

# Package ‘MSGARCH’

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**Type** Package

**Title** Markov-Switching GARCH Models

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**Description** The MSGARCH package offers methods to fit (by Maximum Likelihood or MCMC/Bayesian), simulate, and forecast various Markov-Switching GARCH models as described in Ardia et al. (2017) <<https://ssrn.com/abstract=2845809>>.

**License** GPL (>= 2)

**BugReports** <https://github.com/keblu/MSGARCH/issues>

**URL** <https://github.com/keblu/MSGARCH>

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

**LinkingTo** Rcpp, RcppArmadillo

**Suggests** mcmc, testthat

**RoxygenNote** 6.0.1

**NeedsCompilation** yes

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MSGARCH-package	<i>The R package MSGARCH</i>
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## 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. (2017) <https://ssrn.com/abstract=2845809> for a detailed introduction of the package and its usage.

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## References

- Ardia, D. Bluteau, K. Boudt, K. Catania, L. & Trottier, D.-A. (2017). Markov-switching GARCH models in R: The **MSGARCH** package. <https://ssrn.com/abstract=2845809>
- Eddelbuettel, D. & Francois, R. (2011). **Rcpp**: Seamless R and C++ integration. *Journal of Statistical Software*, 40, 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, 1054-1063. <http://dx.doi.org/10.1016/j.csda.2013.02.005>
- Haas, M. Mittnik, S. & Paoletta, M. S. (2004). A new approach to Markov-switching GARCH models. *Journal of Financial Econometrics*, 2, 493-530. <http://doi.org/10.1093/jjfinec/nbh020>
- Haas, M. Mittnik, S. & Paoletta, M. S. (2004b). Mixed normal conditional heteroskedasticity. *Journal of Financial Econometrics*, 2, 211-250. <http://doi.org/10.1093/jjfinec/nbh009>

## See Also

Useful links:

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

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AIC	<i>Akaike information criterion (AIC).</i>
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## Description

Method which computes the Akaike information criterion (AIC) from a fit object of type MSGARCH\_ML\_FIT created with [FitML](#) or MSGARCH\_MCMC\_FIT created with [FitMCMC](#).

## Usage

```
AIC(fit)

## S3 method for class 'MSGARCH_ML_FIT'
AIC(fit)

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

## Arguments

fit	Fit object of type MSGARCH_ML_FIT created with <a href="#">FitML</a> or MSGARCH_MCMC_FIT created with <a href="#">FitMCMC</a> .
-----	---

## Details

Computes the Akaike information criterion (AIC) based on the work of Akaike (Akaike, 1974). If a matrix of MCMC posterior draws 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, 716-723.

**Examples**

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

# create model specification
# MS(2)-GARCH(1,1)-Normal (default)
spec <- CreateSpec()

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

# compute AIC
AIC(fit)
```

---

BIC

*Bayesian information criterion (BIC).*


---

**Description**

Method which computes the Bayesian information criterion (BIC) from a fit object of type MSGARCH\_ML\_FIT created with [FitML](#) or MSGARCH\_MCMC\_FIT created with [FitMCMC](#).

**Usage**

```
BIC(fit)

## S3 method for class 'MSGARCH_ML_FIT'
BIC(fit)

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

**Arguments**

**fit** Fit object of type MSGARCH\_ML\_FIT created with [FitML](#) or MSGARCH\_MCMC\_FIT created with [FitMCMC](#)

**Details**

Computes the Bayesian information criterion (BIC) based on the work of Schwarz (Schwarz, 1978). If a matrix of MCMC posterior draws is given, the BIC on the posterior mean is calculated.

**Value**

BIC value.

**References**

Schwarz, G. (1978). Estimating the dimension of a model. *Annals of Statistics*, 6, 461-464.

**Examples**

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

# create model specification
# MS(2)-GARCH(1,1)-Normal (default)
spec <- CreateSpec()

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

# compute BIC
BIC(fit)
```

---

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 regime 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 `constraint.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 `constraint.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-regimes 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. (2017) for more details on the models and distributions.

The user must choose between `fixed` or `regime.const` in `constraint.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 inputted prior mean and standard deviation. Those prior means and standard deviations that are not set will take on preset default values.

## 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 inputted fixed parameters.
- `regime.const.pars`: Vector of user inputted parameter set equal across regimes.
- `regime.fixed.pars`: Logical indicating if there is any fixed parameter set by the user.
- `regime.const.pars.bool`: Logical indicating if there is any parameters equal across regime set by the user.

