ctr = list(do.init = FALSE))

# Compute the conditional volatility
ht = MSGARCH::ht(object = fit)

plot(ht)

## End(Not run)
```

kernel	<i>Kernel function.</i>
--------	-------------------------

Description

Method returning the kernel value of a vector of observations given a model specification.

Usage

```
kernel(object, theta, y, log = TRUE)
```

Arguments

object	Model specification of class MSGARCH_SPEC created with <code>create.spec</code> or fit object of type MSGARCH_MLE_FIT created with <code>fit.mle</code> or MSGARCH_BAY_FIT created with <code>fit.bayes</code> .
theta	Vector (of size d) or matrix (of size M x d) of parameter estimates (not require when using a fit object).
y	Vector (of size T) of observations (not require when using a fit object).
log	Boolean indicating if the log kernel is returned. (Default: log = TRUE)

Details

If a matrix of parameter estimates is given, each parameter estimates is evaluated individually. The kernel is a combination of the prior and the likelihood function. The kernel is equal to $\text{prior}(\theta) + L(y|\theta)$ where L is the likelihood of y given the parameter θ . When doing optimization, the goal is to minimize the negative log-kernel.

- Details on the prior
The prior is different for each specification. It ensures that the θ makes the conditional variance process stationary, positive, and that it respect that the sums of the probabilities in the case of a multiple-regime models are all equal to 1. If any of these three conditions is not respected the prior return $-1e10$, meaning that the optimizer or sampler will know that θ is not a good candidate.

Value

(Log-)Kernel value (scalar or vector of size M) of the vector of observations.

References

Hamilton, J. D. (1989) A New Approach to the Economic Analysis of Nonstationary Time Series and the Business Cycle. *Econometrica*, 57, pp.357-38

Examples

```
## Not run:
# load data
data("sp500")
sp500 = sp500[1:1000]

# create model specification
```

```
spec = MSGARCH::create.spec()

# fit the model on the data with ML estimation using DEoptim initialization
set.seed(123)
fit = MSGARCH::fit.mle(spec = spec, y = sp500, ctr = list(do.init = FALSE))

# compute the kernel
kernel = MSGARCH::kernel(fit, log = TRUE)

## End(Not run)
```

pdf

Probability density function.

Description

Method returning the probability density in-sample or of a vector of points at $t = T + 1$.

Usage

```
pdf(object, x, theta, y, log = FALSE, do.its = FALSE)
```

Arguments

object	Model specification of class MSGARCH_SPEC created with create.spec or fit object of type MSGARCH_MLE_FIT created with fit.mle or MSGARCH_BAY_FIT created with fit.bayes .
x	Vector (of size N) of point at $t = T + 1$ to be evaluated (used when <code>do.its = FALSE</code>).
theta	Vector (of size d) or matrix (of size $M \times d$) of parameter estimates (not require when using a fit object).
y	Vector (of size T) of observations (not require when using a fit object).
log	Boolean indicating if the log-density is returned. (Default: <code>log = FALSE</code>)
do.its	Boolean indicating if the in-sample pdf is returned. (Default: <code>do.its = FALSE</code>)

Details

If a matrix of parameter estimates is given, each parameter estimates is evaluated individually. If `do.its = FALSE`, the points x are evaluated as $t = T + 1$ realization and the method uses the variance estimate at $t = T + 1$. If `do.its = TRUE`, y is evaluated using their respective variance estimate at each time t .

Value

A list of class MSGARCH_PDF containing two components:

- pdf:
 - If `do.its = FALSE`: (Log-)Probability density of the points x at $t = T + 1$ (vector of size N or matrix of size $M \times N$)
 - If `do.its = TRUE`: In-sample (Log-)Probability density of y (vector of size T or matrix of size $M \times T$).

- `x`:
If `do.its = FALSE`: Vector (of size N) of point at $t = T + 1$ evaluated.
If `do.its = TRUE`: Vector (of size T) of observations.

The class `MSGARCH_PDF` contains the `plot` method only if `do.its = FALSE`.

Examples

