Package 'MSTest'

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Title Hypothesis Testing for Markov Switching Models

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Description Implementation of hypothesis testing procedures described in Hansen (1992) <doi:10.1002/jae.3950070506>, Carrasco, Hu, & Ploberger (2014) <doi:10.3982/ECTA8609>, Dufour & Luger (2017) <doi:10.1080/07474938.2017.1307548>, and Rodriguez Rondon & Dufour (2024) <https://grodriguezrondon.com/files/RodriguezRondon_Dufour_2024_MonteCarlo_LikelihoodRatioTest_MarkovSwitchingModels_20241015.pdf> that can be used to identify the number of regimes in Markov switching models.

License GPL (>= 2)

LazyData TRUE

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URL https://github.com/roga11/MSTest

BugReports https://github.com/roga11/MSTest/issues

Imports stats, rlang, nloptr, Rcpp (>= 1.0.1), numDeriv, pracma, foreach, GenSA, pso, GA, graphics

LinkingTo Rcpp, RcppArmadillo

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NeedsCompilation yes

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Contents

MSTest-package   *Testing Markov Switching Models*

Description

This package implements hypothesis testing procedures that can be used to identify the number of regimes in a Markov-Switching model.

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References

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ARmdl   *Autoregressive Model*

Description

This function estimates an autoregresive model with p lags. This can be used for the null hypothesis of a linear model against an alternative hypothesis of a Markov switching autoregressive model with k regimes.

Usage

```
ARmdl(Y, p, control = list())
```

Arguments

Y	A (T x 1) matrix of observations.
p	Integer determining the number of autoregressive lags.
control	List with model options including:

- const: Boolean determining whether to estimate model with constant if TRUE or not if FALSE. Default is TRUE.
- getSE: Boolean determining whether to compute standard errors of parameters if TRUE or not if FALSE. Default is TRUE.

Value

List of class ARmdl (S3 object) with model attributes including:

- y: a (T-p x 1) matrix of observations.
- X: a (T-p x p + const) matrix of lagged observations with a leading column of 1s if const=TRUE or not if const=FALSE.
- x: a (T-p x p) matrix of lagged observations.
- fitted: a (T-p x 1) matrix of fitted values.
- resid: a (T-p x 1) matrix of residuals.
- mu: estimated mean of the process.
- beta: a ((1 + p) x 1) matrix of estimated coefficients.
- intercept: estimate of intercept.
- phi: estimates of autoregressive coefficients.
- stdev: estimated standard deviation of the process.
- sigma: estimated variance of the process.
- theta: vector containing: mu, sigma, and phi.
- theta_mu_ind: vector indicating location of mean with 1 and 0 otherwise.
- theta_sig_ind: vector indicating location of variance with 1 and 0 otherwise.
- theta_var_ind: vector indicating location of variance with 1 and 0 otherwise. This is the same as theta_sig_ind in ARmdl.
- theta_phi_ind: vector indicating location of autoregressive coefficients with 1 and 0 otherwise.
- stationary: Boolean indicating if process is stationary if TRUE or non-stationary if FALSE.
- n: number of observations after lag transformation (i.e., n = T-p).
- p: number of autoregressive lags.
- q: number of series. This is always 1 in ARmdl.
- k: number of regimes. This is always 1 in ARmdl.
- control: List with model options used.
- logLike: log-likelihood.
- AIC: Akaike information criterion.
- BIC: Bayesian (Schwarz) information criterion.

- Hess: Hessian matrix. Approximated using [hessian](#) and only returned if getSE=TRUE.

- info_mat: Information matrix. Computed as the inverse of -Hess. If matrix is not PD then nearest PD matrix is obtained using [nearest_spd](#). Only returned if getSE=TRUE.

- nearPD_used: Boolean determining whether nearPD function was used on info_mat if TRUE or not if FALSE. Only returned if getSE=TRUE.

- theta_se: standard errors of parameters in theta. Only returned if getSE=TRUE.

See Also

[MSARmdl](#)

Examples

```
set.seed(1234)
# Define DGP of AR process
mdl_ar <- list(n     = 500,
               mu    = 5,
               sigma = 2,
               phi   = c(0.5,0.2))

# Simulate process using simuAR() function
y_simu <- simuAR(mdl_ar)

# Set options for model estimation
control <- list(const = TRUE,
                getSE = TRUE)

# Estimate model
y_ar_mdl <- ARmdl(y_simu$y, p = 2, control)
y_ar_mdl
```

ARXmdl   *Autoregressive X Model*

Description

This function estimates an ARX model with p lags. This can be used for the null hypothesis of a linear model against an alternative hypothesis of a Markov switching autoregressive model with k regimes.

Usage

```
ARXmdl(Y, p, Z, control = list())
```

Arguments

Y	A (T x 1) matrix of observations.
p	Integer determining the number of autoregressive lags.
Z	A (T x qz) matrix of exogenous regressors.
control	List with model options including:

- const: Boolean determining whether to estimate model with constant if TRUE or not if FALSE. Default is TRUE.
- getSE: Boolean determining whether to compute standard errors of parameters if TRUE or not if FALSE. Default is TRUE.

Value

List of class ARmdl (S3 object) with model attributes including:

- y: a (T-p x 1) matrix of observations.
- X: a (T-p x p + const) matrix of lagged observations with a leading column of 1s if const=TRUE or not if const=FALSE.
- x: a (T-p x p) matrix of lagged observations.
- fitted: a (T-p x 1) matrix of fitted values.
- resid: a (T-p x 1) matrix of residuals.
- mu: estimated mean of the process.
- beta: a ((1 + p + qz) x 1) matrix of estimated coefficients.
- betaZ: a (qz x q) matrix of estimated exogenous regressor coefficients.
- intercept: estimate of intercept.
- phi: estimates of autoregressive coefficients.
- stdev: estimated standard deviation of the process.
- sigma: estimated variance of the process.
- theta: vector containing: mu, sigma, and phi.
- theta_mu_ind: vector indicating location of mean with 1 and 0 otherwise.
- theta_sig_ind: vector indicating location of variance with 1 and 0 otherwise.
- theta_var_ind: vector indicating location of variance with 1 and 0 otherwise. This is the same as theta_sig_ind in ARmdl.
- theta_phi_ind: vector indicating location of autoregressive coefficients with 1 and 0 otherwise.
- stationary: Boolean indicating if process is stationary if TRUE or non-stationary if FALSE.
- n: number of observations after lag transformation (i.e., n = T-p).
- p: number of autoregressive lags.
- q: number of series. This is always 1 in ARmdl.
- k: number of regimes. This is always 1 in ARmdl.
- control: List with model options used.
- logLike: log-likelihood.

- AIC: Akaike information criterion.

- BIC: Bayesian (Schwarz) information criterion.

- Hess: Hessian matrix. Approximated using hessian and only returned if getSE=TRUE.

- info_mat: Information matrix. Computed as the inverse of -Hess. If matrix is not PD then nearest PD matrix is obtained using nearest_spd. Only returned if getSE=TRUE.

- nearPD_used: Boolean determining whether nearPD function was used on info_mat if TRUE or not if FALSE. Only returned if getSE=TRUE.

- theta_se: standard errors of parameters in theta. Only returned if getSE=TRUE.

See Also

MSARmdl

Examples

```
set.seed(1234)
# Define DGP of AR process
mdl_ar <- list(n     = 500,
               mu    = 5,
               sigma = 2,
               phi   = c(0.5,0.2))

# Simulate process using simuAR() function
y_simu <- simuAR(mdl_ar)

# Set options for model estimation
control <- list(const  = TRUE,
                getSE  = TRUE)

# Estimate model
y_ar_mdl <- ARmdl(y_simu$y, p = 2, control)
y_ar_mdl
```

---

chp10GNP   *Carrasco, Hu, & Ploberger 2010 GNP data*

Description

Carrasco, Hu, & Ploberger 2010 GNP data

Usage

```
chp10GNP
```

Format

This data is the extension of the GNP series used in CHP (2014), Econometrica. This series ranges from 1951Q2 to 2010Q4.

Vector of dates

DaNP US GNP series

GNP_gr log difference of US GNP series

Source

<https://www.econometricsociety.org/content/supplement-optimal-test-markov-switching-parameters>

References

Carrasco, Marine, Liang Hu, and Werner Ploberger. 2014. "Optimal test for Markov switching parameters." *Econometrica* 82 (2): 765–784.

CHPbootCV   *Bootstrap critical values for CHP 2014 parameter stability test*

Description

This bootstrap procedure is described on pg. 771 of CHP 2014.

Usage

```
CHPbootCV(mdl, rho_b, N, msvar)
```

Arguments

mdl	List containing model attributes (see [ARmdl](#)).
rho_b	Number determining bounds for distribution of rh0 (i.e. rho ~ [-rho_b,rho_b]).
N	Number of bootstrap simulations.
msvar	Boolean indicator. If TRUE, there is a switch in variance. If FALSE only switch in mean is considered.

Value

Bootstrap critical values

References

Carrasco, Marine, Liang Hu, and Werner Ploberger. 2014. "Optimal test for Markov switching parameters." *Econometrica* 82 (2): 765–784.

CHPTest   *Carrasco, Hu, and Ploberger (2014) parameter stability test*

Description

This function performs the CHP (2014) parameter stability test as outline in Carrasco, M., Hu, L. and Ploberger, W. (2014). Original source code can be found here.

Usage

```
CHPTest(Y, p, control = list())
```

Arguments

Y	A (T x 1) matrix of observations.
p	Integer determining the number of autoregressive lags.
control	List with test procedure options including:

- N: Integer determining the number of Bootstrap iterations. Default is set to 3000 as in paper.
- rho_b: Number determining bounds for distribution of rh0 (i.e. rho ~ [-rho_b,rho_b]).
- msvar: Boolean indicator. If TRUE, there is a switch in variance. If FALSE only switch in mean is considered.
- getSE: Boolean indicator. If TRUE, standard errors for restricted model are estimated. If FALSE no standard errors are estimated. Default is TRUE.

Value

List of class CHPTest (S3 object) with model attributes including:

- mdl_h0: List with restricted model attributes. This will be of class ARmdl (S3 object). See ARmdl.
- supTS: supTS test statistic value.
- expTS: expTS test statistic value.
- supTS_N: A (N x 1) vector with simulated supTS test statistics under null hypothesis.
- expTS_N: A (N x 1) vector with simulated expTS test statistics under null hypothesis.
- pval_supTS: P-value for supTS version of parameter stability test.
- pval_expTS: P-value for expTS version of parameter stability test.
- supTS_cv: Vector with 90%, 95%, and 99% bootstrap critical values for supTS version of parameter stability test.
- expTS_cv: Vector with 90%, 95%, and 99% bootstrap critical values for expTS version of parameter stability test.
- control: List with test procedure options used.

References

Carrasco, Marine, Liang Hu, and Werner Ploberger. 2014. "Optimal test for Markov switching parameters." *Econometrica* 82 (2): 765–784.

Examples

```
# load data used in Hamilton 1989
y84 <- as.matrix(hamilton84GNP$GNP_gr)


# Set test procedure options
control = list(N = 1000,
               rho_b = 0.7,
               msvar = FALSE)

# perform test with switch in mean only on Hamilton 1989 data

  mdl_84_msmu <- CHPTest(y84, p = 4, control = control)
  summary(mdl_84_msmu)
```

DLMCTest   *Monte Carlo moment-based test for Markov switching model*

Description

This function performs the Local Monte Carlo moment-based test for Markov switching autoregressive models proposed in Dufour & Luger (2017).

