Package: MSGARCH (via r-universe)

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Description Fit (by Maximum Likelihood or MCMC/Bayesian), simulate, and forecast various Markov-Switching GARCH models as described in Ardia et al. (2019) <doi:10.18637/jss.v091.i04>.

License GPL (>= 2)

BugReports https://github.com/keblu/MSGARCH/issues

URL https://github.com/keblu/MSGARCH

Imports Rcpp, coda, methods, zoo, expm, fanplot, MASS, numDeriv

LinkingTo Rcpp, RcppArmadillo

Suggests mcmc, testthat

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`MSGARCH-package` *The R package MSGARCH*

Description

The R package **MSGARCH** implements a comprehensive set of functionalities for Markov-switching GARCH (Haas et al. 2004a) and Mixture of GARCH (Haas et al. 2004b) models, This includes fitting, filtering, forecasting, and simulating. Other functions related to Value-at-Risk and Expected-Shortfall are also available.

The main functions of the package are coded in `C++` using **Rcpp** (Eddelbuettel and Francois, 2011) and **RcppArmadillo** (Eddelbuettel and Sanderson, 2014).

MSGARCH focuses on the conditional variance (and higher moments) process. Hence, there is no equation for the mean. Therefore, you must pre-filter via AR(1) before applying the model.

The **MSGARCH** package implements a variety of GARCH specifications together with several 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)). When optimization is performed, we ensure that the variance in each regime is covariance-stationary and strictly positive (refer to the vignette for more information).

We refer to Ardia et al. (2019a) for a detailed introduction to the package and its usage. Refer to Ardia et al. (2018) and Ardia et al. (2019b) for further applications.

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Note

By using **MSGARCH** you agree to the following rules:

- You must cite Ardia et al. (2019a) in working papers and published papers that use **MSGARCH**. Use `citation("MSGARCH")`.
- You must place the following URL in a footnote to help others find **MSGARCH**: https://CRAN.R-project.org/package=MSGARCH.
- You assume all risk for the use of **MSGARCH**.

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References

Ardia, D. Bluteau, K. Boudt, K. Catania, L. (2018). Forecasting risk with Markov-switching GARCH models: A large-scale performance study. *International Journal of Forecasting*, 34(4), 733-747. doi: 10.1016/j.ijforecast.2018.05.004

Ardia, D. Bluteau, K. Boudt, K. Catania, L. Trottier, D.-A. (2019a). Markov-switching GARCH models in R: The **MSGARCH** package. *Journal of Statistical Software*, 91(4), 1-38. doi: 10.18637/jss.v091.i04

Ardia, D. Bluteau, K. Ruede, M. (2019b). Regime changes in Bitcoin GARCH volatility dynamics. *Finance Research Letters*, 29, 266-271. doi: 10.1016/j.frl.2018.08.009

Eddelbuettel, D. & Francois, R. (2011). **Rcpp**: Seamless R and C++ integration. *Journal of Statistical Software*, 40, 1-18. doi: 10.18637/jss.v040.i08

Eddelbuettel, D. & Sanderson, C. (2014). **RcppArmadillo**: Accelerating R with high-performance C++ linear algebra. *Computational Statistics & Data Analysis*, 71, 1054-1063. doi: 10.1016/j.csda.2013.02.005

Haas, M. Mittnik, S. & Paolella, MS. (2004). A new approach to Markov-switching GARCH models. *Journal of Financial Econometrics*, 2, 493-530. doi: 10.1093/jjfinec/nbh020

Haas, M. Mittnik, S. & Paolella, M. S. (2004b). Mixed normal conditional heteroskedasticity. *Journal of Financial Econometrics*, 2, 211-250. doi: 10.1093/jjfinec/nbh009

See Also

Useful links:

- https://github.com/keblu/MSGARCH
- Report bugs at https://github.com/keblu/MSGARCH/issues

`CreateSpec` *Model specification.*

Description

Creates a model specification before fitting and using the **MSGARCH** functionalities.

Usage

```
CreateSpec(
  variance.spec = list(model = c("sGARCH", "sGARCH")),
  distribution.spec = list(distribution = c("norm", "norm")),
  switch.spec = list(do.mix = FALSE, K = NULL),
  constraint.spec = list(fixed = list(), regime.const = NULL),
  prior = list(mean = list(), sd = list())
)
```

Arguments

`variance.spec`	`list` with element `model`. `model` is a `character` vector (of size K, number of regimes) with the variance model specifications. Valid models are `"sARCH"`, `"sGARCH"`, `"eGARCH"`, `"gjrGARCH"`, and `"tGARCH"` (see *Details*). Default: `model = c("sGARCH", "sGARCH")`.
`distribution.spec`	`list` with element `distribution`. `distribution` is a `character` vector (of size K) of conditional distributions. Valid distributions are `"norm"`, `"snorm"`, `"std"`, `"sstd"`, `"ged"`, and `"sged"` (see *Details*). The vector must be of the same length as the models' vector in `variance.spec`. Default: `distribution = c("norm", "norm")`.
`switch.spec`	`list` with element `do.mix` and `K`. `do.mix` is a `logical` indicating if the specification is a mixture type. If `do.mix = TRUE`, a Mixture of GARCH is created, while if `do.mix = FALSE`, a Markov-Switching GARCH is created (see *Details*). Default: `do.mix = FALSE`. `K` is a optional `numeric` scalar indicating the number of regime. In the case where a single regime is specified in `variance.spec` and `distribution.spec`, this parameter allows to automatically expand this single regime to `K` similar regimes without the need to explicitly define them in `variance.spec` and `distribution.spec` (see *Examples*).

`constraint.spec`

`list` with element `fixed` and `regime.const`. Only one of `fixed` and `regime.const` can be set by the user as it is not allowed to set both at the same time.
`fixed` is a `list` with `numeric` entries and named elements. This argument controls for fixed parameters defined by the user. The names of the entries in the `list` have to coincide with the names of the model parameters.
For instance, if `contraint.spec = list(fixed = list(beta_1 = 0))`, `beta_1` will be fixed to `0` during optimization.
`regime.const` is a `character` vector. This argument controls for the parameters which are set equal across regimes. The names of the entries in the `list` have to coincide with the names of the model parameters minus the regime indicator.
For instance, if `contraint.spec = list(regime.const = c("beta"))`, all the parameters named `beta` will be the same in all regimes during optimization.