The `MSGARCH_SPEC` class has the following methods:

- [Sim](#): Simulation method.
- [Volatility](#): In-sample conditional volatility filtering of the overall process.
- [Forecast](#): Forecast of the conditional volatility of the overall process.
- [UncVol](#): Unconditional volatility in each regime and the overall process.
- [Pred](#): Predictive method.
- [PIT](#): Probability Integral Transform.
- [Risk](#): Value-at-Risk and Expected-Shortfall methods.
- [State](#): State probabilities method (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. (2017). Markov-switching GARCH models in R: The MSGARCH package. <https://ssrn.com/abstract=2845809>
- 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.
- Fernandez, C. & Steel, M. F. (1998). On Bayesian modeling of fat tails and skewness. *Journal of the American Statistical Association*, 93, 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, 1779-1801.
- Haas, M. Mittnik, S. & Paoletta, M. S. (2004a). A new approach to Markov-switching GARCH models. *Journal of Financial Econometrics*, 2, 493-530.
- Haas, M. Mittnik, S. & Paoletta, M. S. (2004b). Mixed normal conditional heteroskedasticity. *Journal of Financial Econometrics*, 2, 211-250.
- 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.

## 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.
- 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.

---

DIC	<i>Deviance Information Criterion (DIC).</i>
-----	--

---

### 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

### Examples

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

# create model specification
# MS(2)-GARCH(1,1)-Normal (default)
spec <- CreateSpec()

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

# compute DIC
DIC(fit)
```

---

ExtractStateFit	<i>Single-regime model extractor.</i>
-----------------	---------------------------------------

---

**Description**

Extracts each regime from a fitted multiple regime specification 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 with K element where each element is a fit object of type MSGARCH\_ML\_FIT or MSGARCH\_MCMC\_FIT.

**Examples**

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

# create model specification
# MS(2)-GARCH(1,1)-Normal (default)
spec <- CreateSpec()

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

---

FitMCMC	<i>MCMC/Bayesian estimation.</i>
---------	----------------------------------

---

**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 <a href="#">CreateSpec</a> .
data	Vector (of size T) of observations.
ctr	A list of control parameters: <ul style="list-style-type: none"> <li>• 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*).</li> <li>• n.burn (integer &gt;= 0): Number of discarded draws. (Default: n.burn = 5000L)</li> <li>• n.mcmc (integer &gt; 0): Number of draws. (Default: n.mcmc = 10000L)</li> <li>• n.thin (integer &gt; 0): Thinning factor (every N.thin draws are kept). (Default: n.thin = 10L)</li> <li>• SamplerFUN: Custom MCMC sampler (see *Details*).</li> </ul>

## Details

The total number of draws is equal to  $n.mcmc / n.thin$ . The MCMC/Bayesian estimation relies on the package **adaptMCMC** (Andreas, 2012) which implements the adaptive sampler of Vihola (2012). Starting values when par0 is not provided are chosen automatically before sampling (see Ardia et al. (2016) 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.

## 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  $N.mcmc / N.thin \times d$ ).
- accept: Acceptation 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:

- [AIC](#): Compute Akaike information criterion (AIC).
- [BIC](#): Compute Bayesian information criterion (BIC).
- [DIC](#): Compute Deviance Information Criterion (DIC).
- [Volatility](#): In-sample conditional volatility filtering of the overall process.
- [Forecast](#): Forecast of the conditional volatility of the overall process.
- [UncVol](#): Unconditional volatility in each regime and the overall process.
- [Pred](#): Predictive method.
- [PIT](#): Probability integral transform.

- **Risk**: Value-at-Risk And Expected-Shortfall methods.
- **Sim**: Simulation method.
- **State**: State probabilities methods.
- **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. (2016). Markov-switching GARCH models in R: The MSGARCH package. <https://ssrn.com/abstract=2845809>
- 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.

## Examples

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

# create model specification
# MS(2)-GARCH(1,1)-Normal (default)
spec <- CreateSpec()

# fit the model on the data by MCMC
set.seed(123)
fit <- FitMCMC(spec = spec, data = SMI, ctr = list(n.burn = 500L, n.mcmc = 500L, n.thin = 1L,
                                                  do.adapt = TRUE, acc.rate = 0.4))
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$n.mcmc + ctr$n.burn,
                     data = data, spec = spec)$batch
  return(par)
}

set.seed(123)
fit <- FitMCMC(spec, data = SMI, ctr = list(SamplerFun = f_MCMC,
                                          n.burn = 500L, n.mcmc = 500L))
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 <a href="#">CreateSpec</a> .   |
| data | Vector (of size T) of observations.   |
| ctr  | <p>A list of control parameters:</p> <ul style="list-style-type: none"> <li>• 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*).</li> <li>• do.se Logical. Should standard errors be computed? (Default: do.se = TRUE).</li> <li>• 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 constraint.spec of <a href="#">CreateSpec</a>, do.plm = TRUE is used. (Default: do.plm = FALSE)</li> <li>• OptimFUN: Custom optimization function (see *Details*).</li> </ul> |

**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. (2016) 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  $d \times 4$ ) with optimal parameter estimates, standard errors, t-stats, and p-values. `Hessian` is the Hessian (matrix of size  $d \times d$ ) 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](#): Compute Akaike information criterion (AIC).
- [BIC](#): Compute Bayesian information criterion (BIC).
- [Volatility](#): In-sample conditional volatility filtering of the overall process.
- [Forecast](#): Forecast of the conditional volatility of the overall process.
- [UncVol](#): Unconditional volatility in each regime and the overall process.
- [Pred](#): Predictive method.
- [PIT](#): Probability Integral Transform.
- [Risk](#): Value-at-Risk and Expected-Shortfall methods.
- [Sim](#): Simulation method.
- [State](#): State probabilities methods.
- [ExtractStateFit](#): Single-regime model extractor.
- `summary`: Summary of the fit.

## Examples

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

# create model specification
# MS(2)-GARCH(1,1)-Normal (default)
spec <- CreateSpec()

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

# custom optimizer example
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)
```