Usage

```
DLMCTest(Y, p, control = list())
```

Arguments

Y	Series to be tested
p	Number of autoregressive lags.
control	List with test procedure options including:

- N: Integer determining the number of Monte Carlo simulations. Default is set to 99 as in paper.
- simdist_N: Integer determining the number of simulations for CDF distribution approximation. Default is set to 10000.
- getSE: Boolean indicator. If TRUE, standard errors for restricted model are estimated. If FALSE no standard errors are estimated. Default is TRUE.

Value

List of class `DLMCTest` (S3 object) with attributes including:

- mdl_h0: List with restricted model attributes. This will be of class `ARmdl` if p>0 or `Nmdl` otherwise (S3 objects). See [ARmdl](#) or [Nmdl](#).

- theta: Value of nuisance parameters. Specifically, these are the consistent estimates of nuisance parameters as discussed in Dufour & Luger (2017) LMC procedure.

- S0: A (1 x 4)) matrix containing the four moment-based test statistics defined in (11) - (14) in Dufour & Luger (2017).

- F0_min: Test statistic value for min version of Local Monte Carlo moment-based test.

- F0_prod: Test statistic value for prod version of Local Monte Carlo moment-based test.

- FN_min: A (N x 1) vector with simulated test statistics for min version of Local Monte Carlo moment-based test under null hypothesis.

- FN_prod: A (N x 1) vector with simulated test statistics for prod version of Local Monte Carlo moment-based test under null hypothesis.

- pval_min: P-value for min version of Local Monte Carlo moment-based test.

- pval_prod: P-value for prod version of Local Monte Carlo moment-based test.

- FN_min_cv: Vector with 90%, 95%, and 99% Monte Carlo critical values for min version of Local Monte Carlo moment-based test.

- FN_prod_cv: Vector with 90%, 95%, and 99% Monte Carlo critical values for prod version of Local Monte Carlo moment-based test.

- control: List with test procedure options used.

References

Dufour, J. M., & Luger, R. 2017. "Identification-robust moment-based tests for Markov switching in autoregressive models." *Econometric Reviews*, 36(6-9), 713-727.

Examples

```
set.seed(1234)
# load data used in Hamilton 1989 and extended data used in CHP 2014
y84 <- as.matrix(hamilton84GNP$GNP_gr)
y10 <- as.matrix(chp10GNP$GNP_gr)

# Set test procedure options
lmc_control = list(N = 99,
                   simdist_N = 10000,
                   getSE = TRUE)

# perform test on Hamilton 1989 data
lmc_gnp84 <- DLMCTest(y84, p = 4, control = lmc_control)
summary(lmc_gnp84)
```

DLMMCTest   *Maximized Monte Carlo moment-based test for Markov switching model*

Description

This function performs the maximized Monte Carlo moment-based test for Markov switching autoregressive models proposed in Dufour & Luger (2017).

Usage

```
DLMMCTest(Y, p, control = list())
```

Arguments

Y	Series to be tested
p	Number of autoregressive lags.
control	List with test procedure options including:

- N: Integer determining the number of Monte Carlo simulations. Default is set to 99 as in paper.
- simdist_N: Integer determining the number of simulations for CDF distribution approximation. Default is set to 10000.
- getSE: Boolean indicator. If TRUE, standard errors for restricted model are estimated. If FALSE no standard errors are estimated. Default is TRUE.
- eps: Fixed positive constant that does not depend on T used to determine lower and upper bounds on consistent set considered for nuisance parameter space.
- CI_union: Boolean indicator determining if union between eps and confidence interval is used to determine lower and upper bound on consistent set considered for nuisance parameter space. If TRUE union is used and if FALSE only eps is used. Note that if standard errors obtained are not finite then only eps is used. Default is FALSE.
- lambda: Numeric value for penalty on stationary constraint not being met. Default is 100.
- stationary_ind: Boolean indicator determining if only stationary solutions should be considered if TRUE or any solution can be considered if FALSE. Default is TRUE.
- phi_low: Vector with lower bound for autoregressive parameters when optimizing. Default is NULL.
- phi_upp: Vector with upper bound for autoregressive parameters when optimizing. Default is NULL.
- optim_type: String determining type of numerical optimization algorithm to use. Available options are: pso, GenSA, GA. Default is pso.
- silence: Boolean indicator determining if optimization updates should be silenced if TRUE or not if FALSE. Default is FALSE.

- threshold_stop: Numeric value determining the maximum possible p-value attainable. Default is `1`.
- maxit: Int determining the maximum number of function evaluations. Default is `1000`.
- optim_control: List containing other optimization options specific to the numerical optimization algorithm used. For other options see documentation of numerical algorithm chosen.

Value

List of class `DLMCTest` (`S3` object) with attributes including:

- mdl_h0: List with restricted model attributes. This will be of class `ARmdl` if p>0 or `Nmdl` otherwise (`S3` objects). See [ARmdl](#) or [Nmdl](#).
- theta_max_min: Value of nuisance parameters when min version of p-value is maximized as discussed in Dufour & Luger (2017) MMC procedure.
- theta_max_prod: Value of nuisance parameters when prod version of p-value is maximized as discussed in Dufour & Luger (2017) MMC procedure.
- theta_low: Lower bound on nuisance parameter values used when searching for maximum p-value.
- theta_upp: Upper bound on nuisance parameter values used when searching for maximum p-value.
- S0_min: A (1 x 4)) matrix containing the four moment-based test statistics defined in (11) - (14) in Dufour & Luger (2017) when `theta_min` is used.
- S0_prod: A (1 x 4)) matrix containing the four moment-based test statistics defined in (11) - (14) in Dufour & Luger (2017) when `theta_prod` is used.
- F0_min: Test statistic value for min version of Maximized Monte Carlo moment-based test.
- F0_prod: Test statistic value for prod version of Maximized Monte Carlo moment-based test.
- FN_min: A (N x 1) vector with simulated test statistics for min version of Maximized Monte Carlo moment-based test under null hypothesis.
- FN_prod: A (N x 1) vector with simulated test statistics for prod version of Maximized Monte Carlo moment-based test under null hypothesis.
- pval_min: Maximum p-value for min version of Maximized Monte Carlo moment-based test.
- pval_prod: Maximum p-value for prod version of Local Monte Carlo moment-based test.
- FN_min_cv: Vector with 90%, 95%, and 99% Monte Carlo critical values for min version of Local Monte Carlo moment-based test.
- FN_prod_cv: Vector with 90%, 95%, and 99% Monte Carlo critical values for prod version of Local Monte Carlo moment-based test.
- control: List with test procedure options used.
- optim_min_output: List with optimization output for min version of Maximized Monte Carlo moment-based test.
- optim_prod_output: List with optimization output for prod version of Maximized Monte Carlo moment-based test.

References

Dufour, J. M., & Luger, R. 2017. "Identification-robust moment-based tests for Markov switching in autoregressive models." *Econometric Reviews*, 36(6-9), 713-727.

Examples

```
set.seed(1234)
# load data used in Hamilton 1989 and extended data used in CHP 2014
y84 <- as.matrix(hamilton84GNP$GNP_gr)
y10 <- as.matrix(chp10GNP$GNP_gr)

# Set test procedure options
mmc_control <- list(N = 99,
                    simdist_N = 10000,
                    getSE = TRUE,
                    eps = 0,
                    CI_union = TRUE,
                    lambda = 100,
                    stationary_ind = TRUE,
                    optim_type = "GenSA",
                    silence = FALSE,
                    threshold_stop = 1,
                    maxit = 200)


# perform test on Hamilton 1989 data

  mmc_gnp84 <- DLMMCTest(y84, p = 4, control = mmc_control)
  summary(mmc_gnp84)
```

---

hamilton84GNP *Hamilton 1984 & Hansen 1992 GNP data*

Description

Hamilton 1984 & Hansen 1992 GNP data

Usage

```
hamilton84GNP
```

Format

This data set is used in Hansen (1992) to test the US GNP model proposed by Hamilton (1989). This series ranges from 1951Q2 to 1984Q4.

Vector of dates

Date **GNP** US GNP series

GNP_gr US GNP log difference

Source

https://www.ssc.wisc.edu/~bhansen/progs/jae_92.html

References

Hansen, Bruce E. 1992. "The likelihood ratio test under nonstandard conditions: testing the Markov switching model of GNP." *Journal of applied Econometrics* 7 (S1): S61–S82.

Hamilton, James D. 1989. "A new approach to the economic analysis of nonstationary time series and the business cycle." *Econometrica* 57 (2): 357–384.

HLRTest   *Hansen (1992) likelihood ratio test*

Description

This function performs Hansen's likelihood ratio test as described in Hansen (1992). Original source code can be found here.

Usage

```
HLRTest(Y, p, control = list())
```

Arguments

Y   A (T x 1) matrix of observations.

p   Integer determining the number of autoregressive lags.

control   List with test procedure options including:

- ix: List of Markov Switching parameters. 1 = just mean c(1,2) = mean and first param, (default: 1).
- msvar: Boolean indicator. If TRUE, there is a switch in variance. If FALSE only switch in mean is considered. Default is FALSE.
- qbound: Indicator that bounds q by 1-p (default: FALSE).
- gridsize: Integer determining the number of grid points for markov switching parameters. Default is 20.
- pgrid_from: Double determining the initial grid point for transition probabilities. Default is 0.1.
- pgrid_by: Double determining the step size for grid points of transition probabilities. This, along with p_gridsize will determine the bounds of search space. Default is 0.075.
- pgrid_to: Double determining the end grid point for transition probabilities. Default is 0.925.
- mugrid_from: Double determining the minimum value of mean in second regime. Default is 0.1.

- mugrid_by: Double determining the step size for grid points of mean in second regime. This, along with `gridsize` will determine the max value of mean in second regime. Default is `0.1`.

- siggrid_from: Double determining the minimum value of sigma in second regime (if `msvar = TRUE`). Default is `0.1`.

- siggrid_by: Double determining the step size for grid points of sigma in second regime. This, along with `gridsize` will determine the max value of sigma in second regime. Default is `0.1`.

- N: Integer determining the number of replications. Default is `1000`.

- nwband: Integer determining maximum bandwidth in Bartlett kernel. Critical values and p-values are returned for each bandwidth from `0:nwband` as suggested in Hansen (1996). Default is 4.

- theta_null_low: Vector determining lower bound on parameters under the null hypothesis. Length of vector should be number of model coefficients + 1 for variance. Default is to only bound variance at `0.01`.

- theta_null_upp: Vector determining upper bound on parameters under the null hypothesis. Length of vector should be number of model coefficients + 1 for variance. Default is to no bounds (i.e. `Inf`).

- optim_method: String determining the type of optimization procedure used. Allowed options are "gp-optim" for general purpose optimization using `optim` from or `slsqp`. Default is "gp-optim".

Value

List of class `HLRTest` (S3 object) with model attributes including:

- mdl_h0: List with restricted model attributes. This will be of class `ARmdl` (S3 object). See `ARmdl`.

- LR0: Likelihood ratio test statistic value.

- LRN: A (N x 1) vector with simulated LRT statistics under null hypothesis.

- pval: P-value.

- LR_cv: A (nwband x 3) matrix with 90%, 95%, and 99% critical values in each column respectively.

- coef: Vector of coefficients from restricted model and grid search that maximized standardized LRT.