`prior`

`list` with element `mean` and `sd`. The element `mean` and `sd` are `list` with `numeric` and named elements that allow to adjust the prior mean and standard deviation of the truncated Normal prior. The names of the entries in the lists have to coincide with the names of the model parameters.
For instance, if `prior = list(mean = list(beta_1 = 0.7), sd = list(beta_1 = 0.1))`, the prior mean of `beta_1` will be set to `0.7` while the prior standard deviation will set to `0.1`.

Details

The Markov-Switching specification is based on the Haas et al. (2004a) MSGARCH specification. It is a MSGARCH model that is separated in K single-regime specifications which are updated in parallel. Under the Haas et al. (2004a) specification, the conditional variance is a function of past data and the current state. The Mixture of GARCH option (`do.mix = TRUE`) is based on Haas et al. (2004b). A Mixture of GARCH is a mixture of distributions where the variance process of each distribution is a single-regime process.
For the models, `"sARCH"` is the ARCH(1) model (Engle, 1982), `"sGARCH"` the GARCH(1,1) model (Bollerslev, 1986), `"eGARCH"` the EGARCH(1,1) model (Nelson, 1991), `"gjrGARCH"` the GJR(1,1) model (Glosten et al., 1993), and `"tGARCH"` the TGARCH(1,1) model (Zakoian, 1994).
For the distributions, `"norm"` is the Normal distribution, `"std"` the Student-t distribution, and `"ged"` the GED distribution. Their skewed version, implemented via the Fernandez and & Steel (1998) transformation, are `"snorm"`, `"sstd"` and `"sged"`. Please see Ardia et al. (2019) for more details on the models and distributions.
The user must choose between `fixed` or `regime.const` in `contraint.spec` as both cannot be set at the same time. The `list` `fixed.pars` will ensure that the chosen fixed parameters will be fixed during optimization according to the values set by the user. Thus only the non-fixed parameters are optimized. The vector `regime.const` will ensure that the chosen parameters will be the same across regime during optimization.
The `list` `mean` and `sd` in `prior` will adjust the prior mean and prior standard deviation of the truncated Normal prior for MCMC estimation via `FitMCMC` according to the inputed prior mean and standard deviation. Those prior means and standard deviations that are not set will take on preset default values (a mean of zero and a variance of 1,000).

Value

A list of class MSGARCH_SPEC with the following elements:

- par0: Vector (of size d) of default parameters.
- is.mix: Logical indicating if the specification is a mixture.
- K: Number of regimes.
- lower: Vector (of size d) of lower parameters' bounds.
- upper: Vector (of size d) of upper parameters' bounds.
- n.params: Vector (of size K) of the total number of parameters by regime including distributions' parameters.
- n.params.vol: Vector (of size K) of the total number of parameters by regime excluding distributions' parameters.
- label: Vector (of size d) of parameters' labels.
- name: Vector (of size K) of model specifications' names.
- func: List of internally used R functions.
- rcpp.func: List of internally used Rcpp functions.
- fixed.pars: List of user inputed fixed parameters.
- regime.const.pars: Vector of user imputed parameter set equal across regimes.
- regime.fixed.pars: Logical indicating if there is any fixed parameteter set by the user.
- regime.const.pars.bool: Logical indicating if there is any parameteters equal across regime set by the user.

The MSGARCH_SPEC class has the following methods:

- simulate: Simulation.
- Volatility: In-sample conditional volatility.
- predict: Forecast of the conditional volatility (and predictive distribution).
- UncVol: Unconditional volatility.
- PredPdf: Predictive density (pdf).
- PIT: Probability Integral Transform.
- Risk: Value-at-Risk and Expected-Shortfall.
- State: State probabilities (smoothed, filtered, predictive, Viterbi).
- FitML: Maximum Likelihood estimation.
- FitMCMC: Bayesian estimation.
- print and summary: Summary of the created specification.

References

Ardia, D. Bluteau, K. Boudt, K. Catania, L. Trottier, D.-A. (2019). Markov-switching GARCH models in R: The **MSGARCH** package. *Journal of Statistical Software*, 91(4), 1-38. doi: 10.18637/jss.v091.i04

Engle, R. (1982). Autoregressive conditional heteroscedasticity with estimates of the variance of United Kingdom inflation *Econometrica*, 50, 987-1008.

Bollerslev, T. (1986). Generalized autoregressive conditional heteroskedasticity. *Journal of Econometrics*, 31, 307-327. doi: 10.1016/03044076(86)900631

Fernandez, C. & Steel, M. F. (1998). On Bayesian modeling of fat tails and skewness. *Journal of the American Statistical Association*, 93, 359-371. doi: 10.1080/01621459.1998.10474117

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, 1779-1801. doi: 10.1111/j.15406261.1993.tb05128.x

Haas, M. Mittnik, S. & Paolella, M. S. (2004a). A new approach to Markov-switching GARCH models. *Journal of Financial Econometrics*, 2, 493-530. doi: 10.1093/jjfinec/nbh020

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Nelson, D. B. (1991). Conditional heteroskedasticity in asset returns: A new approach. *Econometrica*, 59, 347-370.

Zakoian, J.-M. (1994). Threshold heteroskedastic models. *Journal of Economic Dynamics and Control*, 18, 931-955. doi: 10.1016/01651889(94)900396

Examples

```
# create a Markov-switching specification
# MS-GARCH(1,1)-GJR(1,1)-Student
spec <- CreateSpec(variance.spec = list(model = c("sGARCH","gjrGARCH")),
                   distribution.spec = list(distribution = c("std","std")),
                   switch.spec = list(do.mix = FALSE))
print(spec)

# create a 3-regime Markov-switching specification with the help of variable K
# MS(3)-GARCH(1,1)- Student
spec <- CreateSpec(variance.spec = list(model = c("sGARCH")),
                   distribution.spec = list(distribution = c("std")),
                   switch.spec = list(do.mix = FALSE, K = 3))
print(spec)

# create a mixture specification
# MIX-GARCH(1,1)-GJR(1,1)-Student
spec <- CreateSpec(variance.spec = list(model = c("sGARCH","gjrGARCH")),
                   distribution.spec = list(distribution = c("std","std")),
                   switch.spec = list(do.mix = TRUE))
print(spec)

# setting fixed parameter for the sGARCH beta parameter
# MS-GARCH(1,1)-GJR(1,1)-Student with beta_1 fixed to 0
spec <- CreateSpec(variance.spec = list(model = c("sGARCH","gjrGARCH")),
```

```
                    distribution.spec = list(distribution = c("std","std")),
                    switch.spec = list(do.mix = FALSE),
                    constraint.spec = list(fixed = list(beta_1 = 0)))
print(spec)

# setting restriction for the shape parameter of the Student-t across regimes
# MS-GARCH(1,1)-GJR(1,1)-Student with shape parameter constraint across regime
spec <- CreateSpec(variance.spec = list(model = c("sGARCH","gjrGARCH")),
                    distribution.spec = list(distribution = c("std","std")),
                    switch.spec = list(do.mix = FALSE),
                    constraint.spec = list(regime.const = c("nu")))
print(spec)

# setting custom parameter priors for the beta parameters
# MS-GARCH(1,1)-GJR(1,1)-Student with prior modification
spec <- CreateSpec(variance.spec = list(model = c("sGARCH","gjrGARCH")),
                    distribution.spec = list(distribution = c("std","std")),
                    switch.spec = list(do.mix = FALSE),
                    prior = list(mean = list(beta_1 = 0.9, beta_2 = 0.3),
                                 sd = list(beta_1 = 0.05, beta_2 = 0.01)))
print(spec)
```