---

Forecast	<i>Forecasting method.</i>
----------	----------------------------

---

## Description

Method returning conditional volatility forecasts and density forecasts of the process.

## Usage

```
Forecast(object, ...)

## S3 method for class 'MSGARCH_SPEC'
Forecast(object, par, data, n.ahead = 1L,
  do.return.draw = FALSE, ctr = list(), ...)

## S3 method for class 'MSGARCH_ML_FIT'
Forecast(object, new.data = NULL, n.ahead = 1L,
  do.return.draw = FALSE, ctr = list(), ...)

## S3 method for class 'MSGARCH_MCMC_FIT'
Forecast(object, new.data = NULL, n.ahead = 1L,
  do.return.draw = FALSE, ctr = list(), ...)
```

## Arguments

object	Model specification of class MSGARCH_SPEC created with <a href="#">CreateSpec</a> or fit object of type MSGARCH_ML_FIT created with <a href="#">FitML</a> or MSGARCH_MCMC_FIT created with <a href="#">FitMCMC</a> .
...	Not used. Other arguments to Forecast.
par	Vector (of size d) or matrix (of size n.mcmc 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.
n.ahead	Scalar indicating the number of step-ahead evaluation.
do.return.draw	Are the sampled simulation draws returned? (Default do.return.draw = FALSE)
ctr	A list of control parameters: <ul style="list-style-type: none"> <li>• n.sim (integer &gt;= 0): Number indicating the number of simulation done for the conditional volatility forecast at n.ahead &gt; 1. (Default: n.sim = 10000L)</li> </ul>
new.data	Vector (of size T*) of new observations. (Default new.data = NULL)

## Details

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



**Value**

A list of class MSGARCH\_CONDVOL with the following elements:

- vol: Conditional volatility Forecast (vector of size n.ahead).
- draw: If do.return.draw = TRUE:  
Draws sample from the predictive distributions (matrix of size n.ahead x n.sim).  
If do.return.draw = FALSE: NULL

The MSGARCH\_FORECAST class contains the plot method.