- control: List with test procedure options used.

References

Hansen, Bruce E. 1992. "The likelihood ratio test under nonstandard conditions: testing the Markov switching model of GNP." *Journal of applied Econometrics* 7 (S1): S61–S82.

Hansen, Bruce E. 1996. "Erratum: The likelihood ratio test under nonstandard conditions: testing the Markov switching model of GNP." *Journal of applied Econometrics* 7 (S1): S61–S82.

Examples

```
# ------------------------- Use simulated process --------------------------
set.seed(1234)
# Define DGP of MS AR process
mdl_ms2 <- list(n     = 200,
                mu    = c(5,1),
                sigma = c(1,1),
                phi   = c(0.5),
                k     = 2,
                P     = rbind(c(0.90, 0.10),
                              c(0.10, 0.90)))

# Simulate process using simuMSAR() function
y_ms_simu <- simuMSAR(mdl_ms2)

hlrt_control  <- list(ix          = 1,
                      gridsize    = 7,
                      pgrid_from  = 0.05,
                      pgrid_by    = 0.05,
                      pgrid_to    = 0.95,
                      mugrid_from = 0,
                      mugrid_by   = 1)


  hlrt <- HLRTest(y_ms_simu$y, p = 1, control = hlrt_control)
  summary(hlrt)
```

HMmdl   *Hidden Markov model*

Description

This function estimates a Hidden Markov model with k regimes.

Usage

```
HMmdl(Y, k, Z = NULL, control = list())
```

Arguments

Y	a (T x q) matrix of observations.
k	integer determining the number of regimes to use in estimation. Must be greater than or equal to 2.
Z	an otpional (T x qz) matrix of exogenous regressors. Default is NULL.
control	List with model options including:

- getSE: Boolean. If `TRUE` standard errors are computed and returned. If `FALSE` standard errors are not computed. Default is `TRUE`.
- msmu: Boolean. If `TRUE` model is estimated with switch in mean. If `FALSE` model is estimated with constant mean. Default is `TRUE`.
- msvar: Boolean. If `TRUE` model is estimated with switch in variance. If `FALSE` model is estimated with constant variance. Default is `TRUE`.
- init_theta: vector of initial values. vector must contain (1 x q) vector `mu`, `vech(sigma)`, and `vec(P)` where sigma is a (q x q) covariance matrix.This is optional. Default is `NULL`, in which case [initVals_MSARmdl](#) is used to generate initial values.
- method: string determining which method to use. Options are `'EM'` for EM algorithm or `'MLE'` for Maximum Likelihood Estimation. Default is `'EM'`.
- maxit: integer determining the maximum number of EM iterations.
- thtol: double determining the convergence criterion for the absolute difference in parameter estimates `theta` between iterations. Default is `1e-6`.
- maxit_converge: integer determining the maximum number of initial values attempted until solution is finite. For example, if parameters in `theta` or `logLike` are NaN another set of initial values (up to `maxit_converge`) is attempted until finite values are returned. This does not occur frequently for most types of data but may be useful in some cases. Once finite values are obtained, this counts as one iteration towards `use_diff_init`. Default is `500`.
- use_diff_init: integer determining how many different initial values to try (that do not return NaN; see `maxit_converge`). Default is `1`.
- mle_variance_constraint: double used to determine the lower bound on the smallest eigenvalue for the covariance matrix of each regime. Default is `1e-3`.
- mle_theta_low: Vector with lower bounds on parameters (Used only if method = "MLE"). Default is `NULL`.
- mle_theta_upp: Vector with upper bounds on parameters (Used only if method = "MLE"). Default is `NULL`.

Value

List of class `HMmdl` (S3 object) with model attributes including:

- y: a (T x q) matrix of observations.
- fitted: a (T x q) matrix of fitted values.
- resid: a (T x q) matrix of residuals.
- mu: a (k x q) matrix of estimated means of each process.
- beta: if q=1, this is a ((1 + qz) x k) matrix of estimated coefficients. If q>1, this is a list containing k separate ((1 + qz) x q) matrix of estimated coefficients for each regime.
- betaZ: a (qz x q) matrix of estimated exogenous regressor coefficients.
- intercept: a (k x q) matrix of estimated intercept of each process. If Z is Null, this is the same as mu.

- stdev: If q=1, this is a (k x 1) matrix with estimated standard. If q>1, this is a List with k (q x q) matrices with estimated standard deviation on the diagonal.

- sigma: If q=1, this is a (k x 1) matrix with variances. If q>1, this is a List with k (q x q) estimated covariance matrix.

- theta: vector containing: mu and vech(sigma).

- theta_mu_ind: vector indicating location of mean with 1 and 0 otherwise.

- theta_sig_ind: vector indicating location of variance and covariances with 1 and 0 otherwise.

- theta_var_ind: vector indicating location of variances with 1 and 0 otherwise.

- theta_P_ind: vector indicating location of transition matrix elements with 1 and 0 otherwise.

- n: number of observations (same as T).

- q: number of series.

- k: number of regimes in estimated model.

- P: a (k x k) transition matrix.

- pinf: a (k x 1) vector with limiting probabilities of each regime.

- St: a (T x k) vector with smoothed probabilities of each regime at each time t.

- deltath: double with maximum absolute difference in vector theta between last iteration.

- iterations: number of EM iterations performed to achieve convergence (if less than maxit).

- theta_0: vector of initial values used.

- init_used: number of different initial values used to get a finite solution. See description of input maxit_converge.

- msmu: Boolean. If TRUE model was estimated with switch in mean. If FALSE model was estimated with constant mean.

- msvar: Boolean. If TRUE model was estimated with switch in variance. If FALSE model was estimated with constant variance.

- control: List with model options used.

- logLike: log-likelihood.

- AIC: Akaike information criterion.

- BIC: Bayesian (Schwarz) information criterion.

- Hess: Hessian matrix. Approximated using hessian and only returned if getSE=TRUE.

- info_mat: Information matrix. Computed as the inverse of -Hess. If matrix is not PD then nearest PD matrix is obtained using nearest_spd. Only returned if getSE=TRUE.

- nearPD_used: Boolean determining whether nearPD function was used on info_mat if TRUE or not if FALSE. Only returned if getSE=TRUE.

- theta_se: standard errors of parameters in theta. Only returned if getSE=TRUE.

- trace: List with Lists of estimation output for each initial value used due to use_diff_init > 1.

References

Dempster, A. P., N. M. Laird, and D. B. Rubin. 1977. "Maximum Likelihood from Incomplete Data via the EM Algorithm." *Journal of the Royal Statistical Society*. Series B 39 (1): 1–38..

Hamilton, James D. 1990. "Analysis of time series subject to changes in regime." *Journal of econometrics*, 45 (1-2): 39–70.

Krolzig, Hans-Martin. 1997. "The markov-switching vector autoregressive model.". Springer.

See Also

Nmdl

LMCLRTest   *Monte Carlo Likelihood Ratio Test*

Description

This function performs the Local Monte Carlo likelihood ratio test (LMC-LRT) proposed in Rodriguez-Rondon & Dufour (2024). As discussed in their work, this test can be applied in very general settings and can be used to compare varioous regimes under the null and under the alternative.

Usage

```
LMCLRTest(Y, p, k0, k1, Z = NULL, control = list())
```

Arguments

Y	Series to be tested. Must be a (T x q) matrix where T is the number of time observations and q is the number of variables.
p	Number of autoregressive lags. Must be greater than or equal to 0.
k0	Number of regimes under null hypothesis. Must be greater than or equal to 1.
k1	Number of regimes under alternative hypothesis. Must be greater than k0.
Z	Exogenous regressors. Optional input and default is NULL. When used, it should be a (T x qz) matrix where T is the number of time observations and q is the number of exogenous variables.
control	List with test procedure options including:

- N: Integer determining the number of Monte Carlo simulations. Default is set to 99 as in paper.
- burnin: Number of simulated observations to remove from beginning. Default is 100.
- converge_check: String or NULL determining if convergence of model(s) should be verified. Allowed inputs are: "null", "alt", "both", or NULL. If NULL (default) no model convergence is verified.
- workers: Integer determining the number of workers to use for parallel computing version of test. Note that parallel pool must already be open. Default is 0.

- mdl_h0_control: List with restricted model options. See [Nmd1], [ARmd1], [VARmd1], [HMmd1], [MSARmd1], or [MSVARmd1] documentation for available and default values.
- mdl_h1_control: List with unrestricted model options. See [HMmd1], [MSARmd1], or [MSVARmd1] documentation for available and default values.
- use_diff_init_sim: Value which determines the number of initial values to use when estimating models for null distribution. Default is set to use the same as specified in `mdl_h0_control` and `mdl_h1_control`.

Value

List of class `LMCLRTest` (S3 object) with attributes including:

- mdl_h0: List with restricted model attributes.
- mdl_h1: List with unrestricted model attributes.
- LRT_0: Value of test statistic from observed data.
- LRN: A (N x 1) vector of test statistics from data simulated under the null hypothesis.
- pval: P-value of Local Monte Carlo Likelihood Ratio Test.
- LRN_cv: Vector with 90%, 95%, and 99% Monte Carlo simulated critical values (from vector LRN). These are not asymptotic critical values.
- control: List with test procedure options used.

References

Rodriguez-Rondon, Gabriel and Jean-Marie Dufour. 2022. "Simulation-Based Inference for Markov Switching Models" *JSM Proceedings, Business and Economic Statistics Section: American Statistical Association*.

Rodriguez-Rondon, Gabriel and Jean-Marie Dufour. 2024. "Monte Carlo Likelihood Ratio Tests for Markov Switching Models." *Unpublished manuscript*.

Examples

```
set.seed(1234)
# Define DGP of MS AR process
mdl_ms2 <- list(n     = 200,
                mu    = c(5,10),
                sigma = c(1,4),
                phi   = c(0.5),
                k     = 2,
                P     = rbind(c(0.90, 0.10),
                              c(0.10, 0.90)))

# Simulate process using simuMSAR() function
y_ms_simu <- simuMSAR(mdl_ms2)


# ------ MS-AR example ----- #
# Set test procedure options
```

```
lmc_control = list(N = 19,
                    burnin = 100,
                    converge_check = NULL,
                    mdl_h0_control = list(const  = TRUE,
                                          getSE  = TRUE),
                    mdl_h1_control = list(msmu   = TRUE,
                                          msvar  = TRUE,
                                          getSE  = TRUE,
                                          method = "EM",
                                          use_diff_init = 1))


  lmctest <- LMCLRTest(y_ms_simu$y, p = 1, k0 = 1 , k1 = 2, control = lmc_control)
  summary(lmctest)
```

MCpval   *Monte Carlo P-value*

Description

This function computes the Monte Carlo P-value.

Usage

```
MCpval(test_stat, null_vec, type = "geq")
```

Arguments

test_stat	Test statistic under the alternative (e.g. S_0).
null_vec	A (N x 1) vector with test statistic under the null hypothesis.
type	String determining type of test. options are: "geq" for right-tail test, "leq" for left-tail test, "abs" for absolute value test and "two-tail" for two-tail test.

Value

MC p-value of test

References

Dufour, Jean-Marie 2006. "Monte Carlo tests with nuisance parameters: A general approach to finite-sample inference and nonstandard asymptotics". *Journal of Econometrics*, 133(2), 443-477.