---

dem2gbp *DEM/GBP exchange rate log-returns*

Description

The vector dem2gbp contains daily observations of the Deutschmark vs British Pound foreign exchange rate log-returns. This dataset has been promoted as an informal benchmark for GARCH time-series software validation. See McCullough and Renfro (1999), and Brooks, Burke, and Persand (2001) for details. The nominal returns are expressed in percent as in Bollerslev and Ghysels (1996). The sample period is from January 3, 1984, to December 31, 1991, for a total of 1974 observations.

Usage

```
data("dem2gbp")
```

Format

vector of size 1,974.

References

Bollerslev T., Ghysels, E. (1996) Periodic autoregressive conditional heteroscedasticity. *Journal of Business and Economic Statistics*, 14, 139-151.

Brooks C., Burke S. P., Persand G. (2001) *International Journal of Forecasting*, 17, 45-57. doi: 10.1016/S01692070(00)000704

McCullough B. D., Renfro C. G. (1999) Benchmarks and software standards: A case study of GARCH procedures. *Journal of Economic and Social Measurement*, 25, 59-71. doi: 10.3233/JEM-19990160

`DIC` *Deviance Information Criterion (DIC).*

Description

Method which computes the Deviance Information Criterion (DIC) from a fit object of type `MSGARCH_MCMC_FIT` created with `FitMCMC`.

Usage

```
DIC(fit)

## S3 method for class 'MSGARCH_MCMC_FIT'
DIC(fit)
```

Arguments

`fit`	Fit object of type `MSGARCH_MCMC_FIT` created with `FitMCMC`.

Details

Computes the Deviance information criterion of Spiegelhalter et al. (2002).

Value

A list with the following elements:

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

References

Spiegelhalter, David J., et al. (2002). Bayesian measures of model complexity and fit. *Journal of the Royal Statistical Society: Series B*, 64, 583-639 doi: 10.1111/14679868.00353

Examples

```
# create model specification
spec <- CreateSpec()

# load data
data("SMI", package = "MSGARCH")

# fit the model on data by MCMC
set.seed(123)
fit <- FitMCMC(spec = spec, data = SMI, ctr = list(nburn = 500L, nmcmc = 500L))

# compute DIC
DIC(fit)
```

ExtractStateFit *Single-regime model extractor.*

Description

Extracts each regime from a fitted multiple regime specificaton and creates a fitted object for each extracted regime.

Usage

```
ExtractStateFit(object)

## S3 method for class 'MSGARCH_ML_FIT'
ExtractStateFit(object)

## S3 method for class 'MSGARCH_MCMC_FIT'
ExtractStateFit(object)
```

Arguments

object	Fit object of type MSGARCH_ML_FIT created with FitML or MSGARCH_MCMC_FIT created with FitMCMC.

Value

A list of K elements where each element is a fit object of type MSGARCH_ML_FIT or MSGARCH_MCMC_FIT.

Examples

```
# create model specification
spec <- CreateSpec()

# load data
data("SMI", package = "MSGARCH")
```

```
# fit the model on the data with ML estimation
fit <- FitML(spec = spec, data = SMI)
SR.fit <- ExtractStateFit(fit)
print(SR.fit)
```

`FitMCMC` *MCMC/Bayesian estimation.*

Description

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

Usage

```
FitMCMC(spec, data, ctr = list())
```

Arguments

`spec`	Model specification of class `MSGARCH_SPEC` created with `CreateSpec`.
`data`	Vector (of size T) of observations.
`ctr`	A list of control parameters:

- `par0`: Vector (of size d) where d must have the same length as the default parameters of the specification. It is the starting value for the chain (if empty the the method automatically set starting parameters; see *Details*).
- `nburn` (integer >= 0): Number of discarded draws. (Default: `nburn = 5000L`)
- `nmcmc` (integer > 0): Number of draws. (Default: `nmcmc = 10000L`)
- `nthin` (integer > 0): Thinning factor (every `nthin` draws are kept). (Default: `nthin = 10L`)
- `do.sort` (bool): Logical indicating if the MCMC draws are post-sorted following Geweke (2007). By default, `do.sort = TRUE`, such that the MCMC draws are ordered to ensure that unconditional variance is an increasing function of the regime (identification constraint). If the user sets `do.sort = FALSE`, no sorting is imposed, and label switching can occur (see *Details*).
- `SamplerFUN`: Custom MCMC sampler (see *Details*).

Details

The total number of draws is equal to `nmcmc / nthin`. The MCMC/Bayesian estimation relies on an **Rcpp** implementation of the adaptive sampler of Vihola (2012). The implementation is based on the R package **adaptMCMC** (Andreas, 2012). Starting values when `par0` is not provided are chosen automatically before sampling (see Ardia et al. (2019) for more details).
`SamplerFUN` allows for a custom sampler to be used. The function must take the form:
`function(f_posterior, data, spec, par0, ctr)`,

where f_posterior is the function to optimize, data is the data, spec is the specification, par0 are the starting parameters, and ctr are the control parameters. The inputs spec and data, must be passed as inputs in the sampler (see *Examples*). The custom sampler must output a matrix containing the MCMC chain.
When do.sort = TRUE, sorting of each MCMC draw conditional on the unconditional variance is done across homogeneous regime specification.

Value

A list of class MSGARCH_MCMC_FIT with the following elements:

- par: The MCMC chain (matrix from the R package coda (Plummer et al., 2006) of size nmcmc / nthin x d).
- accept: Acceptance rate of the sampler.
- spec: Model specification of class MSGARCH_SPEC created with CreateSpec.
- data: Vector (of size T) of observations.
- ctr: list of the control used for the fit.