**Examples**

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

# create model specification
# MS(2)-GARCH(1,1)-Normal (default)
spec <- CreateSpec()

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

# compute the In-sample conditional volatility from the fitted model
forecast <- Forecast(object = fit, n.ahead = 5L)
plot(forecast)
```

---

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, n.ahead = 1L, ctr = list(), ...)
```

```
## S3 method for class 'MSGARCH_ML_FIT'
PIT(object, x = NULL, new.data = NULL,
     do.norm = TRUE, do.its = FALSE, n.ahead = 1L, ctr = list(), ...)
```

```
## S3 method for class 'MSGARCH_MCMC_FIT'
PIT(object, x = NULL, new.data = NULL,
     do.norm = TRUE, do.its = FALSE, n.ahead = 1L, ctr = list(), ...)
```

## Arguments

<code>object</code>	Model specification of class <code>MSGARCH_SPEC</code> created with <a href="#">CreateSpec</a> or fit object of type <code>MSGARCH_ML_FIT</code> created with <a href="#">FitML</a> or <code>MSGARCH_MCMC_FIT</code> created with <a href="#">FitMCMC</a> .
<code>...</code>	Not used. Other arguments to <code>PIT</code> .
<code>x</code>	Vector (of size <code>n</code> ). Used when <code>do.its = FALSE</code> .
<code>par</code>	Vector (of size <code>d</code> ) or matrix (of size <code>n.mcmc x d</code> ) of parameter estimates where <code>d</code> must have the same length as the default parameters of the specification.
<code>data</code>	Vector (of size <code>T</code> ) of observations.
<code>do.norm</code>	Logical indicating if the PIT values are transformed into standard Normal variate. (Default: <code>do.norm = FALSE</code> )
<code>do.its</code>	Logical indicating if the in-sample PIT is returned. (Default: <code>do.its = FALSE</code> )
<code>n.ahead</code>	Scalar indicating the number of step-ahead evaluation. Valid only when <code>do.its = FALSE</code> . (Default: <code>n.ahead = 1L</code> )
<code>ctr</code>	A list of control parameters: <ul style="list-style-type: none"> <li><code>n.sim</code> (integer <math>\geq 0</math>): Number indicating the number of simulation done for the evaluation of the PIT at <code>n.ahead &gt; 1</code>. (Default: <code>n.sim = 10000L</code>)</li> </ul>
<code>new.data</code>	Vector (of size <code>T*</code> ) of new observations. (Default <code>new.data = NULL</code> )

## 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 `n.sim` paths up to  $t = T + T^* + n.ahead$ . The empirical probability integral transforms is then inferred from these simulations.

If `do.its = FALSE`, the vector `x` are evaluated as  $t = T + T^* + 1, \dots, t = T + T^* + n.ahead$  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

$t = T + T^* + 1, \dots, t = T + T^* + n.ahead$  or Normal variate derived from the probability integral transform of `x` (matrix of size `n.ahead 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  $(T + T^*) \times n$ ).

## Examples

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

# create model specification
# MS(2)-GARCH(1,1)-Normal (default)
```

```

spec <- CreateSpec()

# 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 <- Sim(object = spec, par = fit$par, n.ahead= 1000L, n.sim = 1L)
sim.series <- as.vector(sim.series$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)

```

---

Pred

*Predictive density.*


---

## Description

Method returning the predictive probability density.

## Usage

```

Pred(object, ...)

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

## S3 method for class 'MSGARCH_ML_FIT'
Pred(object, x = NULL, new.data = NULL,
      log = FALSE, do.its = FALSE, n.ahead = 1L, ctr = list(), ...)

