

# Package ‘LMest’

December 6, 2024

**Title** Generalized Latent Markov Models

**Description** Latent Markov models for longitudinal continuous and categorical data. See Bartolucci, Pandolfi, Pennoni (2017)<[doi:10.18637/jss.v081.i04](https://doi.org/10.18637/jss.v081.i04)>.

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## Description

The package LMest is a framework for specifying and fitting Latent (or Hidden) Markov (LM) models for the analysis of longitudinal continuous and categorical data. Covariates are also included in the model specification through suitable parameterizations.

## Details

Different LM models are estimated through specific functions requiring a data frame in long format. Responses are mainly categorical, the functions referred to continuous responses are specified with Cont. When responses are continuous, the (multivariate) Gaussian distribution, conditional to the latent process, is assumed. The functions are the following:

**lmest** Function to estimate LM models for categorical responses generating the following classes:

- **LMbasic-class** for the basic LM model without covariates.
- **LMmanifest-class** for the LM model with covariates in the measurement submodel.
- **LMlatent-class** for the LM model with covariates in the latent model.

**lmestCont** Function to estimate LM models for continuous outcomes generating the following classes:

- **LMbasiccont-class** for the basic LM model for continuous responses without covariates.
- **LMlatentcont-class** for the LM model for continuous responses with covariates in the latent model.

**lmestMixed** Function to estimate Mixed LM models for categorical responses with discrete random effects in the latent model generating the following class:

- **LMmixed-class** for the mixed LM model.

**lmestMc** Function to estimate Markov Chain models for categorical responses generating the following classes:

- **MCbasic-class** for the Markov Chain (MC) model without covariates.
- **MCcov-class** for the MC model with covariates.

Maximum likelihood estimation of model parameters is performed through the Expectation-Maximization algorithm, which is implemented by relying on Fortran routines.

Model selection is provided by `lmest` and `lmestCont` functions. In addition, function `lmestSearch` allows us to deal with both model selection and multimodality of the likelihood function. Two main criteria are provided to select the number of latent states: the Akaike Information Criterion and the Bayesian Information Criterion.

Prediction of the latent states is performed by the function `lmestDecoding`: for local and global decoding (Viterbi algorithm) from the output of functions `lmest`, `lmestCont` and `lmestMixed`.

The package allows us to deal with missing responses, including drop-out and non-monotonic missingness, under the missing-at-random assumption.

Standard errors for the parameter estimates are obtained by the function `se` through exact computation of the information matrix or by reliable numerical approximations of this matrix.

The `print` method shows some convergence information, and the `summary` method shows the estimation results.

The package also provides some real and simulated data sets that are listed using the function `data(package = "LMest")`.

### Author(s)

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Maintainer: Francesco Bartolucci <francesco.bartolucci@unipg.it>

### References

Bartolucci, F., Pandolfi, S. and Pennoni, F. (2017). LMest: An R Package for Latent Markov Models for Longitudinal Categorical Data, *Journal of Statistical Software*, **81**, 1-38, doi:10.18637/jss.v081.i04.

Bartolucci, F., Farcomeni, A. and Pennoni, F. (2013). *Latent Markov Models for Longitudinal Data*, Chapman and Hall/CRC press.

Bartolucci, F., Farcomeni, A., and Pennoni, F. (2014). Latent Markov models: A review of a general framework for the analysis of longitudinal data with covariates (with discussion). *TEST*, **23**, 433-465.

### See Also

`lmest`, `lmestCont`, `lmestMc`, `lmestMixed`, `LMmixed-class`, `LMbasic-class`, `LMbasiccont-class`, `LMlatent-class`, `LMlatentcont-class`, `LMmanifest-class`

---

bootstrap	<i>Parametric bootstrap</i>
-----------	-----------------------------

---

### Description

Function that performs bootstrap parametric resampling to compute standard errors for the parameter estimates.

### Usage

```
bootstrap(est, ...)
## S3 method for class 'LMbasic'
bootstrap(est, B = 100, seed = NULL, ...)
## S3 method for class 'LMbasiccont'
bootstrap(est, B=100, seed = NULL, ...)
## S3 method for class 'LMlatent'
bootstrap(est, B = 100, seed = NULL, ...)
## S3 method for class 'LMlatentcont'
bootstrap(est, B = 100, seed = NULL, ...)
```

### Arguments

est	an object obtained from a call to <a href="#">lmest</a> and <a href="#">lmestCont</a>
B	number of bootstrap samples
seed	an integer value with the random number generator state
...	further arguments

### Value

Average of bootstrap estimates and standard errors for the model parameters in est object.

### Author(s)

Francesco Bartolucci, Silvia Pandolfi, Fulvia Pennoni, Alessio Farcomeni, Alessio Serafini

### Examples

```
## Not run:

# LM model for categorical responses with covariates on the latent model

data("data_SRHS_long")
SRHS <- data_SRHS_long[1:2400,]

# Categories rescaled to vary from 0 ("poor") to 4 ("excellent")

SRHS$srhs <- 5 - SRHS$srhs
```

```

out1 <- lmest(responsesFormula = srhs ~ NULL,
             index = c("id","t"),
             data = SRHS,
             k = 3,
             tol = 1e-8,
             start = 1,
             modBasic = 1,
             out_se = TRUE,
             seed = 123)

boot1 <- bootstrap(out1)

out2 <- lmest(responsesFormula = srhs ~ NULL,
             latentFormula = ~
             I(gender - 1) +
             I(0 + (race == 2) + (race == 3)) +
             I(0 + (education == 4)) +
             I(0 + (education == 5)) +
             I(age - 50) + I((age-50)^2/100),
             index = c("id","t"),
             data = SRHS,
             k = 2,
             paramLatent = "multilogit",
             start = 0)

boot2 <- bootstrap(out2)

# LM model for continous responses without covariates

data(data_long_cont)

out3 <- lmestCont(responsesFormula = Y1 + Y2 + Y3 ~ NULL,
                 index = c("id", "time"),
                 data = data_long_cont,
                 k = 3,
                 modBasic=1,
                 tol=10^-5)

boot3 <- bootstrap(out3)

# LM model for continous responses with covariates

out4 <- lmestCont(responsesFormula = Y1 + Y2 + Y3 ~ NULL,
                 latentFormula = ~ X1 + X2,
                 index = c("id", "time"),
                 data = data_long_cont,
                 k = 3,
                 output=TRUE)

boot4 <- bootstrap(out4)

## End(Not run)

```

---

bootstrap\_lm\_basic      *Parametric bootstrap for the basic LM model*

---

### Description

Function that performs bootstrap parametric resampling to compute standard errors for the parameter estimates.

**The function is no longer maintained. Please look at [bootstrap](#) function.**

### Usage

```
bootstrap_lm_basic(piv, Pi, Psi, n, B = 100, start = 0, mod = 0, tol = 10^-6)
```

### Arguments

piv	initial probability vector
Pi	probability transition matrices ( $k \times k \times TT$ )
Psi	matrix of conditional response probabilities ( $mb \times k \times r$ )
n	sample size
B	number of bootstrap samples
start	type of starting values (0 = deterministic, 1 = random)
mod	model on the transition probabilities (0 for time-heter., 1 for time-homog., from 2 to $(TT-1)$ partial homog. of that order)
tol	tolerance level for convergence

### Value

mPsi	average of bootstrap estimates of the conditional response probabilities
mpiv	average of bootstrap estimates of the initial probability vector
mPi	average of bootstrap estimates of the transition probability matrices
sePsi	standard errors for the conditional response probabilities
sepiv	standard errors for the initial probability vector
sePi	standard errors for the transition probability matrices

### Author(s)

Francesco Bartolucci, Silvia Pandolfi, University of Perugia (IT), <http://www.stat.unipg.it/bartolucci>

**Examples**

```
## Not run:
# Example of drug consumption data
# load data
data(data_drug)
data_drug <- as.matrix(data_drug)
S <- data_drug[,1:5]-1
yv <- data_drug[,6]
n <- sum(yv)
# fit of the Basic LM model
k <- 3
out1 <- est_lm_basic(S, yv, k, mod = 1, out_se = TRUE)
out2 <- bootstrap_lm_basic(out1$piv, out1$Pi, out1$Psi, n, mod = 1, B = 1000)

## End(Not run)
```

---

bootstrap\_lm\_basic\_cont

*Parametric bootstrap for the basic LM model for continuous outcomes*


---

**Description**

Function that performs bootstrap parametric resampling to compute standard errors for the parameter estimates.