Dufour, Jean-Marie, and Richard Luger. 2017. "Identification-robust moment-based tests for Markov switching in autoregressive models". *Econometric Reviews*, 36(6-9), 713-727.

| MMCLRTest | *Maximized Monte Carlo Likelihood Ratio Test* |

Description

This function performs the Maximized Monte Carlo likelihood ratio test (MMC-LRT) proposed in Rodriguez-Rondon & Dufour (2024).

Usage

```
MMCLRTest(Y, p, k0, k1, Z = NULL, control = list())
```

Arguments

Y	Series to be tested. Must be a (T x q) matrix where T is the number of time observations and q is the number of variables.
p	Number of autoregressive lags. Must be greater than or equal to 0.
k0	Number of regimes under null hypothesis. Must be greater than or equal to 1.
k1	Number of regimes under alternative hypothesis. Must be greater than k0.
Z	Exogenous regressors. Optional input and default is NULL. When used, it should be a (T x qz) matrix where T is the number of time observations and q is the number of exogenous variables.
control	List with test procedure options including:

- N: Integer determining the number of Monte Carlo simulations. Default is set to 99 as in paper.
- burnin: Number of simulated observations to remove from beginning. Default is 100.
- converge_check: String of NULL determining if convergence of model(s) should be verified. Allowed inputs are: "null", "alt", "both", or NULL. If NULL (default) no model convergence is verified.
- workers: Integer determining the number of workers to use for parallel computing version of test. Note that parallel pool must already be open. Default is 0.
- type: String that determines the type of optimization algorithm used. Arguments allowed are: ″pso″, ″GenSA″, and ″GA″. Default is ″pso″.
- eps: Double determining the constant value that defines a consistent set for search. Default is 0.1.
- CI_union: Boolean determining if union of set determined by eps and confidence set should be used to define consistent set for search. Default is TRUE.
- lambda: Double determining penalty on nonlinear constraint. Default is 100.
- stationary_constraint: Boolean determining if only stationary solutions are considered (if TRUE) or not (if FALSE). Default is TRUE.

- phi_low: Vector with lower bound for autoregressive parameters when optimizing. Default is `NULL`.
- phi_upp: Vector with upper bound for autoregressive parameters when optimizing. Default is `NULL`.
- P_low: Value with lower bound for transition probabilities when optimizing. Default is `0`.
- P_upp: Value with upper bound for transition probabilities when optimizing. Default is `1`.
- variance_constraint: Double used to determine the lower bound for variance in parameter set for search. Value should be between `0` and `1` as it is multiplied by consistent point estimates of variances. Default is `0.01` (i.e., 1% of consistent point estimates.
- silence: Boolean determining if optimization steps should be silenced (if `TRUE`) or not (if `FALSE`). Default is `FALSE`.
- threshold_stop: Double determining the global optimum of function. Default is `1`.
- mdl_h0_control: List with restricted model options. See [Nmdl], [ARmdl], [VARmdl], [HMmdl], [MSARmdl], or [MSVARmdl] documentation for available and default values.
- mdl_h1_control: List with unrestricted model options. See [HMmdl], [MSARmdl], or [MSVARmdl] documentation for available and default values.
- use_diff_init_sim: Value which determines the number of initial values to use when estimating models for null distribution. Default is set to use the same as specified in `mdl_h0_control` and `mdl_h1_control`.
- optim_control: List with optimization algorithm options. See [psoptim], [GenSA], [ga]. Default is to set `list(maxit = 200)` so that maximum number of iterations is 200.

Value

List of class `LMCLRTest` (S3 object) with attributes including:

- mdl_h0: List with restricted model attributes.
- mdl_h1: List with unrestricted model attributes.
- LRT_0: Value of test statistic from observed data.
- LRN: A (N x 1) vector of test statistics from data simulated under the null hypothesis.
- pval: P-value of Local Monte Carlo Likelihood Ratio Test.
- LRN_cv: Vector with 90%, 95%, and 99% Monte Carlo simulated critical values (from vector LRN). These are not asymptotic critical values.
- control: List with test procedure options used.

References

Rodriguez-Rondon, Gabriel and Jean-Marie Dufour. 2022. "Simulation-Based Inference for Markov Switching Models" *JSM Proceedings, Business and Economic Statistics Section: American Statistical Association*.

Rodriguez-Rondon, Gabriel and Jean-Marie Dufour. 2024. "Monte Carlo Likelihood Ratio Tests for Markov Switching Models." *Unpublished manuscript.*

Examples

```
set.seed(1234)
# Define DGP of MS AR process
mdl_ms2 <- list(n     = 200,
                mu    = c(5,10),
                sigma = c(1,4),
                phi   = c(0.5),
                k     = 2,
                P     = rbind(c(0.90, 0.10),
                              c(0.10, 0.90)))

# Simulate process using simuMSAR() function
y_ms_simu <- simuMSAR(mdl_ms2)


# Set test procedure options
mmc_control = list(N = 19,
                   burnin = 100,
                   converge_check = NULL,
                   eps = 0.1,
                   CI_union = TRUE,
                   silence = FALSE,
                   threshold_stop = 0.05 + 1e-6,
                   type = "pso",
                   maxit = 100,
                   mdl_h0_control = list(const  = TRUE,
                                         getSE  = TRUE),
                   mdl_h1_control = list(msmu   = TRUE,
                                         msvar  = TRUE,
                                         getSE  = TRUE,
                                         method = "EM",
                                         use_diff_init = 1))

  MMCtest <- MMCLRTest(y_ms_simu$y, p = 1 , k0 = 1 , k1 = 2, control = mmc_control)
  summary(MMCtest)
```

MSARmdl   *Markov-switching autoregressive model*

Description

This function estimates a Markov-switching autoregressive model

Usage

```
MSARmdl(Y, p, k, control = list())
```

Arguments

Y	(T x 1) vector with observational data.
p	integer for the number of lags to use in estimation. Must be greater than or equal to 1.
k	integer for the number of regimes to use in estimation. Must be greater than or equal to 2.
control	List with model options including:

- getSE: Boolean. If TRUE standard errors are computed and returned. If FALSE standard errors are not computed. Default is TRUE.
- msmu: Boolean. If TRUE model is estimated with switch in mean. If FALSE model is estimated with constant mean. Default is TRUE.
- msvar: Boolean. If TRUE model is estimated with switch in variance. If FALSE model is estimated with constant variance. Default is TRUE.
- init_theta: vector of initial values. vector must contain (1 x q) vector mu, vech(sigma), and vec(P) where sigma is a (q x q) covariance matrix.This is optional. Default is NULL, in which case initVals_MSARmdl is used to generate initial values.
- method: string determining which method to use. Options are 'EM' for EM algorithm or 'MLE' for Maximum Likelihood Estimation. Default is 'EM'.
- maxit: integer determining the maximum number of EM iterations.
- thtol: double determining the convergence criterion for the absolute difference in parameter estimates theta between iterations. Default is 1e-6.
- maxit_converge: integer determining the maximum number of initial values attempted until solution is finite. For example, if parameters in theta or logLike are NaN another set of initial values (up to maxit_converge) is attempted until finite values are returned. This does not occur frequently for most types of data but may be useful in some cases. Once finite values are obtained, this counts as one iteration towards use_diff_init. Default is 500.
- use_diff_init: integer determining how many different initial values to try (that do not return NaN; see maxit_converge). Default is 1.
- mle_stationary_constraint: Boolean determining if only stationary solutions are considered (if TRUE) or not (if FALSE). Default is TRUE.
- mle_variance_constraint: Double used to determine the lower bound for variance in each regime. Value should be between 0 and 1 as it is multiplied by single regime variance. Default is 0.01 (i.e., 1% of single regime variance.
- mle_theta_low: Vector with lower bounds on parameters (Used only if method = "MLE"). Default is NULL.
- mle_theta_upp: Vector with upper bounds on parameters (Used only if method = "MLE"). Default is NULL.

Value

List of class `MSARmdl` (`S3` object) with model attributes including:

- y: a (`T x 1`) matrix of observations.
- X: a (`T-p x p + const`) matrix of lagged observations with a leading column of 1s.
- x: a (`T-p x p`) matrix of lagged observations.
- fitted: a (`T x 1`) matrix of fitted values.
- resid: a (`T x 1`) matrix of residuals.
- intercept: a (`k x 1`) vector of estimated intercepts of each process.
- mu: a (`k x 1`) vector of estimated means of each process.
- beta: a (`(1 + p) x k`) matrix of estimated coefficients.
- phi: estimates of autoregressive coefficients.
- stdev: a (`k x 1`) vector of estimated standard deviation of each process.
- sigma: a (`k x 1`) estimated covariance matrix.
- theta: vector containing: `mu` and `vech(sigma)`.
- theta_mu_ind: vector indicating location of mean with 1 and 0 otherwise.
- theta_sig_ind: vector indicating location of variances with 1 and 0 otherwise.
- theta_var_ind: vector indicating location of variances with 1 and 0 otherwise. This is the same as `theta_sig_ind` in `MSARmdl`.
- theta_P_ind: vector indicating location of transition matrix elements with 1 and 0 otherwise.
- stationary: Boolean indicating if process is stationary if `TRUE` or non-stationary if `FALSE`.
- n: number of observations (same as `T`).
- p: number of autoregressive lags.
- q: number of series. This is always 1 in `MSARmdl`.
- k: number of regimes in estimated model.
- P: a (`k x k`) transition matrix.
- pinf: a (`k x 1`) vector with limiting probabilities of each regime.
- St: a (`T x k`) vector with smoothed probabilities of each regime at each time `t`.
- deltath: double with maximum absolute difference in vector `theta` between last iteration.
- iterations: number of EM iterations performed to achieve convergence (if less than `maxit`).
- theta_0: vector of initial values used.
- init_used: number of different initial values used to get a finite solution. See description of input `maxit_converge`.
- msmu: Boolean. If `TRUE` model was estimated with switch in mean. If `FALSE` model was estimated with constant mean.
- msvar: Boolean. If `TRUE` model was estimated with switch in variance. If `FALSE` model was estimated with constant variance.
- control: List with model options used.
- logLike: log-likelihood.

- AIC: Akaike information criterion.

- BIC: Bayesian (Schwarz) information criterion.

- Hess: Hessian matrix. Approximated using [hessian](#) and only returned if getSE=TRUE.

- info_mat: Information matrix. Computed as the inverse of -Hess. If matrix is not PD then nearest PD matrix is obtained using [nearest_spd](#). Only returned if getSE=TRUE.

- nearPD_used: Boolean determining whether nearPD function was used on info_mat if TRUE or not if FALSE. Only returned if getSE=TRUE.

- theta_se: standard errors of parameters in theta. Only returned if getSE=TRUE.

- trace: List with Lists of estimation output for each initial value used due to use_diff_init > 1.

References

Dempster, A. P., N. M. Laird, and D. B. Rubin. 1977. "Maximum Likelihood from Incomplete Data via the EM Algorithm." *Journal of the Royal Statistical Society*. Series B 39 (1): 1–38..

Hamilton, James D. 1990. "Analysis of time series subject to changes in regime." *Journal of econometrics*, 45 (1-2): 39–70.