## S3 method for class 'MSGARCH_MCMC_FIT'
Pred(object, x = NULL, new.data = NULL,
      log = FALSE, do.its = FALSE, n.ahead = 1L, ctr = list(), ...)

```

## Arguments

object	Model specification of class MSGARCH_SPEC created with <a href="#">CreateSpec</a> or fit object of type MSGARCH_ML_FIT created with <a href="#">FitML</a> or MSGARCH_MCMC_FIT created with <a href="#">FitMCMC</a> .
...	Not used. Other arguments to Pred.
x	Vector (of size n). Used when do.its = FALSE.

<code>par</code>	Vector (of size <code>d</code> ) or matrix (of size <code>n.mcmc x d</code> ) of parameter estimates where <code>d</code> must have the same length as the default parameters of the specification.
<code>data</code>	Vector (of size <code>T</code> ) of observations.
<code>log</code>	Logical indicating if the log-density is returned. (Default: <code>log = FALSE</code> )
<code>do.its</code>	Logical indicating if the in-sample predictive is returned. (Default: <code>do.its = FALSE</code> )
<code>n.ahead</code>	Scalar indicating the number of step-ahead evaluation. Valid only when <code>do.its = FALSE</code> . (Default: <code>n.ahead = 1L</code> )
<code>ctr</code>	A list of control parameters: <ul style="list-style-type: none"> <li><code>n.sim</code> (integer <math>\geq 0</math>) : Number indicating the number of simulation done for the evaluation of the density at <code>n.ahead &gt; 1</code>. (Default: <code>n.sim = 10000L</code>)</li> </ul>
<code>new.data</code>	Vector (of size <code>T*</code> ) of new observations. (Default <code>new.data = NULL</code> )

### 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 `n.sim` paths up to  $t = T + T^* + n.ahead$ . The predictive distribution are then inferred from these simulations via a Gaussian Kernel density. If `do.its = FALSE`, the vector `x` are evaluated as  $t = T + T^* + 1, \dots, t = T + T^* + n.ahead$  realization.

If `do.its = TRUE` and `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 predictive density ((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  $t = T + T^* + 1, \dots, t = T + T^* + n.ahead$  (matrix of size `n.ahead 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

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

# create model specification
# MS(2)-GARCH(1,1)-Normal (default)
spec <- CreateSpec()

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

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

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

# run pred method on mesh at T + 1
pred.x <- Pred(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),
      do.es = TRUE, do.its = FALSE, n.ahead = 1L, ctr = list(), ...)

## S3 method for class 'MSGARCH_ML_FIT'
Risk(object, new.data = NULL, alpha = c(0.01,
    0.05), do.es = TRUE, do.its = FALSE, n.ahead = 1L, ctr = list(), ...)

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

**Arguments**

<code>object</code>	Model specification of class <code>MSGARCH_SPEC</code> created with <a href="#">CreateSpec</a> or fit object of type <code>MSGARCH_ML_FIT</code> created with <a href="#">FitML</a> or <code>MSGARCH_MCMC_FIT</code> created with <a href="#">FitMCMC</a> .
<code>...</code>	Not used. Other arguments to <code>Risk</code> .
<code>par</code>	Vector (of size <code>d</code> ) or matrix (of size <code>n.mcmc x d</code> ) of parameter estimates where <code>d</code> must have the same length as the default parameters of the specification.
<code>data</code>	Vector (of size <code>T</code> ) of observations.
<code>alpha</code>	Vector (of size <code>R</code> ) of Value-at-risk and Expected-shortfall levels. (Default: <code>alpha = c(0.01, 0.05)</code> )
<code>do.es</code>	Logical indicating if Expected-shortfall is also calculated. (Default: <code>do.es = TRUE</code> )
<code>do.its</code>	Logical indicating if the in-sample risk estimators are returned. (Default: <code>do.its = FALSE</code> )
<code>n.ahead</code>	Scalar indicating the number of step-ahead evaluation. (Default: <code>n.ahead = 1L</code> )
<code>ctr</code>	A list of control parameters: <ul style="list-style-type: none"> <li>• <code>n.mesh</code> (integer <math>\geq 0</math>) : Number of points for density evaluation. (Default: <code>n.mesh = 1000L</code>)</li> <li>• <code>n.sim</code> (integer <math>\geq 0</math>) : Number indicating the number of simulation done for estimation of the density at <code>n.ahead &gt; 1</code>. (Default: <code>n.sim = 10000L</code>)</li> </ul>
<code>new.data</code>	Vector (of size <code>T*</code> ) of new observations. (Default <code>new.data = NULL</code> )

**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 `n.sim` paths up to  $t = T + T^* + n.ahead$ . If `do.its = FALSE`, the risk estimators at  $t = T + T^* + 1, \dots, t = T + T^* + n.ahead$  are computed.

## Value

A list of class MSGARCH\_RISK with the following elements:

- VaR:  
If `do.its = FALSE`: Value-at-Risk at  $t = T + T^* + 1, \dots, t = T + T^* + n.ahead$  at the chosen levels (matrix of size `n.ahead` 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  $t = T + T^* + 1, \dots, t = T + T^* + n.ahead$  at the chosen levels (matrix of size `n.ahead` 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

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

# create model specification
# MS(2)-GARCH(1,1)-Normal (default)
spec <- CreateSpec()

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

# compute the Value-at-Risk and Expected-shortfall in-sample
risk.its <- Risk(object = fit, alpha = 0.05, do.es = FALSE, do.its = TRUE)
plot(risk.its)

# compute the one-step ahead Value-at-Risk and Expected-shortfall out-of-sample
Risk(object = fit, alpha = 0.05, do.es = FALSE, do.its = FALSE, n.ahead = 1L)
```

---

Sim

*Simulation of MSGARCH processes.*

---

## Description

Method for simulating MSGARCH processes.