**The function is no longer maintained. Please look at [bootstrap](#) function.**

**Usage**

```
bootstrap_lm_basic_cont(piv, Pi, Mu, Si, n, B = 100, start = 0, mod = 0, tol = 10^-6)
```

**Arguments**

piv	initial probability vector
Pi	probability transition matrices (k x k x TT)
Mu	matrix of conditional means for the response variables (r x k)
Si	var-cov matrix common to all states (r x r)
n	sample size
B	number of bootstrap samples
start	type of starting values (0 = deterministic, 1 = random)
mod	model on the transition probabilities (0 for time-heter., 1 for time-homog., from 2 to (TT-1) partial homog. of that order)
tol	tolerance level for convergence



**Value**

mMu	average of bootstrap estimates of the conditional means of the response variables
mSi	average of bootstrap estimates of the var-cov matrix
mpiv	average of bootstrap estimates of the initial probability vector
mPi	average of bootstrap estimates of the transition probability matrices
seMu	standard errors for the conditional means of the response variables
seSi	standard errors for the var-cov matrix
sepiv	standard errors for the initial probability vector
sePi	standard errors for the transition probability matrices

**Author(s)**

Francesco Bartolucci, Silvia Pandolfi, University of Perugia (IT), <http://www.stat.unipg.it/bartolucci>

**Examples**

```
## Not run:
# Example based on multivariate longitudinal continuous data

data(data_long_cont)
res <- long2matrices(data_long_cont$id, X = cbind(data_long_cont$X1, data_long_cont$X2),
  Y = cbind(data_long_cont$Y1, data_long_cont$Y2, data_long_cont$Y3))
Y <- res$YY
n <- dim(Y)[1]

# fit of the Basic LM model for continuous outcomes
k <- 3
out1 <- est_lm_basic_cont(Y, k, mod = 1)
out2 <- bootstrap_lm_basic_cont(out1$piv, out1$Pi, out1$Mu, out1$Si, n, mod = 1, B = 1000)

## End(Not run)
```

---

bootstrap\_lm\_cov\_latent

*Parametric bootstrap for LM models with individual covariates in the latent model*

---

**Description**

Function that performs bootstrap parametric resampling to compute standard errors for the parameter estimates.

**The function is no longer maintained. Please look at [bootstrap](#) function.**

**Usage**

```
bootstrap_lm_cov_latent(X1, X2, param = "multilogit", Psi, Be, Ga, B = 100,
  fort = TRUE)
```

**Arguments**

X1	matrix of covariates affecting the initial probabilities (n x nc1)
X2	array of covariates affecting the transition probabilities (n x TT-1 x nc2)
param	type of parametrization for the transition probabilities ("multilogit" = standard multinomial logit for every row of the transition matrix, "difflogit" = multinomial logit based on the difference between two sets of parameters)
Psi	array of conditional response probabilities (mb x k x r)
Be	parameters affecting the logit for the initial probabilities
Ga	parameters affecting the logit for the transition probabilities
B	number of bootstrap samples
fort	to use fortran routine when possible (FALSE for not use fortran)

**Value**

mPsi	average of bootstrap estimates of the conditional response probabilities
mBe	average of bootstrap estimates of the parameters affecting the logit for the initial probabilities
mGa	average of bootstrap estimates of the parameters affecting the logit for the transition probabilities
sePsi	standard errors for the conditional response probabilities
seBe	standard errors for the parameters in Be
seGa	standard errors for the parameters in Ga

**Author(s)**

Francesco Bartolucci, Silvia Pandolfi - University of Perugia (IT)

**Examples**

```
## Not run:
# Example based on self-rated health status (SRHS) data
# load SRHS data
data(data_SRHS_long)
dataSRHS <- data_SRHS_long

TT <- 8
head(dataSRHS)
res <- long2matrices(dataSRHS$id, X = cbind(dataSRHS$gender-1,
  dataSRHS$race == 2 | dataSRHS$race == 3, dataSRHS$education == 4,
  dataSRHS$education == 5, dataSRHS$age-50, (dataSRHS$age-50)^2/100),
  Y = dataSRHS$srhs)
```

```

# matrix of responses (with ordered categories from 0 to 4)
S <- 5-res$YY

# matrix of covariates (for the first and the following occasions)
# columns are: gender,race,educational level (2 columns),age,age^2
X1 <- res$XX[,1,]
X2 <- res$XX[,2:TT,]

# estimate the model
out1 <- est_lm_cov_latent(S, X1, X2, k = 2, output = TRUE, out_se = TRUE)

out2 <- bootstrap_lm_cov_latent(X1, X2, Psi = out1$Psi, Be = out1$Be, Ga = out1$Ga, B = 1000)

## End(Not run)

```

---

bootstrap\_lm\_cov\_latent\_cont

*Parametric bootstrap for LM models for continuous outcomes with individual covariates in the latent model*

---

## Description

Function that performs bootstrap parametric resampling to compute standard errors for the parameter estimates.

**The function is no longer maintained. Please look at [bootstrap](#) function.**

## Usage

```
bootstrap_lm_cov_latent_cont(X1, X2, param = "multilogit", Mu, Si, Be, Ga, B = 100)
```

## Arguments

X1	matrix of covariates affecting the initial probabilities (n x nc1)
X2	array of covariates affecting the transition probabilities (n x TT-1 x nc2)
param	type of parametrization for the transition probabilities ("multilogit" = standard multinomial logit for every row of the transition matrix, "difflogit" = multinomial logit based on the difference between two sets of parameters)
Mu	matrix of conditional means for the response variables (r x k)
Si	var-cov matrix common to all states (r x r)
Be	parameters affecting the logit for the initial probabilities
Ga	parameters affecting the logit for the transition probabilities
B	number of bootstrap samples

**Value**

mMu	average of bootstrap estimates of the conditional means for the response variables
mSi	average of bootstrap estimates of the var-cov matrix
mBe	average of bootstrap estimates of the parameters affecting the logit for the initial probabilities
mGa	average of bootstrap estimates of the parameters affecting the logit for the transition probabilities
seMu	standard errors for the conditional means
seSi	standard errors for the var-cov matrix
seBe	standard errors for the parameters in Be
seGa	standard errors for the parameters in Ga

**Author(s)**

Francesco Bartolucci, Silvia Pandolfi - University of Perugia (IT)

**Examples**

```
## Not run:
# Example based on multivariate longitudinal continuous data

data(data_long_cont)
TT <- 5
res <- long2matrices(data_long_cont$id, X = cbind(data_long_cont$X1, data_long_cont$X2),
                    Y = cbind(data_long_cont$Y1, data_long_cont$Y2, data_long_cont$Y3))
Y <- res$YY
X1 <- res$XX[,1,]
X2 <- res$XX[,2:TT,]

# estimate the model
est <- est_lm_cov_latent_cont(Y, X1, X2, k = 3, output = TRUE)
out <- bootstrap_lm_cov_latent_cont(X1, X2, Mu = est$Mu, Si = est$Si,
                                   Be = est$Be, Ga = est$Ga, B = 1000)

## End(Not run)
```

---

data\_criminal\_sim

*Criminal dataset*

---

**Description**

Simulated dataset about crimes committed by a cohort of subjects.