See Also

[ARmdl](#)

Examples

```
# -------------------------- Use simulated process ---------------------------
set.seed(1234)
# Define DGP of MS AR process
mdl_ms2 <- list(n     = 200,
                mu    = c(5,10),
                sigma = c(1,4),
                phi   = c(0.5),
                k     = 2,
                P     = rbind(c(0.90, 0.10),
                              c(0.10, 0.90)))

# Simulate process using simuMSAR() function
y_ms_simu <- simuMSAR(mdl_ms2)

# Set options for model estimation
control <- list(msmu  = TRUE,
                msvar = TRUE,
                method = "EM",
                use_diff_init = 1)

# Estimate model

  ms_mdl <- MSARmdl(y_ms_simu$y, p = 1, k = 2, control = control)
  summary(ms_mdl)
```

MSARXmdl   *Markov-switching autoregressive model*

Description

This function estimates a Markov-switching autoregressive model

Usage

```
MSARXmdl(Y, p, k, Z, control = list())
```

Arguments

Y	a (T x 1) vector with observational data.
p	integer for the number of lags to use in estimation. Must be greater than or equal to 1.
k	integer for the number of regimes to use in estimation. Must be greater than or equal to 2.
Z	a (T x qz) matrix of exogenous regressors.
control	List with model options including:

- getSE: Boolean. If TRUE standard errors are computed and returned. If FALSE standard errors are not computed. Default is TRUE.
- msmu: Boolean. If TRUE model is estimated with switch in mean. If FALSE model is estimated with constant mean. Default is TRUE.
- msvar: Boolean. If TRUE model is estimated with switch in variance. If FALSE model is estimated with constant variance. Default is TRUE.
- init_theta: vector of initial values. vector must contain (1 x q) vector mu, vech(sigma), and vec(P) where sigma is a (q x q) covariance matrix.This is optional. Default is NULL, in which case initVals_MSARmdl is used to generate initial values.
- method: string determining which method to use. Options are 'EM' for EM algorithm or 'MLE' for Maximum Likelihood Estimation. Default is 'EM'.
- maxit: integer determining the maximum number of EM iterations.
- thtol: double determining the convergence criterion for the absolute difference in parameter estimates theta between iterations. Default is 1e-6.
- maxit_converge: integer determining the maximum number of initial values attempted until solution is finite. For example, if parameters in theta or logLike are NaN another set of initial values (up to maxit_converge) is attempted until finite values are returned. This does not occur frequently for most types of data but may be useful in some cases. Once finite values are obtained, this counts as one iteration towards use_diff_init. Default is 500.

- use_diff_init: integer determining how many different initial values to try (that do not return NaN; see maxit_converge). Default is 1.
- mle_stationary_constraint: Boolean determining if only stationary solutions are considered (if TRUE) or not (if FALSE). Default is TRUE.
- mle_variance_constraint: Double used to determine the lower bound for variance in each regime. Value should be between 0 and 1 as it is multiplied by single regime variance. Default is 0.01 (i.e., 1% of single regime variance.
- mle_theta_low: Vector with lower bounds on parameters (Used only if method = "MLE"). Default is NULL.
- mle_theta_upp: Vector with upper bounds on parameters (Used only if method = "MLE"). Default is NULL.

Value

List of class MSARmdl (S3 object) with model attributes including:

- y: a (T x 1) matrix of observations.
- X: a (T-p x p + const) matrix of lagged observations with a leading column of 1s.
- x: a (T-p x p) matrix of lagged observations.
- fitted: a (T x 1) matrix of fitted values.
- resid: a (T x 1) matrix of residuals.
- intercept: a (k x 1) vector of estimated intercepts of each process.
- mu: a (k x 1) vector of estimated means of each process.
- beta: a ((1 + p + qz) x k) matrix of estimated coefficients.
- betaZ: a (qz x q) matrix of estimated exogenous regressor coefficients.
- phi: estimates of autoregressive coefficients.
- stdev: a (k x 1) vector of estimated standard deviation of each process.
- sigma: a (k x 1) estimated covariance matrix.
- theta: vector containing: mu and vech(sigma).
- theta_mu_ind: vector indicating location of mean with 1 and 0 otherwise.
- theta_sig_ind: vector indicating location of variances with 1 and 0 otherwise.
- theta_var_ind: vector indicating location of variances with 1 and 0 otherwise. This is the same as theta_sig_ind in MSARmdl.
- theta_P_ind: vector indicating location of transition matrix elements with 1 and 0 otherwise.
- stationary: Boolean indicating if process is stationary if TRUE or non-stationary if FALSE.
- n: number of observations (same as T).
- p: number of autoregressive lags.
- q: number of series. This is always 1 in MSARmdl.
- k: number of regimes in estimated model.
- P: a (k x k) transition matrix.

- pinf: a (k x 1) vector with limiting probabilities of each regime.

- St: a (T x k) vector with smoothed probabilities of each regime at each time t.

- deltath: double with maximum absolute difference in vector theta between last iteration.

- iterations: number of EM iterations performed to achieve convergence (if less than maxit).

- theta_0: vector of initial values used.

- init_used: number of different initial values used to get a finite solution. See description of input maxit_converge.

- msmu: Boolean. If TRUE model was estimated with switch in mean. If FALSE model was estimated with constant mean.

- msvar: Boolean. If TRUE model was estimated with switch in variance. If FALSE model was estimated with constant variance.

- control: List with model options used.

- logLike: log-likelihood.

- AIC: Akaike information criterion.

- BIC: Bayesian (Schwarz) information criterion.

- Hess: Hessian matrix. Approximated using hessian and only returned if getSE=TRUE.

- info_mat: Information matrix. Computed as the inverse of −Hess. If matrix is not PD then nearest PD matrix is obtained using nearest_spd. Only returned if getSE=TRUE.

- nearPD_used: Boolean determining whether nearPD function was used on info_mat if TRUE or not if FALSE. Only returned if getSE=TRUE.

- theta_se: standard errors of parameters in theta. Only returned if getSE=TRUE.

- trace: List with Lists of estimation output for each initial value used due to use_diff_init > 1.

References

Dempster, A. P., N. M. Laird, and D. B. Rubin. 1977. "Maximum Likelihood from Incomplete Data via the EM Algorithm." *Journal of the Royal Statistical Society*. Series B 39 (1): 1–38..

Hamilton, James D. 1990. "Analysis of time series subject to changes in regime." *Journal of econometrics*, 45 (1-2): 39–70.

See Also

ARmdl

Examples

```
# ------------------------- Use simulated process -------------------------
set.seed(1234)
# Define DGP of MS AR process
mdl_ms2 <- list(n    = 200,
               mu    = c(5,10),
               sigma = c(1,4),
               phi   = c(0.5),
               k     = 2,
```

```
                        P      = rbind(c(0.90, 0.10),
                                       c(0.10, 0.90)))

    # Simulate process using simuMSAR() function
    y_ms_simu <- simuMSAR(mdl_ms2)

    # Set options for model estimation
    control <- list(msmu   = TRUE,
                    msvar  = TRUE,
                    method = "EM",
                    use_diff_init = 1)

    # Estimate model

      ms_mdl <- MSARmdl(y_ms_simu$y, p = 1, k = 2, control = control)
      summary(ms_mdl)
```

MSVARmdl   *Markov-switching vector autoregressive model*

Description

This function estimates a Markov-switching vector autoregressive model

Usage

```
MSVARmdl(Y, p, k, control = list())
```

Arguments

Y	(T x q) vector with observational data.
p	integer for the number of lags to use in estimation. Must be greater than or equal to 0.
k	integer for the number of regimes to use in estimation. Must be greater than or equal to 2.
control	List with optimization options including:

- getSE: Boolean. If TRUE standard errors are computed and returned. If FALSE standard errors are not computed. Default is TRUE.
- msmu: Boolean. If TRUE model is estimated with switch in mean. If FALSE model is estimated with constant mean. Default is TRUE.
- msvar: Boolean. If TRUE model is estimated with switch in variance. If FALSE model is estimated with constant variance. Default is TRUE.

- init_theta: vector of initial values. vector must contain (1 x q) vector mu, vech(sigma), and vec(P) where sigma is a (q x q) covariance matrix. This is optional. Default is NULL, in which case [initVals_MSARmdl](#) is used to generate initial values.
- method: string determining which method to use. Options are 'EM' for EM algorithm or 'MLE' for Maximum Likelihood Estimation. Default is 'EM'.
- maxit: integer determining the maximum number of EM iterations.
- thtol: double determining the convergence criterion for the absolute difference in parameter estimates theta between iterations. Default is 1e-6.
- maxit_converge: integer determining the maximum number of initial values attempted until solution is finite. For example, if parameters in theta or logLike are NaN another set of initial values (up to maxit_converge) is attempted until finite values are returned. This does not occur frequently for most types of data but may be useful in some cases. Once finite values are obtained, this counts as one iteration towards use_diff_init. Default is 500.
- use_diff_init: integer determining how many different initial values to try (that do not return NaN; see maxit_converge). Default is 1.
- mle_stationary_constraint: Boolean determining if only stationary solutions are considered (if TRUE) or not (if FALSE). Default is TRUE.
- mle_variance_constraint: double used to determine the lower bound on the smallest eigenvalue for the covariance matrix of each regime. Default is 1e-3.
- mle_theta_low: Vector with lower bounds on parameters (Used only if method = "MLE"). Default is NULL.
- mle_theta_upp: Vector with upper bounds on parameters (Used only if method = "MLE"). Default is NULL.

Value

List of class MSVARmdl (S3 object) with model attributes including:

- y: a (T-p x q) matrix of observations.
- X: a (T-p x p*q + const) matrix of lagged observations with a leading column of 1s.
- x: a (T-p x p*q) matrix of lagged observations.
- fitted: a (T x q) matrix of fitted values.
- resid: a (T-p x q) matrix of residuals.
- intercept: a (k x q) matrix of estimated intercepts of each process.
- mu: a (k x q) matrix of estimated means of each process.
- beta: a list containing k separate ((1 + p) x q) matrix of estimated coefficients for each regime.
- phi: estimates of autoregressive coefficients.
- Fmat: Companion matrix containing autoregressive coefficients.
- stdev: List with k (q x q) matrices with estimated standard deviation on the diagonal.

- sigma: List with k (q x q) matrices with estimated covariance matrix.

- theta: vector containing: mu and vech(sigma).

- theta_mu_ind: vector indicating location of mean with 1 and 0 otherwise.

- theta_sig_ind: vector indicating location of variance and covariances with 1 and 0 otherwise.

- theta_var_ind: vector indicating location of variances with 1 and 0 otherwise.

- theta_P_ind: vector indicating location of transition matrix elements with 1 and 0 otherwise.

- stationary: Boolean indicating if process is stationary if TRUE or non-stationary if FALSE.

- n: number of observations (same as T).

- p: number of autoregressive lags.

- q: number of series.

- k: number of regimes in estimated model.

- P: a (k x k) transition matrix.

- pinf: a (k x 1) vector with limiting probabilities of each regime.

- St: a (T x k) vector with smoothed probabilities of each regime at each time t.

- deltath: double with maximum absolute difference in vector theta between last iteration.

- iterations: number of EM iterations performed to achieve convergence (if less than maxit).

- theta_0: vector of initial values used.

- init_used: number of different initial values used to get a finite solution. See description of input maxit_converge.

- msmu: Boolean. If TRUE model was estimated with switch in mean. If FALSE model was estimated with constant mean.

- msvar: Boolean. If TRUE model was estimated with switch in variance. If FALSE model was estimated with constant variance.

- control: List with model options used.

- logLike: log-likelihood.

- AIC: Akaike information criterion.

- BIC: Bayesian (Schwarz) information criterion.