The MSGARCH_MCMC_FIT with the following methods:

- DIC: Deviance Information Criterion (DIC).
- simulate: Simulation.
- Volatility: In-sample conditional volatility.
- predict: Forecast of the conditional volatility (and predictive distribution).
- UncVol: Unconditional volatility.
- PredPdf: Predictive density (pdf).
- PIT: Probability Integral Transform.
- Risk: Value-at-Risk and Expected-Shortfall.
- State: State probabilities (smoothed, filtered, predictive, Viterbi).
- ExtractStateFit: Single-regime model extractor.
- 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

Ardia, D. Bluteau, K. Boudt, K. Catania, L. Trottier, D.-A. (2019). Markov-switching GARCH models in R: The **MSGARCH** package. *Journal of Statistical Software*, 91(4), 1-38. doi: 10.18637/jss.v091.i04

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MacDonald, I.L., Zucchini, W. (1997). *Hidden Markov and other models for discrete-valued time series*. CRC press.

Plummer, M. Best, N. Cowles, K. & Vines, K. (2006). coda: Convergence diagnosis and output analysis for MCMC. *R News*, 6, 7-11. https://cran.r-project.org/package=coda

Vihola, M. (2012). Robust adaptive Metropolis algorithm with coerced acceptance rate. *Statistics and Computing*, 22, 997-1008. doi: 10.1007/s1122201192695

Examples

```
# create model specification
spec <- CreateSpec()

# load data
data("SMI", package = "MSGARCH")

# fit the model on the data by MCMC
set.seed(123)
fit <- FitMCMC(spec = spec, data = SMI, ctr = list(nburn = 500L, nmcmc = 500L, nthin = 1L))
summary(fit)

# custom sampler example
## Not run:
library("mcmc")
f_MCMC <- function(f_posterior, data, spec, par0, ctr){
  par <- mcmc::metrop(f_posterior, initial = par0, nbatch = ctr$nmcmc + ctr$nburn,
                      data = data, spec = spec)$batch
  colnames(par) = names(par0)
  return(par)
}

set.seed(123)
fit <- FitMCMC(spec, data = SMI, ctr  = list(SamplerFUN = f_MCMC,
                                             nburn = 500L, nmcmc = 500L, nthin = 1L))
summary(fit)

## End(Not run)
```

`FitML` *Maximum Likelihood estimation.*

Description

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

Usage

```
FitML(spec, data, ctr = list())
```

Arguments

spec	Model specification created with CreateSpec.
data	Vector (of size T) of observations.
ctr	A list of control parameters:

- par0: Vector (of size d) where d must have the same length as the default parameters of the specification. It is the starting value for the optimizer (if empty the the method automatically set starting parameters; see *Details*).
- do.se Logical. Should standard errors be computed? (Default: do.se = TRUE).
- do.plm Logical. If do.plm = FALSE, parameter transformation during the optimization step is performed without ensuring stationarity for the volatility processes. For combinations of parameters that do not imply stationarity the likelihood value is fixed at -1e10. If fixed is defined in the list contraint.spec of CreateSpec, do.plm = TRUE is used. (Default: do.plm = FALSE)
- OptimFUN: Custom optimization function (see *Details*).

Details

By default, OptimFUN is set such that optimization is done via the well-known Broyden- Fletcher-Goldfarb-Shanno (BFGS) algorithm using the optim function with method = "BFGS". Starting values when par0 is not provided are chosen automatically before optimization (see Ardia et al. (2019) for more details)
OptimFUN allows for a custom optimizer to be used. The function must take the form:
function(vPw, f_nll, spec, data, do.plm),
where vPw are starting parameters (transformed), f_nll is the function to be minimize, spec is the specification, data is the data, and do.plm the originally inputed or default do.plm. The inputs spec, data, and do.plm must be passed as inputs in the optimizer (see *Examples*). It must output a list with the following elements:

- value: Optimal negative log-likelihood.
- par: Optimal parameters.

Value

A list of class MSGARCH_ML_FIT with the following elements:

- par: Vector (of size d) of optimal parameters.
- loglik: Log-likelihood of y given the optimal parameters.
- Inference: list with elements MatCoef and Hessian. MatCoef is a matrix (of size d x 4) with optimal parameter estimates, standard errors, t-stats, and p-values. Hessian is the Hessian (matrix of size d x d) of the negative log-likelihood function evaluated at the optimal parameter estimates par.
- spec: Model specification of class MSGARCH_SPEC created with CreateSpec.
- data: Vector (of size T) of observations.
- ctr: list of the control used for the fit.

The MSGARCH_ML_FIT with the following methods:

- AIC: Akaike Information Criterion (AIC).
- BIC: Bayesian Information Criterion (BIC).
- simulate: Simulation.
- Volatility: In-sample conditional volatility.
- predict: Forecast of the conditional volatility (and predictive distribution).
- UncVol: Unconditional volatility.
- PredPdf: Predictive density (pdf).
- PIT: Probability Integral Transform.
- Risk: Value-at-Risk and Expected-Shortfall.
- State: State probabilities (smoothed, filtered, predictive, Viterbi).
- ExtractStateFit: Single-regime model extractor.
- summary: Summary of the fit.

References

Ardia, D. Bluteau, K. Boudt, K. Catania, L. Trottier, D.-A. (2019). Markov-switching GARCH models in R: The **MSGARCH** package. *Journal of Statistical Software*, 91(4), 1-38. doi: 10.18637/jss.v091.i04

Examples

```
# create model specification
spec <- CreateSpec()

# load data
data("SMI", package = "MSGARCH")

# fit the model on the data by ML
fit <- FitML(spec = spec, data = SMI)
summary(fit)

# custom optimizer example
## Not run:
f_custom_optim <- function(vPw, f_nll, spec, data, do.plm){
 out <- stats::optim(vPw, f_nll, spec = spec, data = data,
                     do.plm = do.plm, method = "Nelder-Mead")
 return(out)
}

set.seed(123)
fit <- FitML(spec, data = SMI, ctr = list(OptimFUN = f_custom_optim))
summary(fit)

## End(Not run)
```

PIT *Probability integral transform.*

Description

Method returning the probability integral transform (PIT).