**Usage**

```
data(data_criminal_sim)
```

**Format**

A data frame with 60000 observations on the following 13 variables.

id subject id

sex gender of the subject

time occasion of observation

y1 crime of type 1 (violence against the person)

y2 crime of type 2 (sexual offences)

y3 crime of type 3 (burglary)

y4 crime of type 4 (robbery)

y5 crime of type 5 (theft and handling stolen goods)

y6 crime of type 6 (fraud and forgery)

y7 crime of type 7 (criminal damage)

y8 crime of type 8 (drug offences)

y9 crime of type 9 (motoring offences)

y10 crime of type 10 (other offences)

**References**

Bartolucci, F., Pennoni, F. and Francis, B. (2007), A latent Markov model for detecting patterns of criminal activity, *Journal of the Royal Statistical Society, series A*, **170**, pp. 115-132.

**Examples**

```
data(data_criminal_sim)
```

---

data\_drug

*Dataset about marijuana consumption*

---

**Description**

Longitudinal dataset derived from the National Youth Survey about marijuana consumption measured by ordinal variables with 3 categories with increasing levels of consumption (1 "never in the past year", 2 "no more than once in a month in the past year", 3 "more than once a month in the past year").

**Usage**

```
data(data_drug)
```

**Format**

A data frame with 51 observations on the following 6 variables.

V1 reported drug use at the 1st occasion

V2 reported drug use at the 2nd occasion

V3 reported drug use at the 3rd occasion

V4 reported drug use at the 4th occasion

V5 reported drug use at the 5th occasion

V6 frequency of the response configuration

**Source**

Elliot, D. S., Huizinga, D. and Menard, S. (1989) *Multiple Problem Youth: Delinquency, Substance Use, and Mental Health Problems*. New York: Springer.

**References**

Bartolucci, F. (2006) Likelihood inference for a class of latent Markov models under linear hypotheses on the transition probabilities. *Journal of the Royal Statistical Society, series B*, **68**, 155-178.

**Examples**

```
data(data_drug)
```

---

```
data_employment_sim  Employment dataset
```

---

**Description**

Simulated dataset related to a survey on the employment status of a cohort of graduates.

**Usage**

```
data(data_employment_sim)
```

**Format**

A data frame with 585 observations on the following variables:

id subject id.

time occasion of observation.

emp 0 if unemployed, 1 if employed.

area 1 if graduated in the South area, 2 if graduated in the North area.

grade 1 if grade at graduation is low, 2 if it is medium, 3 if it is high.

edu 1 if parents hold a university degree, 0 if not.

**References**

Pennoni, F., Pandolfi, S. and Bartolucci, F. (2024), LMest: An R Package for Estimating Generalized Latent Markov Models, *Submitted to the R Journal*, pp. 1-30.

**Examples**

```
data(data_employment_sim)
```

---

data_heart_sim	<i>Health dataset</i>
----------------	-----------------------

---

**Description**

Simulated longitudinal dataset coming from a medical study to assess the health state progression of patients after a certain treatment.

**Usage**

```
data(data_heart_sim)
```

**Format**

A data frame referred to 125 units observed at 6 time occasions on the following variables:

id subject id  
time occasion of observation  
sap systolic arterial pressure in mmgh  
dap diastolic arterial pressure in mmgh  
hr heart rate in bpm  
fluid fluid administration in ml/kg/h  
gender 1 for male, 2 for females  
age age in years

**References**

Pennoni, F., Pandolfi, S. and Bartolucci, F. (2024), LMest: An R Package for Estimating Generalized Latent Markov Models, *Submitted to the R Journal*, pp. 1-30.

**Examples**

```
data(data_heart_sim)
```

---

data_long_cont	<i>Multivariate Longitudinal Continuous (Gaussian) Data</i>
----------------	---

---

**Description**

Simulated multivariate longitudinal continuous dataset assuming that there are 500 subjects in the study whose data are collected at 5 equally-spaced time points.

**Usage**

```
data(data_long_cont)
```

**Format**

A data frame with 2500 observations on the following 7 variables.

id subject id.

time occasion of observation.

Y1 a numeric vector for the first longitudinal response.

Y2 a numeric vector for the second longitudinal response.

Y3 a numeric vector for the third longitudinal response.

X1 a numeric vector for the first covariate.

X2 a numeric vector for the second covariate.

**Examples**

```
data(data_long_cont)
```

---

data_market_sim	<i>Marketing dataset</i>
-----------------	--------------------------

---

**Description**

Simulated dataset related to customers of four different brands along with the prices of each transaction.

**Usage**

```
data(data_market_sim)
```



**Format**

A data frame with 200 observations on the following variables:

id subject id.

time occasion of observation.

brand 0 if the customer has purchased the product from brand A, 1 if brand B, 2 if brand C, 3 if brand D.

price 0 if the price of the transaction is in the range [0.1, 10], 1 if it is in (10, 30], 2 if it is in (30, 60], 3 if it is in (30, 100], 4 if it is in (100, 500] (in thousands of Euros).

age age of the customer in years

income income declared by the customer at the time of the first purchase (in thousands of Euros).

**References**

Pennoni, F., Pandolfi, S. and Bartolucci, F. (2024), LMest: An R Package for Estimating Generalized Latent Markov Models, *Submitted to the R Journal*, pp. 1-30.

**Examples**

```
data(data_market_sim)
```

---

data_SRHS_long	<i>Self-reported health status dataset</i>
----------------	--

---

**Description**

Dataset about self-reported health status derived from the Health and Retirement Study conducted by the University of Michigan.

**Usage**

```
data(data_SRHS_long)
```

**Format**

A data frame with 56592 observations on the following 6 variables.

t occasion of observation

id subject id

gender sex of the subject coded as 1 for "male", 2 for "female"

race race coded as 1 for "white", 2 for "black", 3 for "others"

education educational level coded as 1 for "high school", 2 for "general educational diploma", 3 for "high school graduate", 4 for "some college", 5 for "college and above"

age age at the different time occasions

srhs self-reported health status at the different time occasions coded as 1 for "excellent", 2 for "very good", 3 for "good", 4 for "fair", 5 for "poor"

**References**

Bartolucci, F., Bacci, S. and Pennoni, F. (2014) Longitudinal analysis of the self-reported health status by mixture latent autoregressive models, *Journal of the Royal Statistical Society - series C*, **63**, pp. 267-288

**Examples**

```
data(data_SRHS_long)
```

---

 decoding

---

*Perform local and global decoding*


---

**Description**

Function that performs local and global decoding (Viterbi) from the output of `est_lm_basic`, `est_lm_cov_latent`, `est_lm_cov_manifest`, and `est_lm_mixed`.