- Hess: Hessian matrix. Approximated using hessian and only returned if getSE=TRUE.

- info_mat: Information matrix. Computed as the inverse of -Hess. If matrix is not PD then nearest PD matrix is obtained using nearest_spd. Only returned if getSE=TRUE.

- nearPD_used: Boolean determining whether nearPD function was used on info_mat if TRUE or not if FALSE. Only returned if getSE=TRUE.

- theta_se: standard errors of parameters in theta. Only returned if getSE=TRUE.

- trace: List with Lists of estimation output for each initial value used due to use_diff_init > 1.

List with model characteristics

References

Dempster, A. P., N. M. Laird, and D. B. Rubin. 1977. "Maximum Likelihood from Incomplete Data via the EM Algorithm." *Journal of the Royal Statistical Society*. Series B 39 (1): 1–38..

Krolzig, Hans-Martin. 1997. "The markov-switching vector autoregressive model.". Springer.

See Also

VARmdl

Examples

```
set.seed(123)
# Define DGP of MS VAR process
mdl_msvar2 <- list(n     = 200,
                   p     = 1,
                   q     = 2,
                   mu    = rbind(c(5, -2),
                                 c(10, 2)),
                   sigma = list(rbind(c(5.0, 1.5),
                                      c(1.5, 1.0)),
                                rbind(c(7.0, 3.0),
                                      c(3.0, 2.0))),
                   phi   = rbind(c(0.50, 0.30),
                                 c(0.20, 0.70)),
                   k     = 2,
                   P     = rbind(c(0.90, 0.10),
                                 c(0.10, 0.90)))

# Simulate process using simuMSVAR() function
y_msvar_simu <- simuMSVAR(mdl_msvar2)

# Set options for model estimation
control <- list(msmu  = TRUE,
                msvar = TRUE,
                method = "EM",
                use_diff_init = 1)

# Estimate model

  y_msvar_mdl <- MSVARmdl(y_msvar_simu$y, p = 1, k = 2, control = control)
  summary(y_msvar_mdl)
```

MSVARXmdl   *Markov-switching vector autoregressive model*

Description

This function estimates a Markov-switching vector autoregressive model

Usage

```
MSVARXmdl(Y, p, k, Z, control = list())
```

Arguments

Y	(T x q) vector with observational data.
p	integer for the number of lags to use in estimation. Must be greater than or equal to 0.
k	integer for the number of regimes to use in estimation. Must be greater than or equal to 2.
Z	a (T x qz) matrix of exogenous regressors.
control	List with optimization options including:

- getSE: Boolean. If TRUE standard errors are computed and returned. If FALSE standard errors are not computed. Default is TRUE.
- msmu: Boolean. If TRUE model is estimated with switch in mean. If FALSE model is estimated with constant mean. Default is TRUE.
- msvar: Boolean. If TRUE model is estimated with switch in variance. If FALSE model is estimated with constant variance. Default is TRUE.
- init_theta: vector of initial values. vector must contain (1 x q) vector mu, vech(sigma), and vec(P) where sigma is a (q x q) covariance matrix. This is optional. Default is NULL, in which case [initVals_MSARmdl](#) is used to generate initial values.
- method: string determining which method to use. Options are 'EM' for EM algorithm or 'MLE' for Maximum Likelihood Estimation. Default is 'EM'.
- maxit: integer determining the maximum number of EM iterations.
- thtol: double determining the convergence criterion for the absolute difference in parameter estimates theta between iterations. Default is 1e-6.
- maxit_converge: integer determining the maximum number of initial values attempted until solution is finite. For example, if parameters in theta or logLike are NaN another set of initial values (up to maxit_converge) is attempted until finite values are returned. This does not occur frequently for most types of data but may be useful in some cases. Once finite values are obtained, this counts as one iteration towards use_diff_init. Default is 500.
- use_diff_init: integer determining how many different initial values to try (that do not return NaN; see maxit_converge). Default is 1.
- mle_stationary_constraint: Boolean determining if only stationary solutions are considered (if TRUE) or not (if FALSE). Default is TRUE.
- mle_variance_constraint: double used to determine the lower bound on the smallest eigenvalue for the covariance matrix of each regime. Default is 1e-3.
- mle_theta_low: Vector with lower bounds on parameters (Used only if method = "MLE"). Default is NULL.
- mle_theta_upp: Vector with upper bounds on parameters (Used only if method = "MLE"). Default is NULL.

Value

List of class `MSVARmdl` (`S3` object) with model attributes including:

- y: a (`T-p x q`) matrix of observations.
- X: a (`T-p x p*q + const`) matrix of lagged observations with a leading column of 1s.
- x: a (`T-p x p*q`) matrix of lagged observations.
- resid: a (`T-p x q`) matrix of residuals.
- fitted: a (`T x q`) matrix of fitted values.
- intercept: a (`k x q`) matrix of estimated intercepts of each process.
- mu: a (`k x q`) matrix of estimated means of each process.
- beta: a list containing k separate ((`1 + p + qz`) `x q`) matrix of estimated coefficients for each regime.
- betaZ: a (`qz x q`) matrix of estimated exogenous regressor coefficients.
- phi: estimates of autoregressive coefficients.
- Fmat: Companion matrix containing autoregressive coefficients.
- stdev: List with k (`q x q`) matrices with estimated standard deviation on the diagonal.
- sigma: List with k (`q x q`) matrices with estimated covariance matrix.
- theta: vector containing: `mu` and `vech(sigma)`.
- theta_mu_ind: vector indicating location of mean with 1 and 0 otherwise.
- theta_sig_ind: vector indicating location of variance and covariances with 1 and 0 otherwise.
- theta_var_ind: vector indicating location of variances with 1 and 0 otherwise.
- theta_P_ind: vector indicating location of transition matrix elements with 1 and 0 otherwise.
- stationary: Boolean indicating if process is stationary if `TRUE` or non-stationary if `FALSE`.
- n: number of observations (same as `T`).
- p: number of autoregressive lags.
- q: number of series.
- k: number of regimes in estimated model.
- P: a (`k x k`) transition matrix.
- pinf: a (`k x 1`) vector with limiting probabilities of each regime.
- St: a (`T x k`) vector with smoothed probabilities of each regime at each time `t`.
- deltath: double with maximum absolute difference in vector `theta` between last iteration.
- iterations: number of EM iterations performed to achieve convergence (if less than `maxit`).
- theta_0: vector of initial values used.
- init_used: number of different initial values used to get a finite solution. See description of input `maxit_converge`.
- msmu: Boolean. If `TRUE` model was estimated with switch in mean. If `FALSE` model was estimated with constant mean.
- msvar: Boolean. If `TRUE` model was estimated with switch in variance. If `FALSE` model was estimated with constant variance.

- control: List with model options used.

- logLike: log-likelihood.

- AIC: Akaike information criterion.

- BIC: Bayesian (Schwarz) information criterion.

- Hess: Hessian matrix. Approximated using [hessian](#) and only returned if getSE=TRUE.

- info_mat: Information matrix. Computed as the inverse of −Hess. If matrix is not PD then nearest PD matrix is obtained using [nearest_spd](#). Only returned if getSE=TRUE.

- nearPD_used: Boolean determining whether nearPD function was used on info_mat if TRUE or not if FALSE. Only returned if getSE=TRUE.

- theta_se: standard errors of parameters in theta. Only returned if getSE=TRUE.

- trace: List with Lists of estimation output for each initial value used due to use_diff_init > 1.

List with model characteristics

References

Dempster, A. P., N. M. Laird, and D. B. Rubin. 1977. "Maximum Likelihood from Incomplete Data via the EM Algorithm." *Journal of the Royal Statistical Society*. Series B 39 (1): 1–38..

Krolzig, Hans-Martin. 1997. "The markov-switching vector autoregressive model.". Springer.

See Also

[VARmdl](#)

Examples

```
set.seed(123)
# Define DGP of MS VAR process
mdl_msvar2 <- list(n    = 200,
                   p    = 1,
                   q    = 2,
                   mu   = rbind(c(5, -2),
                               c(10, 2)),
                   sigma = list(rbind(c(5.0, 1.5),
                                     c(1.5, 1.0)),
                               rbind(c(7.0, 3.0),
                                     c(3.0, 2.0))),
                   phi  = rbind(c(0.50, 0.30),
                               c(0.20, 0.70)),
                   k    = 2,
                   P    = rbind(c(0.90, 0.10),
                               c(0.10, 0.90)))

# Simulate process using simuMSVAR() function
y_msvar_simu <- simuMSVAR(mdl_msvar2)

# Set options for model estimation
```

```
control <- list(msmu  = TRUE,
                msvar = TRUE,
                method = "EM",
                use_diff_init = 1)

# Estimate model

y_msvar_mdl <- MSVARmdl(y_msvar_simu$y, p = 1, k = 2, control = control)
summary(y_msvar_mdl)
```

Nmdl   *Normal distribution model*

Description

This function estimates a univariate or multivariate normally distributed model. This can be used for the null hypothesis of a linear model against an alternative hypothesis of a HMM with k regimes.

Usage

```
Nmdl(Y, Z = NULL, control = list())
```

Arguments

Y   a (T x q) matrix of observations.

Z   an otpional (T x qz) matrix of exogenous regressors. Default is NULL.

control   List with model options including:

- const: Boolean determining whether to estimate model with constant if TRUE or not if FALSE. Default is TRUE.
- getSE: Boolean determining whether to compute standard errors of parameters if TRUE or not if FALSE. Default is TRUE.

Value

List of class Nmdl (S3 object) with model attributes including:

- y: a (T x q) matrix of observations.
- fitted: a (T x q) matrix of fitted values.
- resid: a (T x q) matrix of residuals.
- mu: a (1 x q) vector of estimated means of each process.
- intercept: a (1 x q) vector of estimated intercept of each process. If Z is NULL, it is the same as mu.
- beta: a ((1 + p + qz) x q) matrix of estimated coefficients.
- betaZ: a (qz x q) matrix of estimated exogenous regressor coefficients (If Z is provided).

- stdev: a (q x 1) vector of estimated standard deviation of each process.

- sigma: a (q x q) estimated covariance matrix.

- theta: vector containing: mu, betaZ (if matrix Z is provided), and vech(sigma).

- theta_mu_ind: vector indicating location of mean with 1 and 0 otherwise.

- theta_sig_ind: vector indicating location of variance and covariances with 1 and 0 otherwise.

- theta_var_ind: vector indicating location of variances with 1 and 0 otherwise.

- n: number of observations (same as T).

- q: number of series.

- k: number of regimes. This is always 1 in Nmdl.

- control: List with model options used.

- logLike: log-likelihood.

- AIC: Akaike information criterion.

- BIC: Bayesian (Schwarz) information criterion.

- Hess: Hessian matrix. Approximated using hessian and only returned if getSE=TRUE.

- info_mat: Information matrix. Computed as the inverse of -Hess. If matrix is not PD then nearest PD matrix is obtained using nearest_spd. Only returned if getSE=TRUE.

- nearPD_used: Boolean determining whether nearPD function was used on info_mat if TRUE or not if FALSE. Only returned if getSE=TRUE.

- theta_se: standard errors of parameters in theta. Only returned if getSE=TRUE.