Usage

```
PIT(object, ...)

## S3 method for class 'MSGARCH_SPEC'
PIT(
  object,
  x = NULL,
  par = NULL,
  data = NULL,
  do.norm = FALSE,
  do.its = FALSE,
  nahead = 1L,
  do.cumulative = FALSE,
  ctr = list(),
  ...
)

## S3 method for class 'MSGARCH_ML_FIT'
PIT(
  object,
  x = NULL,
  newdata = NULL,
  do.norm = TRUE,
  do.its = FALSE,
  nahead = 1L,
  do.cumulative = FALSE,
  ctr = list(),
  ...
)

## S3 method for class 'MSGARCH_MCMC_FIT'
PIT(
  object,
  x = NULL,
  newdata = NULL,
  do.norm = TRUE,
  do.its = FALSE,
  nahead = 1L,
  do.cumulative = FALSE,
```

```
  ctr = list(),
  ...
)
```

Arguments

object	Model specification of class MSGARCH_SPEC created with CreateSpec or fit object of type MSGARCH_ML_FIT created with FitML or MSGARCH_MCMC_FIT created with FitMCMC.
...	Not used. Other arguments to PIT.
x	Vector (of size n). Used when do.its = FALSE.
par	Vector (of size d) or matrix (of size nmcmc x d) of parameter estimates where d must have the same length as the default parameters of the specification.
data	Vector (of size T) of observations.
do.norm	Logical indicating if the PIT values are transformed into standard Normal variate. (Default: do.norm = FALSE)
do.its	Logical indicating if the in-sample PIT is returned. (Default: do.its = FALSE)
nahead	Scalar indicating the number of step-ahead evaluation. Valid only when do.its = FALSE. (Default: nahead = 1L)
do.cumulative	Logical indicating if the PIT is computed on the cumulative simulations (typically log-returns, as they can be aggregated). Only available for do.its = FALSE. (Default: do.cumulative = FALSE)
ctr	A list of control parameters: • nsim (integer >= 0): Number indicating the number of simulation done for the evaluation of the PIT at nahead > 1. (Default: nsim = 10000L)
newdata	Vector (of size T*) of new observations. (Default: newdata = NULL)

Details

If a matrix of MCMC posterior draws is given, the Bayesian probability integral transform is calculated. Two or more step-ahead probability integral transform are estimated via simulation of nsim paths up to t = T + T* + nahead. The empirical probability integral transforms is then inferred from these simulations.
If do.its = FALSE, the vector x are evaluated as t = T + T* + 1, ... ,t = T + T* + nahead realizations.
If do.its = TRUE, x is evaluated at each time t up to time t = T + T*.
Finally if x = NULL the vector data is evaluated for sample evaluation of the PIT.
The do.norm argument transforms the PIT value into Normal variates so that normality test can be done.

Value

A vector or matrix of class MSGARCH_PIT.
If do.its = FALSE: Probability integral transform of the points x at
t = T + T* + 1, ... ,t = T + T* + nahead or Normal variate derived from the probability integral transform of x (matrix of size nahead x n).

If do.its = TRUE: In-sample probability integral transform or Normal variate derived from the probability integral transform of data if x = NULL (vector of size T + T*) or in-sample probability integral transform or Normal variate derived from the probability integral transform of x (matrix of size (T + T*) x n).

Examples

```
# create model specification
spec <- CreateSpec()

# load data
data("SMI", package = "MSGARCH")

# fit the model on the data by ML
fit <- FitML(spec = spec, data = SMI)

# run PIT method in-sample
pit.its <- PIT(object = fit, do.norm = TRUE, do.its = TRUE)

# diagnostic of PIT with qqnorm
qqnorm(pit.its)
qqline(pit.its)

# simulate a serie from the model
set.seed(123)
sim.series <- simulate(object = spec, par = fit$par, nahead= 1000L, nsim = 1L)
sim.series <- as.vector(sim.series$draw)

# run PIT method on the simualed serie with the true par
pit.x <- PIT(object = spec, par = fit$par, data = sim.series, do.norm = TRUE, do.its = TRUE)
qqnorm(pit.x)
qqline(pit.x)
```

---

predict.MSGARCH_SPEC *predict method.*

Description

Conditional volatility (and predictive distribution) forecasts.

Usage

```
## S3 method for class 'MSGARCH_SPEC'
predict(
  object,
  newdata = NULL,
  nahead = 1L,
  do.return.draw = FALSE,
  par = NULL,
```

```
  do.cumulative = FALSE,
  ctr = list(),
  ...
)

## S3 method for class 'MSGARCH_ML_FIT'
predict(
  object,
  newdata = NULL,
  nahead = 1L,
  do.return.draw = FALSE,
  do.cumulative = FALSE,
  ctr = list(),
  ...
)

## S3 method for class 'MSGARCH_MCMC_FIT'
predict(
  object,
  newdata = NULL,
  nahead = 1L,
  do.return.draw = FALSE,
  do.cumulative = FALSE,
  ctr = list(),
  ...
)
```

Arguments

object	Model specification of class MSGARCH_SPEC created with CreateSpec or fit object of type MSGARCH_ML_FIT created with FitML or MSGARCH_MCMC_FIT created with FitMCMC.
newdata	Vector (of size T*) of new observations. (Default newdata = NULL)
nahead	Scalar indicating the number of step-ahead evaluation.
do.return.draw	Are simulation draws from the predictive distribution returned? (Default do.return.draw = FALSE)
par	Vector (of size d) or matrix (of size nmcmc x d) of parameter estimates where d must have the same length as the default parameters of the specification.
do.cumulative	Logical indicating if the conditional volatility prediction is computed on the cumulative simulations (typically log-returns, as they can be aggregated). (Default: do.cumulative = FALSE)
ctr	A list of control parameters: • nsim (integer >= 0): Number indicating the number of simulation done for the conditional volatlity forecast at nahead > 1. (Default: nsim = 10000L)
...	Not used. Other arguments to predict.

Details

If a matrix of MCMC posterior draws is given, the Bayesian predictive conditional volatility (and predictive distribution) forecasts are returned.

Value

A list of class MSGARCH_FORECAST with the following elements:

- vol: Condititional volatility forecast (vector of size nahead).
- draw: If do.return.draw = TRUE:
  Draws sampled from the predictive distributions (matrix of size nahead x nsim).
  If do.return.draw = FALSE:
  NULL

The MSGARCH_FORECAST class contains the plot method.