**The function is no longer maintained. Please look at [lmestDecoding](#) function**

**Usage**

```
decoding(est, Y, X1 = NULL, X2 = NULL, fort = TRUE)
```

**Arguments**

<code>est</code>	output from <code>est_lm_basic</code> , <code>est_lm_cov_latent</code> , <code>est_lm_cov_manifest</code> , or <code>est_lm_mixed</code>
<code>Y</code>	single vector or matrix of responses
<code>X1</code>	matrix of covariates on the initial probabilities ( <code>est_lm_cov_latent</code> ) or on the responses ( <code>est_lm_cov_manifest</code> )
<code>X2</code>	array of covariates on the transition probabilities
<code>fort</code>	to use Fortran routines

**Value**

<code>U1</code>	matrix of local decoded states corresponding to each row of <code>Y</code>
<code>Ug</code>	matrix of global decoded states corresponding to each row of <code>Y</code>

**Author(s)**

Francesco Bartolucci, Silvia Pandolfi, University of Perugia (IT), <http://www.stat.unipg.it/bartolucci>

## References

Viterbi A. (1967) Error Bounds for Convolutional Codes and an Asymptotically Optimum Decoding Algorithm. *IEEE Transactions on Information Theory*, **13**, 260-269.

Juan B., Rabiner L. (1991) Hidden Markov Models for Speech Recognition. *Technometrics*, **33**, 251-272.

## Examples

```
## Not run:
# example for the output from est_lm_basic

data(data_drug)
data_drug <- as.matrix(data_drug)
S <- data_drug[,1:5]-1
yv <- data_drug[,6]
n <- sum(yv)

# fit the Basic LM model

k <- 3
est <- est_lm_basic(S, yv, k, mod = 1)

# decoding for a single sequence

out1 <- decoding(est, S[1,])

# decoding for all sequences

out2 <- decoding(est, S)

# example for the output from est_lm_cov_latent with difflogit parametrization
data(data_SRHS_long)
dataSRHS <- data_SRHS_long[1:1600,]

TT <- 8
head(dataSRHS)
res <- long2matrices(dataSRHS$id, X = cbind(dataSRHS$gender-1,
dataSRHS$race == 2 | dataSRHS$race == 3, dataSRHS$education == 4,
dataSRHS$education == 5, dataSRHS$age-50, (dataSRHS$age-50)^2/100),
Y= dataSRHS$srhs)

# matrix of responses (with ordered categories from 0 to 4)
S <- 5-res$YY

# matrix of covariates (for the first and the following occasions)
# columns are: gender,race,educational level (2 columns),age,age^2)
X1 <- res$XX[,1,]
X2 <- res$XX[,2:TT,]

# estimate the model
```

```

est <- est_lm_cov_latent(S, X1, X2, k = 2, output = TRUE, param = "difflogit")
# decoding for a single sequence
out1 <- decoding(est, S[1,,], X1[1,,], X2[1,,])
# decoding for all sequences
out2 <- decoding(est, S, X1, X2)

## End(Not run)

```

---

draw

---

*Draw simulated sample from a Generalized Latent Markov Model*


---

### Description

Draw a sample for LMest objects of classes: LMbasic, LMbasiccont, LMlatent, LMlatentcont, and LMmixed

### Usage

```

## S3 method for class 'LMbasic'
draw(est, n = NULL, TT = NULL, format = c("long", "matrices"), seed = NULL, ...)
## S3 method for class 'LMlatent'
draw(est, n = NULL, TT = NULL, data, index, format = c("long", "matrices"),
      fort = TRUE, seed = NULL, ...)
## S3 method for class 'LMbasiccont'
draw(est, n = NULL, TT = NULL, format = c("long", "matrices"), seed = NULL, ...)
## S3 method for class 'LMlatentcont'
draw(est, n = NULL, TT = NULL, data, index, format = c("long", "matrices"),
      fort = TRUE, seed = NULL, ...)
## S3 method for class 'LMmixed'
draw(est, n = NULL, TT = NULL, format = c("long", "matrices"), seed = NULL, ...)

```

### Arguments

est	object of class LMbasic ( <a href="#">LMbasic-class</a> ), LMlatent ( <a href="#">LMlatent-class</a> ), class LMbasiccont ( <a href="#">LMbasiccont-class</a> ), LMlatentcont ( <a href="#">LMlatentcont-class</a> ), or LMmixed ( <a href="#">LMmixed-class</a> )
n	sample size
format	character string indicating the format of final responses matrix
seed	an integer value with the random number generator state
data	a data frame in long format, with rows corresponding to observations and columns corresponding to covariates, a column corresponding to time occasions and a column containing the unit identifier when est is of class LMlatent or LMlatentcont
index	a character vector with two elements indicating the name of the "id" column as first element and the "time" column as second element when est is of class LMlatent or LMlatentcont

fort	to use fortran routine when possible (FALSE for not use fortran) when est is of class LMLatent or LMLatentcont
TT	number of time occasions when est is of class LMmixed
...	further arguments

**Value**

Y	matrix of response configurations unit by unit when est is of class LMbasic or LMmixed; array of continuous outcomes ( $n \times TT \times r$ ) when est is of class LMbasiccont or LMLatentcont
S	matrix of distinct response configurations when est is of class LMbasic or LMmixed
yv	corresponding vector of frequencies when est is of class LMbasic or LMmixed
piv	vector of initial probabilities of the latent Markov chain when est is of class LMbasic
Pi	set of transition probabilities matrices ( $k \times k \times TT$ ) when est is of class LMbasic
Psi	array of conditional response probabilities ( $mb \times k \times r$ ) when est is of class LMbasic
n	sample size
TT	number of time occasions
est	object of class LMbasic, LMLatent, LMbasiccont, LMLatentcont, or LMmixed
U	matrix containing the sequence of latent states ( $n \times TT$ ) when est is of class LMLatent or LMLatentcont
Psi	array of conditional response probabilities ( $mb \times k \times r$ ) when est is of class LMLatent
Be	parameters affecting the logit for the initial probabilities when est is of class LMLatent or LMLatentcont
Ga	parameters affecting the logit for the transition probabilities when est is of class LMLatent or LMLatentcont
latentFormula	a symbolic description of the model to be fitted when est is of class LMLatent. Detailed description is given in <a href="#">lmest</a>
data	a data frame in long format, with rows corresponding to observations and columns corresponding to variables, a column corresponding to time occasions and a column containing the unit identifier when est is of class LMLatent or LMLatentcont
Mu	array of conditional means for the response variables ( $r \times k$ ) when est is of class LMLatentcont
Si	var-cov matrix common to all states ( $r \times r$ ) when est is of class LMLatentcont
latentFormula	a symbolic description of the model to be fitted. A detailed description is given in <a href="#">lmestCont</a>

**Author(s)**

Francesco Bartolucci, Silvia Pandolfi, Fulvia Pennoni

**Examples**

```

## Not run:
# draw a sample for 1000 units and only one response variable when est is of class LMbasic
n <- 1000
TT <- 6
k <- 2
r <- 1 #number of response variables
mb <- 3 #maximum number of response categories

piv <- c(0.7,0.3)
Pi <- matrix(c(0.9,0.1,0.1,0.9), k, k)
Pi <- array(Pi, c(k, k, TT))
Pi[, ,1] <- 0
Psi <- matrix(c(0.7,0.2,0.1,0.5,0.4,0.1), mb, k)
Psi <- array(Psi, c(mb, k, r))
est = list(piv=piv, Pi=Pi, Psi=Psi, n=n, TT=TT)
class(est) = "LMbasic"

out <- draw(est)

data("data_SRHS_long")
SRHS <- data_SRHS_long[1:2400,]

SRHS$srhs <- 5 - SRHS$srhs

est <- lmest(responsesFormula = srhs ~ NULL,
             index = c("id", "t"),
             data = SRHS,
             k = 3)

out1 <- draw(est = est, format = "matrices", seed = 4321, n = 100)

# draw a sample for 7074 units and only one response variable when est is of class LMlatent
data(data_SRHS_long)

data_SRHS_long$srhs <- 5 - data_SRHS_long$srhs
n <- length(unique(data_SRHS_long$id))
TT <- max(data_SRHS_long$t)

est <- lmest(responsesFormula = srhs ~ NULL,
             latentFormula = ~
             I(gender - 1) +
             I(0 + (race == 2) + (race == 3)) +
             I(0 + (education == 4)) +
             I(0 + (education == 5)) +
             I(age - 50) + I((age-50)^2/100),
             index = c("id", "t"),
             data = data_SRHS_long,
             k = 2,
             paramLatent = "multilogit",
             start = 0)