Examples

```
set.seed(1234)

# ----- Univariate ----- #
# Define DGP
mdl_norm <- list(n     = 1000,
                 q     = 1,
                 mu    = as.matrix(5),
                 sigma = as.matrix(5.0))

# Simulate process using simuNorm() function
y_norm_simu <- simuNorm(mdl_norm)

# estimate parameters
y_norm_mdl <- Nmdl(y_norm_simu$y)
summary(y_norm_mdl)


# ----- Multivariate ----- #
# Define DGP
mdl_norm <- list(n     = 1000,
                 q     = 2,
                 mu    = c(5, -2),
                 sigma = rbind(c(5.0, 1.5),
                               c(1.5, 1.0)))
```

```
# Simulate process using simuNorm() function
y_norm_simu <- simuNorm(mdl_norm)

# estimate parameters
y_norm_mdl <- Nmdl(y_norm_simu$y)
summary(y_norm_mdl)
```

---

simuAR   *Simulate autoregressive process*

Description

This function simulates an autoregresive process.

Usage

```
simuAR(mdl_h0, burnin = 100)
```

Arguments

mdl_h0   List containing the following DGP parameters

- n: Length of series.
- mu: Mean of process.
- sigma: Standard deviation of process.
- phi: Vector of autoregressive coefficients.
- eps: An optional (T+burnin x q) matrix with standard normal errors to be used. Errors will be generated if not provided.

burnin   Number of simulated observations to remove from beginning. Default is 100.

Value

List with simulated autoregressive series and its DGP parameters.

Examples

```
set.seed(1234)
# Define DGP of AR process
mdl_ar <- list(n     = 500,
               mu    = 5,
               sigma = 2,
               phi   = c(0.5,0.2))

# Simulate process using simuAR() function
y_simu <- simuAR(mdl_ar)

plot(y_simu)
```

---

simuARX   *Simulate autoregressive X process*

Description

This function simulates an autoregresive X process.

Usage

```
simuARX(mdl_h0, burnin = 100)
```

Arguments

mdl_h0   List containing the following DGP parameters

- n: Length of series.
- mu: Mean of process.
- sigma: Standard deviation of process.
- phi: Vector of autoregressive coefficients.
- eps: An optional (T+burnin x q) matrix with standard normal errors to be used. Errors will be generated if not provided.
- Z: A (T x qz) matrix with exogenous regressors (Optional) and where qz is the number of exogenous variables.
- betaZ: A (qz x 1) matrix true coefficients on exogenous regressors (Optional) and where qz is the number of exogenous variables.

burnin   Number of simulated observations to remove from beginning. Default is 100.

Value

List with simulated autoregressive series and its DGP parameters.

Examples

```
set.seed(1234)
# Define DGP of AR process
mdl_ar <- list(n     = 500,
               mu    = 5,
               sigma = 2,
               phi   = c(0.5,0.2))

# Simulate process using simuAR() function
y_simu <- simuAR(mdl_ar)

plot(y_simu)
```

---

simuHMM   *Simulate Hidden Markov model with normally distributed errors*

Description

This function simulates a Hidden Markov Model process.

Usage

```
simuHMM(mdl_h0, burnin = 100)
```

Arguments

mdl_h0   List containing the following DGP parameters

- n: Length of series.
- k: Number of regimes.
- mu: A (k x q) vector of means.
- sigma: A (q x q) covariance matrix.
- q: Number of series.
- P: A (k x k) transition matrix (columns must sum to one).
- eps: An optional (T+burnin x q) matrix with standard normal errors to be used. Errors will be generated if not provided.
- Z: A (T x qz) matrix with exogenous regressors (Optional) and where qz is the number of exogenous variables.
- betaZ: A (qz x q) matrix true coefficients on exogenous regressors (Optional) and where qz is the number of exogenous variables.

burnin   Number of simulated observations to remove from beginning. Default is 100.

Value

List with simulated series and its DGP parameters.

Examples

```
set.seed(1234)

# ----- Univariate ----- #
# Define DGP
mdl_hmm <- list(n     = 1000,
                q     = 1,
                mu    = as.matrix(c(5,
                                   -2)),
                sigma = list(as.matrix(5.0),
                             as.matrix(7.0)),
                k     = 2,
                P     = rbind(c(0.90, 0.10),
```

```
                                     c(0.10, 0.90)))

# Simulate process using simuHMM() function
y_hmm_simu <- simuHMM(mdl_hmm)

plot(y_hmm_simu)

# ----- Multivariate ----- #
# Define DGP
mdl_hmm <- list(n     = 1000,
                q     = 2,
                mu    = rbind(c(5, -2),
                              c(10, 2)),
                sigma = list(rbind(c(5.0, 1.5),
                                   c(1.5, 1.0)),
                             rbind(c(7.0, 3.0),
                                   c(3.0, 2.0))),
                k     = 2,
                P     = rbind(c(0.90, 0.10),
                              c(0.10, 0.90)))

# Simulate process using simuHMM() function
y_hmm_simu <- simuHMM(mdl_hmm)


plot(y_hmm_simu)
```

---

simuMSAR   *Simulate Markov-switching autoregressive process*

Description

This function simulates a Markov-switching autoregressive process.

Usage

```
simuMSAR(mdl_h0, burnin = 100)
```

Arguments

mdl_h0   List containing the following DGP parameters

- n: Length of series.
- k: Number of regimes.
- mu: A (k x 1) vector with mean of process in each regime.
- sigma: A (k x 1) vector with standard deviation of process in each regime.
- phi: Vector of autoregressive coefficients.
- P: A (k x k) transition matrix (columns must sum to one).
- eps: An optional (T+burnin x q) matrix with standard normal errors to be used. Errors will be generated if not provided.

burnin   Number of simulated observations to remove from beginning. Default is 100.

Value

List with simulated Markov-switching autoregressive process and its DGP properties.

Examples

```
set.seed(1234)
# Define DGP of MS AR process
mdl_ms2 <- list(n    = 500,
                mu   = c(5,10),
                sigma = c(1,2),
                phi  = c(0.5, 0.2),
                k    = 2,
                P    = rbind(c(0.90, 0.10),
                             c(0.10, 0.90)))

# Simulate process using simuMSAR() function
y_ms_simu <- simuMSAR(mdl_ms2)

plot(y_ms_simu)
```

---

simuMSARX   *Simulate Markov-switching ARX process*

Description

This function simulates a Markov-switching autoregressive process.

Usage

```
simuMSARX(mdl_h0, burnin = 100)
```

Arguments

mdl_h0   List containing the following DGP parameters

- n: Length of series.
- k: Number of regimes.
- mu: A (k x 1) vector with mean of process in each regime.
- sigma: A (k x 1) vector with standard deviation of process in each regime.
- phi: Vector of autoregressive coefficients.
- P: A (k x k) transition matrix (columns must sum to one).
- eps: An optional (T+burnin x q) matrix with standard normal errors to be used. Errors will be generated if not provided.
- Z: A (T x qz) matrix with exogenous regressors (Optional) and where qz is the number of exogenous variables.
- betaZ: A (qz x 1) matrix true coefficients on exogenous regressors (Optional) and where qz is the number of exogenous variables.

burnin   Number of simulated observations to remove from beginning. Default is 100.

Value

List with simulated Markov-switching autoregressive process and its DGP properties.

Examples

```
set.seed(1234)
# Define DGP of MS AR process
mdl_ms2 <- list(n     = 500,
                mu    = c(5,10),
                sigma = c(1,2),
                phi   = c(0.5, 0.2),
                k     = 2,
                P     = rbind(c(0.90, 0.10),
                              c(0.10, 0.90)))

# Simulate process using simuMSAR() function
y_ms_simu <- simuMSAR(mdl_ms2)

plot(y_ms_simu)
```

---

simuMSVAR   *Simulate Markov-switching vector autoregressive process*

Description

This function simulates a Markov-switching vector autoregressive process.

Usage

```
simuMSVAR(mdl_h0, burnin = 100)
```

Arguments

mdl_h0   List containing the following DGP parameters

- n: Length of series.
- k: Number of regimes.
- mu: A (k x q) matrix of means.
- sigma: List with k (q x q) covariance matrices.
- phi: A (q x qp) matrix of autoregressive coefficients.
- p: Number of autoregressive lags.
- q: Number of series.
- P: A (k x k) transition matrix (columns must sum to one).
- eps: An optional (T+burnin x q) matrix with standard normal errors to be used. Errors will be generated if not provided.

burnin   Number of simulated observations to remove from beginning. Default is 100.

Value

List with simulated vector autoregressive series and its DGP parameters.

Examples

```
set.seed(1234)
# Define DGP of MS VAR process
mdl_msvar2 <- list(n    = 1000,
                   p    = 1,
                   q    = 2,
                   mu   = rbind(c(5, -2),
                               c(10, 2)),
                   sigma = list(rbind(c(5.0, 1.5),
                                      c(1.5, 1.0)),
                                rbind(c(7.0, 3.0),
                                      c(3.0, 2.0))),
                   phi  = rbind(c(0.50, 0.30),
                               c(0.20, 0.70)),
                   k    = 2,
                   P    = rbind(c(0.90, 0.10),
                               c(0.10, 0.90)))

# Simulate process using simuMSVAR() function
y_msvar_simu <- simuMSVAR(mdl_msvar2)

plot(y_msvar_simu)
```

---

simuMSVARX   *Simulate Markov-switching VARX process*

Description

This function simulates a Markov-switching VARX process.

Usage

```
simuMSVARX(mdl_h0, burnin = 100)
```

Arguments

mdl_h0   List containing the following DGP parameters

- n: Length of series.
- k: Number of regimes.
- mu: A (k x q) matrix of means.
- sigma: List with k (q x q) covariance matrices.
- phi: A (q x qp) matrix of autoregressive coefficients.
- p: Number of autoregressive lags.

- q: Number of series.
- P: A (k x k) transition matrix (columns must sum to one).
- eps: An optional (T+burnin x q) matrix with standard normal errors to be used. Errors will be generated if not provided.
- Z: A (T x qz) matrix with exogenous regressors (Optional) and where qz is the number of exogenous variables.
- betaZ: A (qz x q) matrix true coefficients on exogenous regressors (Optional) and where qz is the number of exogenous variables.

burnin   Number of simulated observations to remove from beginning. Default is 100.

Value

List with simulated vector autoregressive series and its DGP parameters.

Examples

```
set.seed(1234)
# Define DGP of MS VAR process
mdl_msvar2 <- list(n     = 1000,
                   p     = 1,
                   q     = 2,
                   mu    = rbind(c(5, -2),
                                 c(10, 2)),
                   sigma = list(rbind(c(5.0, 1.5),
                                      c(1.5, 1.0)),
                                rbind(c(7.0, 3.0),
                                      c(3.0, 2.0))),
                   phi   = rbind(c(0.50, 0.30),
                                 c(0.20, 0.70)),
                   k     = 2,
                   P     = rbind(c(0.90, 0.10),
                                 c(0.10, 0.90)))

# Simulate process using simuMSVAR() function
y_msvar_simu <- simuMSVAR(mdl_msvar2)

plot(y_msvar_simu)
```

---

simuNorm   *Simulate normally distributed process*

Description

This function simulates a normally distributed process.

Usage

```
simuNorm(mdl_h0, burnin = 0)
```

Arguments

mdl_h0	List containing the following DGP parameters

- n: Length of series.
- mu: A (q x 1) vector of means.
- sigma: A (q x q) covariance matrix.
- q: Number of series.
- eps: An optional (T+burnin x q) matrix with standard normal errors to be used. Errors will be generated if not provided.
- Z: A (T x qz) matrix with exogenous regressors (Optional) and where qz is the number of exogenous variables.
- betaZ: A (qz x q) matrix true coefficients on exogenous regressors (Optional) and where qz is the number of exogenous variables.

burnin	Number of simulated observations to remove from beginning. Default is 100.