```
## Not run:
# load data
data("sp500")
sp500 = sp500[1:1000]

# create model specification
spec = MSGARCH::create.spec()

# fit the model on the data with ML estimation using DEoptim initialization
set.seed(123)
fit = MSGARCH::fit.mle(spec = spec, y = sp500, ctr = list(do.init = FALSE))

# run pdf method in-sample
pdf.its = MSGARCH::pdf(object = fit, log = FALSE, do.its = TRUE)

sum(pdf.its$pdf, na.rm = TRUE)
# create mesh

x = seq(-3,3,0.01)

# run pdf method on mesh at T + 1
pdf = MSGARCH::pdf(object = fit, x = x, log = FALSE, do.its = FALSE)

plot(pdf)

## End(Not run)
```

pit

Probability Integral Transform.

Description

Method returning the predictive probability integral transform (PIT) in-sample or of a vector of points at $t = T + 1$.

Usage

```
pit(object, x, theta, y, do.norm = FALSE, do.its = FALSE)
```

Arguments

<code>object</code>	Model specification of class <code>MSGARCH_SPEC</code> created with <code>create.spec</code> or fit object of type <code>MSGARCH_MLE_FIT</code> created with <code>fit.mle</code> or <code>MSGARCH_BAY_FIT</code> created with <code>fit.bayes</code> .
<code>x</code>	Vector (of size N) of point at $t = T + 1$ to be evaluated (used when <code>do.its = FALSE</code>).

theta	Vector (of size d) or matrix (of size M x d) of parameter estimates (not require when using a fit object).
y	Vector (of size T) of observations (not require when using a fit object).
do.norm	Boolean indicating if the PIT value are transforms into standard Normal variate. (Default: do.norm = FALSE).
do.its	Boolean indicating if the in-sample pit is returned. (Default: do.its = FALSE)

Details

If a matrix of MCMC posterior draws estimates is given, the Bayesian probability integral transform is calculated. If `do.its = FALSE`, the points x are evaluated as $t = T + 1$ realization and the method uses the variance estimate at $t = T + 1$. If `do.its = TRUE`, y is evaluated using their respective variance estimate at each time t . The `do.norm` argument transforms the PIT value into Normal variate so that normality test can be done.

Value

A list of class MSGARCH_PIT containing two components:

- `pit`:
If `do.its = FALSE`: probability integral transform of the points x at $t = T + 1$ or Normal variate derived from the probability integral transform of x (vector of size N).
If `do.its = TRUE`: In-sample probability integral transform or Normal variate derived from the probability integral transform of y (vector of size T or matrix of size M x T).
- `x`:
If `do.its = FALSE`: Vector (of size N) of at point $t = T + 1$ evaluated.
If `do.its = TRUE`: Vector (of size T) of observations.

The class MSGARCH_PIT contains the `plot` method only if `do.its = FALSE`.

Examples

```
## Not run:
# load data
data("sp500")
sp500 = sp500[1:1000]

# create model specification
spec = MSGARCH::create.spec()

# fit the model on the data with ML estimation using DEoptim initialization
set.seed(123)
fit = MSGARCH::fit.mle(spec = spec, y = sp500, ctr = list(do.init = FALSE))

# run pit method in-sample
pit.its = MSGARCH::pit(object = fit, do.norm = FALSE, do.its = TRUE)

plot(pit.its)

# generate random draws at T + 1 from model
set.seed(123)
sim.ahead = MSGARCH::simahead(object = fit, n = 1, m = 10000)

x = sim.ahead$draws
```

```
# run pit method on random draws at T + 1 from model
pit = MSGARCH::pit(object = fit, x = x, do.norm = FALSE)

plot(pit)

## End(Not run)
```

pred	<i>Predictive function.</i>
------	-----------------------------

Description

Method returning the predictive probability density in-sample or of a vector of points at $t = T + 1$.

Usage