```

```

out <- draw(est = est, data = data_SRHS_long, index = c("id","t"),
           format = "matrices",seed = 4321)

est1 = list(Psi = est$Psi, Be = est$Be, Ga = est$Ga,
           paramLatent = "multilogit",n=n,TT=TT)

attributes(est1)$latentFormula = ~
  I(gender - 1) +
  I( 0 + (race == 2) + (race == 3)) +
  I(0 + (education == 4)) +
  I(0 + (education == 5)) +
  I(age - 50) + I((age-50)^2/100)
class(est1) = "LMlatent"

out1 <- draw(est = est1, data = data_SRHS_long, index = c("id","t"),
           format = "matrices",
           seed = 4321)

# draw a sample for 1000 units and 3 response variable when est is of class LMbasiccont
n <- 1000
TT <- 5
k <- 2
r <- 3 #number of response variables

piv <- c(0.7,0.3)
Pi <- matrix(c(0.9,0.1,0.1,0.9), k, k)
Pi <- array(Pi, c(k, k, TT))
Pi[, ,1] <- 0
Mu <- matrix(c(-2,-2,0,0,2,2), r, k)
Si <- diag(r)
est = list(piv=piv,Pi=Pi,Mu=Mu,Si=Si,n=n,TT=TT)
class(est) = "LMbasiccont"

out <- draw(est)

data(data_long_cont)

est <- lmestCont(responsesFormula = Y1 + Y2 + Y3 ~ NULL,
               index = c("id", "time"),
               data = data_long_cont,
               k = 3,
               modBasic = 1,
               tol = 10^-5)

out2 <- draw(est = est, n = 100, format = "long", seed = 4321)

# draw a sample for 1000 units and 3 response variable when est is of class LMlatentcont
data(data_long_cont)

est <- lmestCont(responsesFormula = Y1 + Y2 + Y3~ NULL,
               latentFormula = ~ X1 + X2,
               index = c("id", "time"),

```

```

        data = data_long_cont,
        k = 3)
out <- draw(est = est, data = data_long_cont, index = c("id", "time"), format = "matrices",
           seed = 4321)

est1 <- list(Mu = est$Mu, Si = est$Si, Be = est$Be, Ga = est$Ga, paramLatent="multilogit", n=est$n,
            TT=est$TT)
attributes(est1)$latentFormula = ~ X1 + X2
class(est1) = "LMlatentcont"
out1 <- draw(est = est1, data = data_long_cont,
            index = c("id", "time"),
            fort=TRUE, seed = 4321, format = "matrices")

## End(Not run)

# draw a sample for 1000 units and only one response variable and 5 time occasions
# when est if of class LMmixed
k1 <- 2
k2 <- 3
la <- rep(1/k1, k1)
Piv <- matrix(1/k2, k2, k1)
Pi <- array(0, c(k2, k2, k1))
Pi[, ,1] <- diag(k2)
Pi[, ,2] <- 1/k2
Psi <- cbind(c(0.6,0.3,0.1), c(0.1,0.3,0.6), c(0.3,0.6,0.1))
est <- list(la=la, Piv=Piv, Pi=Pi, Psi=Psi, n=1000,TT=5)
class(est) = "LMmixed"

out <- draw(est = est)

## Not run:
# Example based on criminal data when est if of class LMmixed
data(data_criminal_sim)
data_criminal_sim = data.frame(data_criminal_sim)

# Estimate mixed LM model for females
responsesFormula <- lmestFormula(data = data_criminal_sim,
                                response = "y")$responsesFormula
est <- lmestMixed(responsesFormula = responsesFormula,
                 index = c("id","time"),
                 k1 = 2,
                 k2 = 2,
                 data = data_criminal_sim[data_criminal_sim$sex == 2,])

out <- draw(est = est, n = 100, TT = 6, seed = 4321)

## End(Not run)

```



**Description**

Function that draws samples from the basic LM model with specific parameters.

**The function is no longer maintained. Please look at [draw.LMbasic](#) function.**

**Usage**

```
draw_lm_basic(piv, Pi, Psi, n)
```

**Arguments**

piv	vector of initial probabilities of the latent Markov chain
Pi	set of transition probabilities matrices (k x k x TT)
Psi	array of conditional response probabilities (mb x k x r)
n	sample size

**Value**

Y	matrix of response configurations unit by unit
S	matrix of distinct response configurations
yv	corresponding vector of frequencies

**Author(s)**

Francesco Bartolucci, Silvia Pandolfi, University of Perugia (IT), <http://www.stat.unipg.it/bartolucci>

**Examples**

```
## Not run:
# draw a sample for 1000 units and only one response variable
n <- 1000
TT <- 6
k <- 2
r <- 1 #number of response variables
mb <- 3 #maximum number of response categories

piv <- c(0.7, 0.3)
Pi <- matrix(c(0.9,0.1,0.1,0.9), k, k)
Pi <- array(Pi, c(k, k, TT))
Pi[, ,1] <- 0
Psi <- matrix(c(0.7,0.2,0.1,0.5,0.4,0.1), mb, k)
Psi <- array(Psi, c(mb, k, r))
out <- draw_lm_basic(piv, Pi, Psi, n = 1000)

## End(Not run)
```

---

draw\_lm\_basic\_cont      *Draw samples from the basic LM model for continuous outcomes*

---

### Description

Function that draws samples from the basic LM model for continuous outcomes with specific parameters.

**The function is no longer maintained. Please look at [draw.LMbasiccont](#) function.**

### Usage

```
draw_lm_basic_cont(piv, Pi, Mu, Si, n)
```

### Arguments

piv	vector of initial probabilities of the latent Markov chain
Pi	set of transition probabilities matrices ( $k \times k \times TT$ )
Mu	matrix of conditional means for the response variables ( $r \times k$ )
Si	var-cov matrix common to all states ( $r \times r$ )
n	sample size

### Value

Y	array of continuous outcomes ( $n \times TT \times r$ )
---	---

### Author(s)

Francesco Bartolucci, Silvia Pandolfi, University of Perugia (IT), <http://www.stat.unipg.it/bartolucci>

### Examples

```
## Not run:

# draw a sample for 1000 units and 3 response variable
n <- 1000
TT <- 5
k <- 2
r <- 3 #number of response variables

piv <- c(0.7,0.3)
Pi <- matrix(c(0.9,0.1,0.1,0.9), k, k)
Pi <- array(Pi, c(k, k, TT))
Pi[, ,1] <- 0
Mu <- matrix(c(-2,-2,0,0,2,2), r, k)
Si <- diag(r)
out <- draw_lm_basic_cont(piv, Pi, Mu, Si, n)

## End(Not run)
```

---

draw\_lm\_cov\_latent      *Draw samples from LM model with covariates in the latent model*

---

### Description

Function that draws samples from the LM model with individual covariates with specific parameters.