## Usage

```
Sim(object, ...)
```

## S3 method for class 'MSGARCH\_SPEC'

```
Sim(object, data = NULL, n.ahead = 1L, n.sim = 1L,
     par = NULL, n.burnin = 500L, ...)
```

## S3 method for class 'MSGARCH\_ML\_FIT'

```
Sim(object, new.data = NULL, n.ahead = 1L,
```

```

n.sim = 1L, n.burnin = 500L, ...)

## S3 method for class 'MSGARCH_MCMC_FIT'
Sim(object, new.data = NULL, n.ahead = 1L,
     n.sim = 1L, n.burnin = 500L, ...)

```

### Arguments

<code>object</code>	Model specification of class <code>MSGARCH_SPEC</code> created with <a href="#">CreateSpec</a> or fit object of type <code>MSGARCH_ML_FIT</code> created with <a href="#">FitML</a> or <code>MSGARCH_MCMC_FIT</code> created with <a href="#">FitMCMC</a> .
<code>...</code>	Not used. Other arguments to <code>Sim</code> .
<code>data</code>	Vector (of size <code>T</code> ) of observations for filtering.
<code>n.ahead</code>	Simulation length. (Default: <code>n.ahead = 1L</code> )
<code>n.sim</code>	Number of simulations. (Default: <code>n.sim = 1L</code> )
<code>par</code>	Vector (of size <code>d</code> ) or matrix (of size <code>n.ahead x d</code> ) of parameter estimates where <code>d</code> must have the same length as the default parameters of the specification.
<code>n.burnin</code>	Burnin period discarded (first simulation draws). Not used when data is provided. (Default: <code>n.burnin = 500L</code> )
<code>new.data</code>	Vector (of size <code>T*</code> ) of new observations.. (Default <code>new.data = NULL</code> )

### Details

If a matrix of parameters estimates is provided, `n.sim` simulations will be done for each row.. When data is provided, the conditional variance and state probability are update up to time  $T + T^* + 1$  before beginning the simulations. If `data = NULL`, new simulations will start from scratch where the first `n.burnin` simulation will be discarded. Passing a `MSGARCH_ML_FIT` or `MSGARCH_MCMC_FIT` object will automatically filter the corresponding data in the object and start the simulation ahead of data.

### Value

A list of class `MSGARCH_SIM` with the following elements:.

- `draw`: Matrix (of size `n.ahead x n.sim`) of simulated draws.
- `state`: Matrix (of size `n.ahead x n.sim`) of simulated states.
- `CondVol`: Array (of size `n.ahead x n.sim x K`) of simulated conditional volatility.

The `MSGARCH_SIM` class contains the `plot` method.

### Examples

```

# create model specification
# MS(2)-GARCH(1,1)-Normal (default)
spec <- CreateSpec()

# generate process
par.sim <- c(0.1,0.6,0.2,0.2,0.8,0.1,0.99,0.01)
set.seed(123)
sim <- Sim(object = spec, n.ahead = 1000L, n.sim = 1L, par = par.sim, n.burnin = 500L)
plot(sim)

```

```
# generate process after filtering for fitted model
# load data
data("SMI", package = "MSGARCH")

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

set.seed(123)
sim <- Sim(fit, n.ahead = 30L, n.sim = 1000L)
plot(sim)
```

---

SMI	<i>Swiss market index dataset</i>
-----	-----------------------------------

---

### 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. <http://www.jstatsoft.org/v40/i06/>

---

State	<i>State probabilities.</i>
-------	-----------------------------

---

### Description

Method returning the filtered, predictive, 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, new.data = NULL, ...)

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

**Arguments**

object	Model specification of class MSGARCH_SPEC created with <a href="#">CreateSpec</a> or fit object of type MSGARCH_ML_FIT created with <a href="#">FitML</a> or MSGARCH_MCMC_FIT created with <a href="#">FitMCMC</a> .
...	Not used. Other arguments to State.
par	Vector (of size d) or matrix (of size n.mcmc 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.
new.data	Vector (of size T*) of new observations. (Default new.data = 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  $(T + T^*) \times (n.mcmc \text{ or } 1) \times K$ ).
- PredProb: Predictive probabilities (array of size  $(T + T^* + 1) \times (n.mcmc \text{ or } 1) \times K$ ).
- SmoothProb: Smoothed probabilities (array of size  $(T + T^* + 1) \times (n.mcmc \text{ or } 1) \times K$ ).
- Viterbi: Most likely path (matrix of size  $(T + T^*) \times (n.mcmc \text{ or } 1)$ ).