```
pred(object, x, theta, y, log = TRUE, do.its = FALSE)
```

Arguments

object	Model specification of class MSGARCH_SPEC created with <code>create.spec</code> or fit object of type MSGARCH_MLE_FIT created with <code>fit.mle</code> or MSGARCH_BAY_FIT created with <code>fit.bayes</code> .
x	Vector (of size N) of point at $t = T + 1$ to be evaluated (used when <code>do.its = FALSE</code>).
theta	Vector (of size d) or matrix (of size M x d) of parameter estimates (not require when using a fit object).
y	Vector (of size T) of observations (not require when using a fit object).
log	Boolean indicating if the log-density is returned. (Default: <code>log = TRUE</code>)
do.its	Boolean indicating if the in-sample predictive is returned. (Default: <code>do.its = FALSE</code>)

Details

If a matrix of MCMC posterior draws estimates is given, the Bayesian Probability integral transform is calculated. If `do.its = FALSE`, the points x are evaluated as $t = T + 1$ realization and the method uses the variance estimate at $t = T + 1$. If `do.its = TRUE`, y is evaluated using their respective variance estimate at each time t .

Value

A list of class MSGARCH_PRED containing two components:

- `pred`:
If `do.its = FALSE`: (Log-)Predictive of of the points x at $t = T + 1$ (vector of size N).
If `do.its = TRUE`: In-sample Predictive of y (vector of size T or matrix of size M x T).
- `x`:
If `do.its = FALSE`: Vector (of size N) of point at $t = T + 1$ evaluated.
If `do.its = TRUE`: Vector (of size T) of observations.

The class MSGARCH_PRED contains the `plot` method only if `do.its = FALSE`.

Examples

```
## Not run:
# load data
data("sp500")
sp500 = sp500[1:1000]

# create model specification
spec = MSGARCH::create.spec()

# fit the model on the data with ML estimation using DEoptim initialization
set.seed(123)
fit = MSGARCH::fit.mle(spec = spec, y = sp500, ctr = list(do.init = FALSE))

# run pred method in-sample
pred.its = MSGARCH::pred(object = fit, log = TRUE, do.its = TRUE)

sum(pred.its$pred, na.rm = TRUE)

# create mesh
x = seq(-3,3,0.01)

# run pred method on mesh at T + 1
pred = MSGARCH::pred(object = fit, x = x, log = TRUE, do.its = FALSE)

plot(pred)

## End(Not run)
```

Pstate

Filtered state probabilities.

Description

Method returning the filtered probabilities of the states.

Usage

```
Pstate(object, theta, y)
```

Arguments

object	Model specification of class MSGARCH_SPEC created with create.spec or fit object of type MSGARCH_MLE_FIT created with fit.mle or MSGARCH_BAY_FIT created with fit.bayes .
theta	Vector (of size d) or matrix (of size M x d) of parameter estimates (not require when using a fit object).
y	Vector (of size T) of observations (not require when using a fit object).

Details

If a matrix of parameter estimates is given, each parameter estimates is evaluated individually.

Value

Filtered state probabilities of class MSGARCH_PSTATE (array of size $(T + 1) \times M \times K$). The class MSGARCH_PSTATE contains the plot method.

Examples

```
## Not run:
# load data
data("sp500")
sp500 = sp500[1:1000]

# create model specification
spec = MSGARCH::create.spec()

# fit the model on the data with ML estimation using DEoptim initialization
set.seed(123)
fit = MSGARCH::fit.mle(spec = spec, y = sp500, ctr = list(do.init = FALSE))

# compute the filtered state probabilities
Pstate = MSGARCH::Pstate(object = fit)

plot(Pstate)

## End(Not run)
```

risk	<i>Value-at-Risk And Expected-shortfall.</i>
------	--

Description

Method returning the Value-at-Risk and Expected-shortfall in-sample or at $t = T + 1$ based on the predictive density.

Usage