**The function is no longer maintained. Please look at [draw.LMlatent](#) function.**

### Usage

```
draw_lm_cov_latent(X1, X2, param = "multilogit", Psi, Be, Ga, fort = TRUE)
```

### Arguments

X1	design matrix for the covariates on the initial probabilities (n x nc1)
X2	design matrix for the covariates on the transition probabilities (n x TT-1 x nc2)
param	type of parametrization for the transition probabilities ("multilogit" = standard multinomial logit for every row of the transition matrix, "difflogit" = multinomial logit based on the difference between two sets of parameters)
Psi	array of conditional response probabilities (mb x k x r)
Be	parameters affecting the logit for the initial probabilities
Ga	parameters affecting the logit for the transition probabilities
fort	to use fortran routine when possible (FALSE for not use fortran)

### Value

Y	matrix of response configurations unit by unit (n x TT x r)
U	matrix containing the sequence of latent states (n x TT)

### Author(s)

Francesco Bartolucci, Silvia Pandolfi, University of Perugia (IT), <http://www.stat.unipg.it/bartolucci>

### Examples

```
## Not run:

# draw a sample for 1000 units, 10 response variable and 2 covariates
n <- 1000
TT <- 5
k <- 2
nc <- 2 #number of covariates
r <- 10 #number of response variables
mb <- 2 #maximum number of response categories
```

```

fort <- TRUE

Psi <- matrix(c(0.9,0.1,0.1,0.9), mb, k)
Psi <- array(Psi, c(mb, k, r))
Ga <- matrix(c(-log(0.9/0.1),0.5,1), (nc+1)*(k-1), k)
Be <- array(c(0,0.5,1), (nc+1)*(k-1))
#Simulate covariates
X1 <- matrix(0, n, nc)
for(j in 1:nc) X1[,j] <- rnorm(n)
X2 <- array(0,c(n, TT-1, nc))
for (t in 1:(TT-1)) for(j in 1:nc){
  if(t==1){
    X2[,t,j] <- 0.5*X1[,j] + rnorm(n)
  }else{
    X2[,t,j] <- 0.5 *X2[,t-1,j] + rnorm(n)
  }
}

out <- draw_lm_cov_latent(X1, X2, Psi = Psi, Be = Be, Ga = Ga, fort = fort)

## End(Not run)

```

---

draw\_lm\_cov\_latent\_cont

*Draw samples from LM model for continuous outcomes with covariates in the latent model*

---

## Description

Function that draws samples from the LM model for continuous outcomes with individual covariates with specific parameters.

**The function is no longer maintained. Please look at [draw.LMlatentcont](#) function.**

## Usage

```
draw_lm_cov_latent_cont(X1, X2, param = "multilogit", Mu, Si, Be, Ga, fort = TRUE)
```

## Arguments

X1	design matrix for the covariates on the initial probabilities (n x nc1)
X2	design matrix for the covariates on the transition probabilities (n x TT-1 x nc2)
param	type of parametrization for the transition probabilities ("multilogit" = standard multinomial logit for every row of the transition matrix, "difflogit" = multinomial logit based on the difference between two sets of parameters)
Mu	array of conditional means for the response variables (r x k)
Si	var-cov matrix common to all states (r x r)

Be parameters affecting the logit for the initial probabilities  
 Ga parametes affecting the logit for the transition probabilities  
 fort to use fortran routine when possible (FALSE for not use fortran)

**Value**

Y array of continuous outcomes (n x TT x r)  
 U matrix containing the sequence of latent states (n x TT)

**Author(s)**

Francesco Bartolucci, Silvia Pandolfi, University of Perugia (IT), <http://www.stat.unipg.it/bartolucci>

**Examples**

```
## Not run:
# draw a sample for 1000 units, 10 response variable and 2 covariates
n <- 1000
TT <- 5
k <- 2
nc <- 2 #number of covariates
r <- 3 #number of response variables
fort <- TRUE

Mu <- matrix(c(-2,-2,0,0,2,2), r, k)
Si <- diag(r)
Ga <- matrix(c(-log(0.9/0.1),0.5,1), (nc+1)*(k-1), k)
Be <- array(c(0,0.5,1), (nc+1)*(k-1))

#Simulate covariates
X1 <- matrix(0, n, nc)
for(j in 1:nc) X1[,j] <- rnorm(n)
X2 <- array(0, c(n,TT-1,nc))
for (t in 1:(TT-1)) for(j in 1:nc){
  if(t==1){
    X2[,t,j] <- 0.5*X1[,j] + rnorm(n)
  }else{
    X2[,t,j] <- 0.5*X2[,t-1,j] + rnorm(n)
  }
}

out <- draw_lm_cov_latent_cont(X1, X2, param = "multilogit", Mu, Si, Be, Ga, fort = fort)

## End(Not run)
```

---

draw_lm_mixed	<i>Draws samples from the mixed LM model</i>
---------------	--

---

### Description

Function that draws samples from the mixed LM model with specific parameters.

**The function is no longer maintained. Please look at [draw.LMmixed](#) function.**

### Usage

```
draw_lm_mixed(la, Piv, Pi, Psi, n, TT)
```

### Arguments

la	vector of mass probabilities for the first latent variable
Piv	matrix of initial probabilities of the latent Markov chain ( $k_2 \times k_1$ )
Pi	set of transition matrices ( $k_2 \times k_2 \times k_1$ )
Psi	array of conditional response probabilities ( $m_b \times k_2 \times r$ )
n	sample size
TT	number of time occasions

### Value

Y	matrix of response configurations unit by unit
S	matrix of distinct response configurations
yv	corresponding vector of frequencies

### Author(s)

Francesco Bartolucci, Silvia Pandolfi, University of Perugia (IT), <http://www.stat.unipg.it/bartolucci>

### Examples

```
## Not run:
# draw a sample for 1000 units and only one response variable and 5 time occasions
k1 <- 2
k2 <- 3
la <- rep(1/k1,k1)
Piv <- matrix(1/k2,k2,k1)
Pi <- array(0,c(k2,k2,k1))
Pi[, ,1] <- diag(k2)
Pi[, ,2] <- 1/k2
Psi <- cbind(c(0.6,0.3,0.1),c(0.1,0.3,0.6),c(0.3,0.6,0.1))
out <- draw_lm_mixed(la,Piv,Pi,Psi,n=1000,TT=5)

## End(Not run)
```

---

est_lm_basic	<i>Estimate basic LM model</i>
--------------	--------------------------------

---

**Description**

Main function for estimating the basic LM model.

**The function is no longer maintained. Please look at [lmest](#) function.**

**Usage**

```
est_lm_basic(S, yv, k, start = 0, mod = 0, tol = 10^-8, maxit = 1000,
            out_se = FALSE, piv = NULL, Pi = NULL, Psi = NULL)
```

**Arguments**

S	array of available configurations (n x TT x r) with categories starting from 0 (use NA for missing responses)
yv	vector of frequencies of the available configurations
k	number of latent states
start	type of starting values (0 = deterministic, 1 = random, 2 = initial values in input)
mod	model on the transition probabilities (0 for time-heter., 1 for time-homog., from 2 to (TT-1) partial homog. of that order)
tol	tolerance level for convergence
maxit	maximum number of iterations of the algorithm
out_se	to compute the information matrix and standard errors
piv	initial value of the initial probability vector (if start=2)
Pi	initial value of the transition probability matrices (k x k x TT) (if start=2)
Psi	initial value of the conditional response probabilities (mb x k x r) (if start=2)

**Value**

lk	maximum log-likelihood
piv	estimate of initial probability vector
Pi	estimate of transition probability matrices
Psi	estimate of conditional response probabilities
np	number of free parameters
aic	value of AIC for model selection
bic	value of BIC for model selection
lkv	log-likelihood trace at every step
V	array containing the posterior distribution of the latent states for each response configuration and time occasion

sepiv	standard errors for the initial probabilities
sePi	standard errors for the transition probabilities
sePsi	standard errors for the conditional response probabilities
call	command used to call the function

**Author(s)**

Francesco Bartolucci, Silvia Pandolfi, University of Perugia (IT), <http://www.stat.unipg.it/bartolucci>

**References**

Bartolucci, F., Farcomeni, A. and Pennoni, F. (2013) *Latent Markov Models for Longitudinal Data*, Chapman and Hall/CRC press.