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**

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

# create model specification
# MS(2)-GARCH(1,1)-Normal (default)
spec <- CreateSpec()

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

```
# compute the filtered state probabilities
state <- State(object = fit)
plot(state, type.prob = "smoothed")
plot(state, type.prob = "predictive")
plot(state, type.prob = "filtered")
plot(state, type.prob = "viterbi")
```

TransMat

*Transition matrix.*

## Description

Method returning the transition matrix.

## Usage

```
TransMat(object, ...)
```

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

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

## Arguments

object	Model specification of class MSGARCH_SPEC created with <a href="#">CreateSpec</a> or fit object of type MSGARCH_ML_FIT created with <a href="#">FitML</a> .
...	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.
n.ahead	Number of steps ahead. (Default: n.ahead = 1L)

## Value

A matrix (of size  $K \times K$ ) 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

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

# create model specification
# MS(2)-GARCH(1,1)-Normal (default)
spec <- CreateSpec()

# 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, n.ahead = 10)
print(trans.mat)
```

---

UncVol	<i>Unconditional volatility.</i>
--------	----------------------------------

---

## Description

Method returning the unconditional volatility of the process in each state and for the overall 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 <a href="#">CreateSpec</a> or fit object of type MSGARCH_ML_FIT created with <a href="#">FitML</a> or MSGARCH_MCMC_FIT created with <a href="#">FitMCMC</a> .
...	Not used. Other arguments to TransMat.
par	Vector (of size d) or matrix (of size n.mcmc 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: <ul style="list-style-type: none"> <li>• n.sim (integer &gt;= 0) : Number indicating the number of simulation done for estimation of the unconditional volatility. (Default: n.sim = 250L)</li> <li>• n.ahead (integer &gt;= 0) : Number indicating the number of step ahead performs to estimate the unconditional volatility .(Default: n.ahead = 5000L)</li> <li>• n.burn (integer &gt;= 0) : Number indicating the number of discarded step ahead to estimate the unconditional volatility. (Default: n.burn = 1000L)</li> </ul>

## Details

If a matrix of MCMC posterior draws is given, the Bayesian unconditional volatility are calculated. The unconditional volatility is estimated by first simulating n.sim paths up to n.burn + n.ahead, calculating a forecast of the conditional volatility at each step ahead, discarding the first n.burn step ahead conditional volatilities forecasts, and computing the mean of the remaining n.ahead - n.burn conditional volatilities forecasts. This method is based on the fact that the conditional volatility forecast will converge to the unconditional volatility the further the forecast is 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 volatility of arbitrarily complex models.

## Value

A scalar corresponding to the process unconditional volatility.

**Examples**

```
# create model specification
# MS(2)-GARCH(1,1)-Normal (default)
spec <- CreateSpec()

# compute the unconditional volatility of each regime and the overall process
## Not run:
par <- c(0.1, 0.1, 0.8, 0.2, 0.1, 0.8, 0.99, 0.01)
UncVol(object = spec, par = par)

## End(Not run)
```

---

Volatility

*Volatility filtering.*


---

**Description**

Method returning the conditional volatility of the process.

**Usage**

```
Volatility(object, ...)

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

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

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

**Arguments**

object	Model specification of class MSGARCH_SPEC created with <a href="#">CreateSpec</a> or fit object of type MSGARCH_ML_FIT created with <a href="#">FitML</a> or MSGARCH_MCMC_FIT created with <a href="#">FitMCMC</a> .
...	Not used. Other arguments to Volatility.
par	Vector (of size d) or matrix (of size n.mcmc 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.
new.data	Vector (of size T*) of new observations. (Default new.data = NULL)

**Details**

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

**Value**

Conditional volatility (vector of size T + T\*) of class MSGARCH\_CONDVOL.  
The MSGARCH\_CONDVOL class contains the plot method.

**Examples**

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

# create model specification
# MS(2)-GARCH(1,1)-Normal (default)
spec <- CreateSpec()

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

# compute the In-sample conditional volatility from the fitted model
cond.vol <- Volatility(object = fit)
plot(cond.vol)
```

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