```
risk(object, theta, y, level = c(0.95, 0.99), ES = TRUE, do.its = FALSE)
```

Arguments

object	Model specification of class MSGARCH_SPEC created with create.spec or fit object of type MSGARCH_MLE_FIT created with fit.mle or MSGARCH_BAY_FIT created with fit.bayes .
theta	Vector (of size d) or matrix (of size $M \times d$) of parameter estimates (not require when using a fit object).
y	Vector (of size T) of observations (not require when using a fit object).
level	Vector (of size R) of Value-at-risk and Expected-shortfall levels. (Default: level = c(0.95, 0.99))
ES	Boolean indicating if Expected-shortfall is also calculated. (Default: ES = TRUE)
do.its	Boolean indicating if the in-sample risk estimator are returned. (Default: do.its = FALSE)

Details

If a matrix of MCMC posterior draws estimates is given, the Bayesian Value-at-Risk and Expected-shortfall are calculated. If `do.its = FALSE`, the risk estimator at $t = T + 1$, the method uses the variance estimated at $t = T + 1$. If `do.its = TRUE`, The in-sample risk estimator are calculated.

Value

A list containing of class MSGARCH_RISK containing two or three components:

- VaR :
If `do.its = FALSE`: Value-at-Risk at $t = T + 1$ at the choosen levels (vector of size R).
If `do.its = TRUE`: In-sample Value-at-Risk at the choosen levels (Matrix of size T x R).
- ES :
If `do.its = FALSE`: Expected-shortfall at $t = T + 1$ at the choosen levels (vector of size R).
If `do.its = TRUE`: In-sample Expected-shortfall at the choosen levels (Matrix of size T x R).
- y : Vector (of size T) of observations.

The MSGARCH_RISK contains the plot method. The Bayesian risk estimator can take long time to calculate depending on the size of the chain.

Examples

```
## Not run:
# load data
data("sp500")
sp500 = sp500[1:1000]

# create model specification
spec = MSGARCH::create.spec()

# fit the model on the data with ML estimation using DEoptim initialization
set.seed(123)
fit = MSGARCH::fit.mle(spec = spec, y = sp500, ctr = list(do.init = FALSE))

# compute the Value-at-Risk and Expected-shortfall
# Risk estimation in-sample
risk.its = MSGARCH::risk(object = fit, level = c(0.95,0.99), ES = TRUE, do.its = TRUE)

plot(risk.its)

# Risk estimation at T + 1
risk = MSGARCH::risk(object = fit, level = c(0.95,0.99), ES = TRUE, do.its = FALSE)

## End(Not run)
```

sim

Process simulation method.

Description

Method simulating a MSGARCH process.

Usage

```
sim(object, n, m, theta, burnin = 500)
```

Arguments

object	Model specification of class MSGARCH_SPEC created with create.spec .
n	Simulation length. (Default: n = 1000)
m	Number of simulations. (Default: m = 1)
theta	Vector (of size d) or matrix (of size M x d) of parameter estimates.
burnin	(integer >= 0) Burnin period discarded (first simulation draws). (Default: burnin = 500)

Details

If a matrix of parameter estimates is given, each parameter estimates is evaluated individually and $m = M$. The difference between [sim](#) and [simahead](#) is that [sim](#) starts the simulation at $t = 0$ creating an entire new process while [simahead](#) starts the simulation at $t = T + 1$ taking in consideration all the information available in the original time serie y .

Value

A list of class MSGARCH_SIM containing two components.

- draws: Matrix (of size M x n) of simulated draws.
- state: Matrix (of size M x n) of simulated states.

The MSGARCH_SIM class contains the plot method.

Examples

```
# create model specification
spec = MSGARCH::create.spec()

# generate process
set.seed(123)
sim = MSGARCH::sim(object = spec, n = 1000, m = 1, theta = spec$theta0, burnin = 500)

plot(sim)
```

simahead

Step ahead simulation method.

Description

Method returning step ahead simulation up to time n.

Usage