Examples

```
# create specification
spec <- CreateSpec()

# load data
data("SMI", package = "MSGARCH")

# predict from specification
par <- c(0.1, 0.1, 0.8, 0.2, 0.1, 0.8, 0.99, 0.01)
set.seed(1234)
pred <- predict(object = spec, par = par, newdata = SMI, nahead = 5L)
head(pred)
plot(pred)

# predict from ML fit
fit <- FitML(spec = spec, data = SMI)
set.seed(1234)
pred <- predict(object = fit, nahead = 5L, do.return.draw = TRUE)
head(pred)
plot(pred)

## Not run:
set.seed(1234)
fit <- FitMCMC(spec = spec, data = SMI)
pred <- predict(object = fit, nahead = 5L, do.return.draw = TRUE)
plot(pred)

## End(Not run)
```

PredPdf *Predictive density.*

Description

Method returning the predictive density (pdf).

Usage

```
PredPdf(object, ...)

## S3 method for class 'MSGARCH_SPEC'
PredPdf(
  object,
  x = NULL,
  par = NULL,
  data = NULL,
  log = FALSE,
  do.its = FALSE,
  nahead = 1L,
  do.cumulative = FALSE,
  ctr = list(),
  ...
)

## S3 method for class 'MSGARCH_ML_FIT'
PredPdf(
  object,
  x = NULL,
  newdata = NULL,
  log = FALSE,
  do.its = FALSE,
  nahead = 1L,
  do.cumulative = FALSE,
  ctr = list(),
  ...
)

## S3 method for class 'MSGARCH_MCMC_FIT'
PredPdf(
  object,
  x = NULL,
  newdata = NULL,
  log = FALSE,
  do.its = FALSE,
  nahead = 1L,
  do.cumulative = FALSE,
```

```
  ctr = list(),
  ...
)
```

Arguments

object	Model specification of class MSGARCH_SPEC created with CreateSpec or fit object of type MSGARCH_ML_FIT created with FitML or MSGARCH_MCMC_FIT created with FitMCMC.
...	Not used. Other arguments to PredPdf.
x	Vector (of size n). Used when do.its = FALSE.
par	Vector (of size d) or matrix (of size nmcmc x d) of parameter estimates where d must have the same length as the default parameters of the specification.
data	Vector (of size T) of observations.
log	Logical indicating if the log-density is returned. (Default: log = FALSE)
do.its	Logical indicating if the in-sample predictive is returned. (Default: do.its = FALSE)
nahead	Scalar indicating the number of step-ahead evaluation. Valid only when do.its = FALSE. (Default: nahead = 1L)
do.cumulative	Logical indicating if predictive density is computed on the cumulative simulations (typically log-returns, as they can be aggregated). Only available for do.its = FALSE. (Default: do.cumulative = FALSE)
ctr	A list of control parameters: • nsim (integer >= 0) : Number indicating the number of simulation done for the evaluation of the density at nahead > 1. (Default: nsim = 10000L)
newdata	Vector (of size T*) of new observations. (Default newdata = NULL)

Details

If a matrix of MCMC posterior draws is given, the Bayesian predictive probability density is calculated. Two or more step-ahead predictive probability density are estimated via simulation of nsim paths up to t = T + T* + nahead. The predictive distribution are then inferred from these simulations via a Gaussian Kernel density. If do.its = FALSE, the vector x are evaluated as t = T + T* + 1, ... , t = T + T* + nahead realization.
If do.its = TRUE and x is evaluated at each time t up top time t = T + T*.
Finally, if x = NULL the vector data is evaluated for sample evaluation of the predictive denisty ((log-)likelihood of each sample points).

Value

A vector or matrix of class MSGARCH_PRED.
If do.its = FALSE: (Log-)predictive of the points x at t = T + T* + 1, ... , t = T + T* + nahead (matrix of size nahead x n).
If do.its = TRUE: In-sample predictive of data if x = NULL (vector of size T + T*) or in-sample predictive of x (matrix of size (T + T*) x n).

Examples

```
# create model specification
spec <- CreateSpec()

# load data
data("SMI", package = "MSGARCH")

# fit the model on the data by ML
fit <- FitML(spec = spec, data = SMI)

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

# create a mesh
x <- seq(-3,3,0.01)

# run PredPdf method on mesh at T + 1
pred.x <- PredPdf(object = fit, x = x, log = TRUE, do.its = FALSE)
```

Risk *Value-at-Risk and Expected-shortfall.*

Description

Method returning the Value-at-Risk and Expected-shortfall risk measures.

Usage

```
Risk(object, ...)

## S3 method for class 'MSGARCH_SPEC'
Risk(
  object,
  par,
  data,
  alpha = c(0.01, 0.05),
  nahead = 1L,
  do.es = TRUE,
  do.its = FALSE,
  do.cumulative = FALSE,
  ctr = list(),
  ...
)

## S3 method for class 'MSGARCH_ML_FIT'
Risk(
  object,
  newdata = NULL,
```

```
  alpha = c(0.01, 0.05),
  do.es = TRUE,
  do.its = FALSE,
  nahead = 1L,
  do.cumulative = FALSE,
  ctr = list(),
  ...
)

## S3 method for class 'MSGARCH_MCMC_FIT'
Risk(
  object,
  newdata = NULL,
  alpha = c(0.01, 0.05),
  do.es = TRUE,
  do.its = FALSE,
  nahead = 1L,
  do.cumulative = FALSE,
  ctr = list(),
  ...
)
```

Arguments

object	Model specification of class MSGARCH_SPEC created with CreateSpec or fit object of type MSGARCH_ML_FIT created with FitML or MSGARCH_MCMC_FIT created with FitMCMC.
...	Not used. Other arguments to Risk.
par	Vector (of size d) or matrix (of size nmcmc x d) of parameter estimates where d must have the same length as the default parameters of the specification.
data	Vector (of size T) of observations.
alpha	Vector (of size R) of Value-at-risk and Expected-shortfall levels. (Default: alpha = c(0.01, 0.05))
nahead	Scalar indicating the number of step-ahead evaluation. (Default: nahead = 1L). Not used when do.its = TRUE as it only returns in-sample one-step ahead risk measures.
do.es	Logical indicating if Expected-shortfall is also calculated. (Default: do.es = TRUE)
do.its	Logical indicating if the in-sample risk estimators are returned. (Default: do.its = FALSE).
do.cumulative	Logical indicating if the risk measures are computed on the cumulative simulations (typically log-returns, as they can be aggregated). Only available for do.its = FALSE. (Default: do.cumulative = FALSE)
ctr	A list of control parameters: • nmesh (integer >= 0) : Number of points for density evaluation. (Default: nmesh = 1000L)

- nsim (integer >= 0) : Number indicating the number of simulation done for estimation of the density at nahead > 1. (Default: nsim = 10000L)

newdata Vector (of size T*) of new observations. (Default newdata = NULL)

Details

If a matrix of MCMC posterior draws is given, the Bayesian Value-at-Risk and Expected-shortfall are calculated. Two or more step ahead risk measures are estimated via simulation of nsim paths up to t = T + T* + nahead. If do.its = FALSE, the risk estimators at t = T + T* + 1, ... ,t = T + T* + nahead are computed. do.cumulative = TRUE indicate the function to compute the risk meausre over aggregated period up to nahead period using the cumsum function on the simulated data.