**Examples**

```
## Not run:
# Example of drug consumption data

# load data
data(data_drug)
data_drug <- as.matrix(data_drug)
S <- data_drug[,1:5]-1
yv <- data_drug[,6]

# fit of the Basic LM model
k <- 3
out <- est_lm_basic(S, yv, k, mod = 1)
summary(out)

# Example based on criminal data

# load criminal data
data(data_criminal_sim)
out <- long2wide(data_criminal_sim, "id" , "time" , "sex",
c("y1","y2","y3","y4","y5","y6","y7","y8","y9","y10"),aggr = T, full = 999)
XX <- out$XX
YY <- out$YY
freq <- out$freq

# fit basic LM model with increasing number of states to select the most suitable
Res0 <- vector("list", 7)
for(k in 1:7){
  Res0[[k]] <- est_lm_basic(YY, freq, k, mod = 1, tol = 10^-4)
  save(list <- ls(), file = "example_criminal_temp.RData")
}
out1 <- Res0[[6]]

## End(Not run)
```



---

est\_lm\_basic\_cont      *Estimate basic LM model for continuous outcomes*

---

### Description

Main function for estimating the basic LM model for continuous outcomes.

**The function is no longer maintained. Please look at [lmestCont](#) function.**

### Usage

```
est_lm_basic_cont(Y, k, start = 0, mod = 0, tol = 10^-8, maxit = 1000,
                 out_se = FALSE, piv = NULL, Pi = NULL, Mu = NULL, Si = NULL)
```

### Arguments

Y	array of continuous outcomes (n x TT x r)
k	number of latent states
start	type of starting values (0 = deterministic, 1 = random, 2 = initial values in input)
mod	model on the transition probabilities (0 for time-heter., 1 for time-homog., from 2 to (TT-1) partial homog. of that order)
tol	tolerance level for convergence
maxit	maximum number of iterations of the algorithm
out_se	to compute the information matrix and standard errors
piv	initial value of the initial probability vector (if start=2)
Pi	initial value of the transition probability matrices (k x k x TT) (if start=2)
Mu	initial value of the conditional means (r x k) (if start=2)
Si	initial value of the var-cov matrix common to all states (r x r) (if start=2)

### Value

lk	maximum log-likelihood
piv	estimate of initial probability vector
Pi	estimate of transition probability matrices
Mu	estimate of conditional means of the response variables
Si	estimate of var-cov matrix common to all states
np	number of free parameters
aic	value of AIC for model selection
bic	value of BIC for model selection
lkv	log-likelihood trace at every step
V	array containing the posterior distribution of the latent states for each units and time occasion
call	command used to call the function

**Author(s)**

Francesco Bartolucci, Silvia Pandolfi, University of Perugia (IT), <http://www.stat.unipg.it/bartolucci>

**References**

Bartolucci, F., Farcomeni, A. and Pennoni, F. (2013) *Latent Markov Models for Longitudinal Data*, Chapman and Hall/CRC press.

**Examples**

```
## Not run:
# Example based on multivariate longitudinal continuous data

data(data_long_cont)
res <- long2matrices(data_long_cont$id, X=cbind(data_long_cont$X1, data_long_cont$X2),
  Y=cbind(data_long_cont$Y1, data_long_cont$Y2, data_long_cont$Y3))
Y <- res$YY

# fit of the Basic LM model for continuous outcomes
k <- 3
out <- est_lm_basic_cont(Y, k, mod = 1, tol = 10^-5)
summary(out)

## End(Not run)
```

---

est\_lm\_cov\_latent      *Estimate LM model with covariates in the latent model*

---

**Description**

Main function for estimating the LM model with covariates in the latent model.

**The function is no longer maintained. Please look at [lmest](#) function.**

**Usage**

```
est_lm_cov_latent(S, X1=NULL, X2=NULL, yv = rep(1, nrow(S)), k, start = 0, tol = 10^-8,
  maxit = 1000, param = "multilogit", Psi, Be, Ga, fort = TRUE,
  output = FALSE, out_se = FALSE, fixPsi = FALSE)
```

**Arguments**

S	array of available configurations (n x TT x r) with categories starting from 0 (use NA for missing responses)
X1	matrix of covariates affecting the initial probabilities (n x nc1)
X2	array of covariates affecting the transition probabilities (n x TT-1 x nc2)

yv	vector of frequencies of the available configurations
k	number of latent states
start	type of starting values (0 = deterministic, 1 = random, 2 = initial values in input)
tol	tolerance level for checking convergence of the algorithm
maxit	maximum number of iterations of the algorithm
param	type of parametrization for the transition probabilities ("multilogit" = standard multinomial logit for every row of the transition matrix, "difflogit" = multinomial logit based on the difference between two sets of parameters)
Psi	initial value of the array of the conditional response probabilities (mb x k x r)
Be	initial value of the parameters affecting the logit for the initial probabilities (if start=2)
Ga	initial value of the parameters affecting the logit for the transition probabilities (if start=2)
fort	to use fortran routine when possible (FALSE for not use fortran)
output	to return additional output (V,PI,Piv,Ul)
out_se	to compute the information matrix and standard errors
fixPsi	TRUE if Psi is given in input and is not updated anymore

**Value**

lk	maximum log-likelihood
Be	estimated array of the parameters affecting the logit for the initial probabilities
Ga	estimated array of the parameters affecting the logit for the transition probabilities
Piv	estimate of initial probability matrix
PI	estimate of transition probability matrices
Psi	estimate of conditional response probabilities
np	number of free parameters
aic	value of AIC for model selection
bic	value of BIC for model selection
lkv	log-likelihood trace at every step
V	array containing the posterior distribution of the latent states for each response configuration and time occasion
Ul	matrix containing the predicted sequence of latent states by the local decoding method
sePsi	standard errors for the conditional response matrix
seBe	standard errors for Be
seGa	standard errors for Ga
call	command used to call the function

**Author(s)**

Francesco Bartolucci, Silvia Pandolfi, University of Perugia, <http://www.stat.unipg.it/bartolucci>

**References**

Bartolucci, F., Farcomeni, A. and Pennoni, F. (2013) *Latent Markov Models for Longitudinal Data*, Chapman and Hall/CRC press.