```
simahead(object, n, m, theta, y)
```

Arguments

object	Model specification of class MSGARCH_SPEC created with <code>create.spec</code> or fit object of type MSGARCH_MLE_FIT created with <code>fit.mle</code> or MSGARCH_BAY_FIT created with <code>fit.bayes</code> .
n	Number of step ahead time step. (Default: $n = 1$)
m	Number of simulations. (Default: $m = 1$)
theta	Vector (of size d) or matrix (of size $M \times d$) of parameter estimates (not require when using a fit object).
y	Vector (of size T) of observations (not require when using a fit object).

Details

If a matrix of parameter estimates is given, each parameter estimates is evaluated individually and $m = M$. The MSGARCH_SIM class contains the `plot` method. The difference between `sim` and `simahead` is that `sim` starts the simulation at $t = 0$ creating an entire new process while `simahead` starts the simulation at $t = T + 1$ taking in consideration all the information available in the original time serie y .

Value

A list of class MSGARCH_SIM containing two components:

- `draws`: Matrix (of size $m \times n$) of step ahead simulated draws.
- `state`: Matrix (of size $m \times n$) of step ahead simulated states.

The MSGARCH_SIM class contains the `plot` method.

Examples

```
## Not run:
# load data
data("sp500")
sp500 = sp500[1:1000]

# create model specification
spec = MSGARCH::create.spec()

# fit the model on the data with ML estimation using DEoptim initialization
set.seed(123)
fit = MSGARCH::fit.mle(spec = spec, y = sp500, ctr = list(do.init = FALSE))

# generate random draws
set.seed(123)
simahead = MSGARCH::simahead(object = fit, n = 30, m = 1000)

plot(simahead)

## End(Not run)
```

sp500	<i>Log return of the S&P 500 index closing Value</i>
-------	--

Description

The S&P 500 index closing value log return from 1998-01-01 to 2015-12-31 from Yahoo Finance <https://finance.yahoo.com/>.

Usage

```
data("sp500")
```

Format

Matrix containing 4529 observations.

Source

Yahoo Finance <https://finance.yahoo.com/>

transmat	<i>Transition Matrix.</i>
----------	---------------------------

Description

Method returning the transition matrix.

Usage

```
transmat(object, theta, n)
```

Arguments

object	Model specification of class MSGARCH_SPEC created with create.spec or fit object of type MSGARCH_MLE_FIT created with fit.mle .
theta	Vector (of size d) of parameter estimates (not require when using a fit object).
n	Number of steps ahead. (Default: n = 1)

Value

A matrix (of size K x K) in the case of a Markov-Switching model or a vector (of size K) in the case of a Mixture model. The columns indicates the starting states while the rows indicates the transition states.

Examples

```
## Not run:
# load data
data("sp500")
sp500 = sp500[1:1000]

# create model specification
spec = MSGARCH::create.spec()

# fit the model on the data with ML estimation using DEoptim initialization
set.seed(123)
fit = MSGARCH::fit.mle(spec = spec, y = sp500, ctr = list(do.init = FALSE))

# Extract the transition matrix 10 steps ahead
transmat.mle = MSGARCH::transmat(fit, n = 10)

print(transmat.mle)

## End(Not run)
```

unc.vol

Unconditional volatility of each regime.

Description

Method returning the unconditional volatility of the process in each state.

Usage

```
unc.vol(object, theta)
```

Arguments

object	Model specification of class MSGARCH_SPEC created with create.spec or fit object of type MSGARCH_MLE_FIT created with fit.mle or MSGARCH_BAY_FIT created with fit.bayes .
theta	Vector (of size d) or matrix (of size M x d) of parameter estimates (not require when using a fit object).

Details

If a matrix of parameter estimates is given, each parameter estimates is evaluated individually.

Value

Unconditional volatility (vector of size K or matrix of size M x K) of each regime.

Examples

```
# create model specification
spec = MSGARCH::create.spec()

# compute the unconditional volatility in each regime
unc.vol = MSGARCH::unc.vol(object = spec, theta = spec$theta0)
```

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