Value

A list of class MSGARCH_RISK with the following elements:

- VaR:
  If do.its = FALSE: Value-at-Risk at t = T + T* + 1, ... ,t = T + T* + nahead at the chosen levels (matrix of size nahead x R).
  If do.its = TRUE: In-sample Value-at-Risk at the chosen levels (Matrix of size (T + T*) x R).
- ES:
  If do.its = FALSE: Expected-shortfall at t = T + T* + 1, ... ,t = T + T* + nahead at the chosen levels (matrix of size nahead x R).
  If do.its = TRUE: In-sample Expected-shortfall at the chosen levels (Matrix of size (T + T*) x R).

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

Examples

```
# create specification
spec <- CreateSpec()

# load data
data("SMI", package = "MSGARCH")

# risk from specification
par <- c(0.1, 0.1, 0.8, 0.2, 0.1, 0.8, 0.99, 0.01)
set.seed(1234)
risk <- Risk(object = spec, par = par, data = SMI, nahead = 5L)
head(risk)
plot(risk)

# risk from ML fit
fit <- FitML(spec = spec, data = SMI)
set.seed(1234)
risk <- Risk(object = fit, nahead = 5L)
head(risk)
plot(risk)
```

```
## Not run:
# risk from MCMC fit
set.seed(1234)
fit <- FitMCMC(spec = spec, data = SMI)
risk <- Risk(object = fit, nahead = 5L)
head(risk)
plot(risk)

## End(Not run)
```

`simulate.MSGARCH_SPEC` *Simulation of MSGARCH processes.*

Description

Method for simulating MSGARCH processes.

Usage

```
## S3 method for class 'MSGARCH_SPEC'
simulate(
  object,
  nsim = 1L,
  seed = NULL,
  nahead = 1L,
  par = NULL,
  nburn = 500L,
  ...
)

## S3 method for class 'MSGARCH_ML_FIT'
simulate(object, nsim = 1L, seed = NULL, nahead = 1L, nburn = 500L, ...)

## S3 method for class 'MSGARCH_MCMC_FIT'
simulate(object, nsim = 1L, seed = NULL, nahead = 1L, nburn = 500L, ...)
```

Arguments

object	Model specification of class MSGARCH_SPEC created with CreateSpec or fit object of type MSGARCH_ML_FIT created with FitML or MSGARCH_MCMC_FIT created with FitMCMC.
nsim	Number of simulations. (Default: nsim = 1L)
seed	Integer indicating if and how the random number generator should be initialized. If seed = NULL, the state of the random generator will not change. (Default: seed = NULL)
nahead	Simulation length. (Default: nahead = 1L)
par	Vector (of size d) or matrix (of size nahead x d) of parameter

nburn	Burnin period discarded (first simulation draws).
...	Not used. Other arguments to simulate.

Details

If a matrix of parameters estimates is provided, nsim simuations will be done for each row.

Value

A list of class MSGARCH_SIM with the following elements:.

- draw: Matrix (of size nahead x nsim) of simulated draws.
- state: Matrix (of size nahead x nsim) of simulated states.
- CondVol: Array (of size nahead x nsim x K) of simulated conditional volatilities.

The MSGARCH_SIM class contains the plot method.

Examples

```
# create specification
spec <- CreateSpec()

# simulation from specification
par <- c(0.1, 0.1, 0.8, 0.2, 0.1, 0.8, 0.99, 0.01)
set.seed(1234)
sim <- simulate(object = spec, nsim = 1L, nahead = 1000L,
                nburn = 500L, par = par)
head(sim)
plot(sim)

# load data
data("SMI", package = "MSGARCH")

# simulation from ML fit
fit <- FitML(spec = spec, data = SMI)
set.seed(1234)
sim <- simulate(object = fit, nsim = 1L, nahead = 1000L,
                nburn = 500L)
head(sim)
plot(sim)

## Not run:
# simulation from MCMC fit
fit <- FitMCMC(spec = spec, data = SMI)
set.seed(1234)
sim <- simulate(object = fit, nahead = 100L, nburn = 500L)
head(sim)
plot(sim)

## End(Not run)
```

SMI *Swiss market index dataset*

Description

See Mullen et al. (2011) for a description of this dataset.

Usage

```
data("SMI")
```

Format

zoo object containing 2,500 observations ranging from 1990-11-12 to 2000-10-20.

Source

DEoptim package

References

Mullen, K.M, Ardia, D., Gil, D., Windover, D., Cline, J. (2011). DEoptim: An R Package for Global Optimization by Differential Evolution. *Journal of Statistical Software*, 40(6), 1-26. doi: 10.18637/jss.v040.i06

State *State probabilities.*

Description

Method returning the filtered, predictive, and smoothed probabilities of the states, and the most probable path computed with the Viterbi algorithm.

Usage

```
State(object, ...)

## S3 method for class 'MSGARCH_SPEC'
State(object, par, data, ...)

## S3 method for class 'MSGARCH_ML_FIT'
State(object, newdata = NULL, ...)

## S3 method for class 'MSGARCH_MCMC_FIT'
State(object, newdata = NULL, ...)
```

Arguments

object	Model specification of class MSGARCH_SPEC created with CreateSpec or fit object of type MSGARCH_ML_FIT created with FitML or MSGARCH_MCMC_FIT created with FitMCMC.
...	Not used. Other arguments to State.
par	Vector (of size d) or matrix (of size nmcmc x d) of parameter estimates where d must have the same length as the default parameters of the specification.
data	Vector (of size T) of observations.
newdata	Vector (of size T*) of new observations. (Default newdata = NULL)

Details

If a matrix of parameter estimates is given, each parameter estimate (each row) is evaluated individually.

Value

A list of class MSGARCH_PSTATE with the following elements:

- FiltProb: Filtered probabilities (array of size (T + T*) x (nmcmc or 1) x K).
- PredProb: Predictive probabilities (array of size (T + T* + 1) x (nmcmc or 1) x K).
- SmoothProb: Smoothed probabilities (array of size (T + T* + 1) x (nmcmc or 1) x K).
- Viterbi: Most likely path (matrix of size (T + T*) x (nmcmc or 1)).