Value

List with simulated series and its DGP parameters.

Examples

```
set.seed(1234)
# Define DGP
mdl_norm <- list(n    = 1000,
                 q    = 2,
                 mu   = c(5, -2),
                 sigma = rbind(c(5.0, 1.5),
                              c(1.5, 1.0)))

# Simulate process using simuNorm() function
y_norm_simu <- simuNorm(mdl_norm)

plot(y_norm_simu)
```

---

simuVAR	*Simulate VAR process*

Description

This function simulates a vector autoregresive process.

Usage

```
simuVAR(mdl_h0, burnin = 100)
```

Arguments

mdl_h0   List containing the following DGP parameters

- n: Length of series.
- mu: A (q x 1) vector of means.
- sigma: A (q x q) covariance matrix.
- phi: A (q x qp) matrix of autoregressive coefficients.
- p: Number of autoregressive lags.
- q: Number of series.
- eps: An optional (T+burnin x q) matrix with standard normal errors to be used. Errors will be generated if not provided.

burnin   Number of simulated observations to remove from beginning. Default is 100.

Value

List with simulated vector autoregressive series and its DGP parameters.

---

simuVARX   *Simulate VAR process*

Description

This function simulates a vector autoregresive process.

Usage

```
simuVARX(mdl_h0, burnin = 100)
```

Arguments

mdl_h0   List containing the following DGP parameters

- n: Length of series.
- mu: A (q x 1) vector of means.
- sigma: A (q x q) covariance matrix.
- phi: A (q x (q x p)) matrix of autoregressive coefficients.
- p: Number of autoregressive lags.
- q: Number of series.
- eps: An optional (T+burnin x q) matrix with standard normal errors to be used. Errors will be generated if not provided.
- Z: A (T x qz) matrix with exogenous regressors (Optional) and where qz is the number of exogenous variables.
- betaZ: A (qz x q) matrix true coefficients on exogenous regressors (Optional) and where qz is the number of exogenous variables.

burnin   Number of simulated observations to remove from beginning. Default is 100.

Value

List with simulated vector autoregressive series and its DGP parameters.

USGNP   *US GNP data 1947Q2 - 2024Q2*

Description

US GNP data 1947Q2 - 2024Q2

Usage

USGNP

Format

This data is used in Rodriguez-Rondon & Dufour (2024). The series ranges from 1947Q2 to 2024Q2.

Vector of dates

Date **GNP** US GNP series

GNP_gr log difference of US GNP series

Source

<https://fred.stlouisfed.org/graph/?g=UKDQ>

References

U.S. Bureau of Economic Analysis, Gross National Product [GNP], retrieved from FRED, Federal Reserve Bank of St. Louis; <https://fred.stlouisfed.org/series/GNP>, September, 2024.

Rodriguez-Rondon, Gabriel and Jean-Marie Dufour. 2024. "Monte Carlo Likelihood Ratio Tests for Markov Switching Models." *Unpublished manuscript*.

USRGDP   *US Real GDP data 1947Q2 - 2024Q2*

Description

US Real GDP data 1947Q2 - 2024Q2

Usage

    USRGDP

Format

This data is used in Rodriguez-Rondon & Dufour (2024). The series ranges from 1947Q2 to 2024Q2.

Vector of dates

RGDP US Real GDP series

RGDP_gr log difference of US Real GDP series

Source

<https://fred.stlouisfed.org/series/GDPC1>

References

U.S. Bureau of Economic Analysis, Real Gross Domestic Product [GDPC1], retrieved from FRED, Federal Reserve Bank of St. Louis; <https://fred.stlouisfed.org/series/GDPC1>, September, 2024.

Rodriguez-Rondon, Gabriel and Jean-Marie Dufour. 2024. "Monte Carlo Likelihood Ratio Tests for Markov Switching Models." *Unpublished manuscript*.

VARmdl   *Vector autoregressive model*

Description

This function estimates a vector autoregresive model with p lags. This can be used for the null hypothesis of a linear model against an alternative hypothesis of a Markov switching vector autoregressive model with k regimes.

Usage

    VARmdl(Y, p, control = list())

Arguments

Y	a (T x q) matrix of observations.
p	integer determining the number of autoregressive lags.
control	List with model options including:

- const: Boolean determining whether to estimate model with constant if TRUE or not if FALSE. Default is TRUE.
- getSE: Boolean determining whether to compute standard errors of parameters if TRUE or not if FALSE. Default is TRUE.

Value

List of class VARmdl (S3 object) with model attributes including:

- y: a (T-p x q) matrix of observations.
- X: a (T-p x p*q + const) matrix of lagged observations with a leading column of 1s if const=TRUE or not if const=FALSE.
- x: a (T-p x p*q) matrix of lagged observations.
- fitted: a (T-p x q) matrix of fitted values.
- resid: a (T-p x q) matrix of residuals.
- mu: a (1 x q) vector of estimated means of each process.
- beta: a ((1 + p) x q) matrix of estimated coefficients. .
- intercept: estimate of intercepts.
- phi: a (q x p*q) matrix of estimated autoregressive coefficients.
- Fmat: Companion matrix containing autoregressive coefficients.
- stdev: a (q x 1) vector of estimated standard deviation of each process.
- sigma: a (q x q) estimated covariance matrix.
- theta: vector containing: mu, vech(sigma), and vec(t(phi)).
- theta_mu_ind: vector indicating location of mean with 1 and 0 otherwise.
- theta_sig_ind: vector indicating location of variance and covariances with 1 and 0 otherwise.
- theta_var_ind: vector indicating location of variances with 1 and 0 otherwise.
- theta_phi_ind: vector indicating location of autoregressive coefficients with 1 and 0 otherwise.
- stationary: Boolean indicating if process is stationary if TRUE or non-stationary if FALSE.
- n: number of observations after lag transformation (i.e., n = T-p).
- p: number of autoregressive lags.
- q: number of series.
- k: number of regimes. This is always 1 in VARmdl.
- Fmat: matrix from companion form. Used to determine is process is stationary.
- control: List with model options used.
- logLike: log-likelihood.
- AIC: Akaike information criterion.

- BIC: Bayesian (Schwarz) information criterion.
- Hess: Hessian matrix. Approximated using [hessian](#) and only returned if getSE=TRUE.
- info_mat: Information matrix. Computed as the inverse of -Hess. If matrix is not PD then nearest PD matrix is obtained using [nearest_spd](#). Only returned if getSE=TRUE.
- nearPD_used: Boolean determining whether nearPD function was used on info_mat if TRUE or not if FALSE. Only returned if getSE=TRUE.
- theta_se: standard errors of parameters in theta. Only returned if getSE=TRUE.

See Also

[MSVARmdl](#)

Examples

```
# ----- Bivariate VAR(1) process ----- #
set.seed(1234)
# Define DGP of VAR process
mdl_var <- list(n    = 1000,
                p    = 1,
                q    = 2,
                mu   = c(5,-2),
                sigma = rbind(c(5.0, 1.5),
                              c(1.5, 1.0)),
                phi  = rbind(c(0.50, 0.30),
                              c(0.20, 0.70)))

# Simulate process using simuVAR() function
y_simu <- simuVAR(mdl_var)

# Set options for model estimation
control <- list(const  = TRUE,
                getSE  = TRUE)

# Estimate model
y_var_mdl <- VARmdl(y_simu$y, p = 2, control = control)
summary(y_var_mdl)
```

VARXmdl   *Vector X autoregressive model*

Description

This function estimates a vector autoregresive model with p lags. This can be used for the null hypothesis of a linear model against an alternative hypothesis of a Markov switching vector autoregressive model with k regimes.

Usage

```
VARXmdl(Y, p, Z, control = list())
```

Arguments

Y	a (`T x q`) matrix of observations.
p	integer determining the number of autoregressive lags.
Z	a (`T x qz`) matrix of exogenous regressors.
control	List with model options including:

- const: Boolean determining whether to estimate model with constant if `TRUE` or not if `FALSE`. Default is `TRUE`.
- getSE: Boolean determining whether to compute standard errors of parameters if `TRUE` or not if `FALSE`. Default is `TRUE`.

Value

List of class `VARmdl` (`S3` object) with model attributes including:

- y: a (`T-p x q`) matrix of observations.
- X: a (`T-p x p*q + const`) matrix of lagged observations with a leading column of 1s if `const=TRUE` or not if `const=FALSE`.
- x: a (`T-p x p*q`) matrix of lagged observations.
- fitted: a (`T-p x q`) matrix of fitted values.
- resid: a (`T-p x q`) matrix of residuals.
- mu: a (`1 x q`) vector of estimated means of each process.
- beta: a (`(1 + p + qz) x q`) matrix of estimated coefficients.
- betaZ: a (`qz x q`) matrix of estimated exogenous regressor coefficients.
- intercept: estimate of intercepts.
- phi: a (`q x p*q`) matrix of estimated autoregressive coefficients.
- Fmat: Companion matrix containing autoregressive coefficients.
- stdev: a (`q x 1`) vector of estimated standard deviation of each process.
- sigma: a (`q x q`) estimated covariance matrix.
- theta: vector containing: mu, `vech(sigma)`, and `vec(t(phi))`.
- theta_mu_ind: vector indicating location of mean with 1 and 0 otherwise.
- theta_sig_ind: vector indicating location of variance and covariances with 1 and 0 otherwise.
- theta_var_ind: vector indicating location of variances with 1 and 0 otherwise.
- theta_phi_ind: vector indicating location of autoregressive coefficients with 1 and 0 otherwise.
- stationary: Boolean indicating if process is stationary if `TRUE` or non-stationary if `FALSE`.
- n: number of observations after lag transformation (i.e., `n = T-p`).
- p: number of autoregressive lags.
- q: number of series.
- k: number of regimes. This is always 1 in `VARmdl`.
- Fmat: matrix from companion form. Used to determine is process is stationary.
- control: List with model options used.

- logLike: log-likelihood.

- AIC: Akaike information criterion.

- BIC: Bayesian (Schwarz) information criterion.

- Hess: Hessian matrix. Approximated using hessian and only returned if getSE=TRUE.

- info_mat: Information matrix. Computed as the inverse of -Hess. If matrix is not PD then nearest PD matrix is obtained using nearest_spd. Only returned if getSE=TRUE.

- nearPD_used: Boolean determining whether nearPD function was used on info_mat if TRUE or not if FALSE. Only returned if getSE=TRUE.

- theta_se: standard errors of parameters in theta. Only returned if getSE=TRUE.

See Also

MSVARmdl

Examples

```
# ----- Bivariate VAR(1) process ----- #
set.seed(1234)
# Define DGP of VAR process
mdl_var <- list(n    = 1000,
                p    = 1,
                q    = 2,
                mu   = c(5,-2),
                sigma = rbind(c(5.0, 1.5),
                              c(1.5, 1.0)),
                phi  = rbind(c(0.50, 0.30),
                             c(0.20, 0.70)))

# Simulate process using simuVAR() function
y_simu <- simuVAR(mdl_var)

# Set options for model estimation
control <- list(const = TRUE,
                getSE  = TRUE)

# Estimate model
y_var_mdl <- VARmdl(y_simu$y, p = 2, control = control)
summary(y_var_mdl)
```

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