The class MSGARCH_PSTATE contains the plot method. The plot method contains as input type.prob which is one of "filtered", "predictive", "smoothed", "viterbi". (Default: type.prob = "smoothed")

Examples

```
# create specification
spec <- CreateSpec()

# load data
data("SMI", package = "MSGARCH")

# state from specification
par <- c(0.1, 0.1, 0.8, 0.2, 0.1, 0.8, 0.99, 0.01)
state <- State(object = spec, par = par, data = SMI)
plot(state, type.prob = "filtered")

# state from ML fit
fit <- FitML(spec = spec, data = SMI)
state <- State(object = fit)
plot(state, type.prob = "smoothed")

## Not run:
# state from MCMC fit
set.seed(1234)
```

```
fit <- FitMCMC(spec = spec, data = SMI)
state <- State(object = fit)
plot(state, type.prob = "smoothed")

## End(Not run)
```

TransMat *Transition matrix.*

Description

Method returning the transition matrix.

Usage

```
TransMat(object, ...)

## S3 method for class 'MSGARCH_SPEC'
TransMat(object, par = NULL, nahead = 1L, ...)

## S3 method for class 'MSGARCH_ML_FIT'
TransMat(object, nahead = 1L, ...)
```

Arguments

object	Model specification of class MSGARCH_SPEC created with CreateSpec or fit object of type MSGARCH_ML_FIT created with FitML.
...	Not used. Other arguments to TransMat.
par	Vector (of size d) of parameter estimates (not required when using a fit object) where d must have the same length as the default parameters of the specification.
nahead	Number of steps ahead. (Default: nahead = 1L)

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 of GARCH model. The row indicates the starting states while the columns indicates the transition states.

Examples

```
# create model specification
spec <- CreateSpec()

# load data
data("SMI", package = "MSGARCH")

# fit the model on the data by ML
fit <- FitML(spec = spec, data = SMI)
```

```
# Extract the transition matrix 10 steps ahead
trans.mat <- TransMat(fit, nahead = 10)
print(trans.mat)
```

UncVol *Unconditional volatility.*

Description

Method returning the unconditional volatility of the process.

Usage

```
UncVol(object, ...)

## S3 method for class 'MSGARCH_SPEC'
UncVol(object, par = NULL, ctr = list(), ...)

## S3 method for class 'MSGARCH_ML_FIT'
UncVol(object, ctr = list(), ...)

## S3 method for class 'MSGARCH_MCMC_FIT'
UncVol(object, ctr = list(), ...)
```

Arguments

object	Model specification of class MSGARCH_SPEC created with CreateSpec or fit object of type MSGARCH_ML_FIT created with FitML or MSGARCH_MCMC_FIT created with FitMCMC.
...	Not used. Other arguments to UncVol.
par	Vector (of size d) or matrix (of size nmcmc x d) of parameter estimates where d must have the same length as the default parameters of the specification.
ctr	A list of control parameters: • nsim (integer >= 0) : Number of simulations used for the estimation of the unconditional volatility. (Default: nsim = 250L) • nahead (integer >= 0) : Number of step ahead performed to estimate the unconditional volatility .(Default: nahead = 5000L) • nburn (integer >= 0) : Number of discarded step to estimate the unconditional volatility. (Default: nburn = 1000L)

Details

If a matrix of MCMC posterior draws is given, the Bayesian unconditional volatility is calculated. The unconditional volatility is estimated by first simulating `nsim` paths up to `nburn + nahead`, calculating a forecast of the conditional volatility at each step ahead, discarding the first `nburn` step ahead conditional volatilities forecasts, and computing the mean of the remaining `nahead - nburn` conditional volatilites forecasts. This method is based on the fact that the conditional volatility forecast will converge to the unconditional volatilty the further the forecast his from the starting point. We take the average as a way to remove the noise that comes with the simulation process. Overall, this method allows to compute the unconditional volatilty complex models.

Value

A `scalar` of unconditional volatility.

Examples

```
# create specification
spec <- CreateSpec()

## Not run:
# unconditional volatility from specification
par <- c(0.1, 0.1, 0.8, 0.2, 0.1, 0.8, 0.99, 0.01)
UncVol(object = spec, par = par)

# load data
data("SMI", package = "MSGARCH")

# unconditional volatility from ML fit
fit <- FitML(spec = spec, data = SMI)
UncVol(object = fit)
var(SMI)

# unconditional volatility from MCMC fit
set.seed(1234)
fit <- FitMCMC(spec = spec, data = SMI)
UncVol(object = fit)

## End(Not run)
```

`Volatility` *Volatility filtering.*

Description

Method returning the in-sample conditional volatility.

Usage

```
Volatility(object, ...)

## S3 method for class 'MSGARCH_SPEC'
Volatility(object, par, data, ...)

## S3 method for class 'MSGARCH_ML_FIT'
Volatility(object, newdata = NULL, ...)

## S3 method for class 'MSGARCH_MCMC_FIT'
Volatility(object, newdata = NULL, ...)
```

Arguments

object	Model specification of class MSGARCH_SPEC created with CreateSpec or fit object of type MSGARCH_ML_FIT created with FitML or MSGARCH_MCMC_FIT created with FitMCMC.
...	Not used. Other arguments to Volatility.
par	Vector (of size d) or matrix (of size nmcmc x d) of parameter estimates where d must have the same length as the default parameters of the specification.
data	Vector (of size T) of observations.
newdata	Vector (of size T*) of new observations. (Default newdata = NULL)

Details

If a matrix of MCMC posterior draws is given, the Bayesian predictive conditional volatility is calculated.

Value

In-sample condititional volatility (vector of size T + T*) of class MSGARCH_CONDVOL.
The MSGARCH_CONDVOL class contains the plot method.

Examples

```
# create specification
spec <- CreateSpec()

# load data
data("SMI", package = "MSGARCH")

# in-sample volatility from specification
par <- c(0.1, 0.1, 0.8, 0.2, 0.1, 0.8, 0.99, 0.01)
vol <- Volatility(object = spec, par = par, data = SMI)
head(vol)
plot(vol)

# in-sample volatility from ML fit
fit <- FitML(spec = spec, data = SMI)
```

```
vol <- Volatility(object = fit)
head(vol)
plot(vol)

## Not run:
# in-sample volatility from MCMC fit
set.seed(1234)
fit <- FitMCMC(spec = spec, data = SMI)
vol <- Volatility(object = fit)
head(vol)
plot(vol)

## End(Not run)
```

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