**Examples**

```
## Not run:
# Example based on self-rated health status (SRHS) data
# load SRHS data
data(data_SRHS_long)
dataSRHS = data_SRHS_long

TT <- 8
head(dataSRHS)
res <- long2matrices(dataSRHS$id, X = cbind(dataSRHS$gender-1,
dataSRHS$race == 2 | dataSRHS$race == 3, dataSRHS$education == 4,
dataSRHS$education == 5, dataSRHS$age-50, (dataSRHS$age-50)^2/100),
Y = dataSRHS$srhs)

# matrix of responses (with ordered categories from 0 to 4)
S <- 5-res$YY
n <- dim(S)[1]

# matrix of covariates (for the first and the following occasions)
# columns are: gender,race,educational level (2 columns),age,age^2)
X1 <- res$XX[,1,]
X2 <- res$XX[,2:TT,]

# estimate the model
est2f <- est_lm_cov_latent(S, X1, X2, k = 2, output = TRUE, out_se = TRUE)
summary(est2f)

# average transition probability matrix
PI <- round(apply(est2f$PI[,,,2:TT], c(1,2), mean), 4)

# Transition probability matrix for white females with high educational level
ind1 <- X1[,1] == 1 & X1[,2] == 0 & X1[,4] == 1)
PI1 <- round(apply(est2f$PI[,,,ind1,2:TT], c(1,2), mean), 4)

# Transition probability matrix for non-white male, low educational level
ind2 <- (X1[,1] == 0 & X1[,2] == 1 & X1[,3] == 0 & X1[,4] == 0)
PI2 <- round(apply(est2f$PI[,,,ind2,2:TT], c(1,2), mean), 4)

## End(Not run)
```

---

 est\_lm\_cov\_latent\_cont

*Estimate LM model for continuous outcomes with covariates in the latent model*

---

### Description

Main function for estimating the LM model for continuous outcomes with covariates in the latent model.

**The function is no longer maintained. Please look at [lmestCont](#) function.**

### Usage

```
est_lm_cov_latent_cont(Y, X1 = NULL, X2 = NULL, yv = rep(1,nrow(Y)), k, start = 0,
  tol = 10^-8, maxit = 1000, param = "multilogit",
  Mu = NULL, Si = NULL, Be = NULL, Ga = NULL,
  output = FALSE, out_se = FALSE)
```

### Arguments

Y	array of continuous outcomes (n x TT x r)
X1	matrix of covariates affecting the initial probabilities (n x nc1)
X2	array of covariates affecting the transition probabilities (n x TT-1 x nc2)
yv	vector of frequencies of the available configurations
k	number of latent states
start	type of starting values (0 = deterministic, 1 = random, 2 = initial values in input)
tol	tolerance level for checking convergence of the algorithm
maxit	maximum number of iterations of the algorithm
param	type of parametrization for the transition probabilities ("multilogit" = standard multinomial logit for every row of the transition matrix, "difflogit" = multinomial logit based on the difference between two sets of parameters)
Mu	initial value of the conditional means (r x k) (if start=2)
Si	initial value of the var-cov matrix common to all states (r x r) (if start=2)
Be	initial value of the parameters affecting the logit for the initial probabilities (if start=2)
Ga	initial value of the parameters affecting the logit for the transition probabilities (if start=2)
output	to return additional output (V,PI,Piv,UI)
out_se	to compute the information matrix and standard errors

**Value**

lk	maximum log-likelihood
Be	estimated array of the parameters affecting the logit for the initial probabilities
Ga	estimated array of the parameters affecting the logit for the transition probabilities
Mu	estimate of conditional means of the response variables
Si	estimate of var-cov matrix common to all states
np	number of free parameters
aic	value of AIC for model selection
bic	value of BIC for model selection
lkv	log-likelihood trace at every step
Piv	estimate of initial probability matrix
PI	estimate of transition probability matrices
Ul	matrix containing the predicted sequence of latent states by the local decoding method
call	command used to call the function

**Author(s)**

Francesco Bartolucci, Silvia Pandolfi, University of Perugia, <http://www.stat.unipg.it/bartolucci>

**References**

Bartolucci, F., Farcomeni, A. and Pennoni, F. (2013) *Latent Markov Models for Longitudinal Data*, Chapman and Hall/CRC press.

**Examples**

```
## Not run:
# Example based on multivariate longitudinal continuous data

data(data_long_cont)
TT <- 5
res <- long2matrices(data_long_cont$id, X = cbind(data_long_cont$X1, data_long_cont$X2),
  Y = cbind(data_long_cont$Y1, data_long_cont$Y2, data_long_cont$Y3))
Y <- res$YY
X1 <- res$XX[,1,]
X2 <- res$XX[,2:TT,]

# estimate the model
est <- est_lm_cov_latent_cont(Y, X1, X2, k = 3, output = TRUE)
summary(est)

# average transition probability matrix
PI <- round(apply(est$PI[,,,2:TT], c(1,2), mean), 4)
PI

## End(Not run)
```

---

est\_lm\_cov\_manifest     *Estimate LM model with covariates in the measurement model*

---

### Description

Main function for estimating LM model with covariates in the measurement model based on a global logit parameterization.

**The function is no longer maintained. Please look at [lmest](#) function.**

### Usage

```
est_lm_cov_manifest(S, X, yv = rep(1,nrow(S)), k, q = NULL, mod = c("LM", "FM"),
  tol = 10^-8, maxit = 1000, start = 0, mu = NULL, al = NULL,
  be = NULL, si = NULL, rho = NULL, la = NULL, PI = NULL,
  output = FALSE, out_se = FALSE)
```

### Arguments

S	array of available configurations (n x TT) with categories starting from 0
X	array (n x TT x nc) of covariates with eventually includes lagged response (nc = number of covariates)
yv	vector of frequencies of the available configurations
k	number of latent states
q	number of support points for the AR(1) process
mod	model ("LM" = Latent Markov with stationary transition, "FM" = finite mixture)
tol	tolerance for the convergence (optional) and tolerance of conditional probability if tol>1 then return
maxit	maximum number of iterations of the algorithm
start	type of starting values (0 = deterministic, 1 = random, 2 = initial values in input)
mu	starting value for mu (optional)
al	starting value for al (optional)
be	starting value for be (optional)
si	starting value for si when mod="FM" (optional)
rho	starting value for rho when mod="FM" (optional)
la	starting value for la (optional)
PI	starting value for PI (optional)
output	to return additional output (PRED0, PRED1)
out_se	TRUE for computing information matrix and standard errors

**Value**

mu	vector of cutpoints
al	support points for the latent states
be	estimate of the vector of regression parameters
si	sigma of the AR(1) process (mod = "FM")
rho	parameter vector for AR(1) process (mod = "FM")
la	vector of initial probabilities
PI	transition matrix
lk	maximum log-likelihood
np	number of parameters
aic	value of AIC index
bic	value of BIC index
PRED0	prediction of latent state
PRED1	prediction of the overall latent effect
sebe	standard errors for the regression parameters be
selrho	standard errors for logit type transformation of rho
J1	information matrix
call	command used to call the function

**Author(s)**

Francesco Bartolucci, Silvia Pandolfi - University of Perugia (IT)

**References**

Bartolucci, F., Farcomeni, A. and Pennoni, F. (2013) *Latent Markov Models for Longitudinal Data*, Chapman and Hall/CRC press.

Bartolucci, F., Bacci, S. and Pennoni, F. (2014) Longitudinal analysis of the self-reported health status by mixture latent autoregressive models, *Journal of the Royal Statistical Society - series C*, **63**, pp. 267-288

**Examples**

```
## Not run:
# Example based on self-rated health status (SRHS) data

# load SRHS data
data(data_SRHS_long)
dataSRHS <- data_SRHS_long
head(dataSRHS)

res <- long2matrices(dataSRHS$id, X = cbind(dataSRHS$gender-1,
  dataSRHS$race == 2 | dataSRHS$race == 3, dataSRHS$education == 4,
  dataSRHS$education == 5, dataSRHS$age-50, (dataSRHS$age-50)^2/100),
```



```

Y = dataSRHS$srhs)

X <- res$XX
S <- 5-res$YY

# *** fit stationary LM model
res0 <- vector("list", 10)
tol <- 10^-6;
for(k in 1:10){
  res0[[k]] <- est_lm_cov_manifest(S, X, k, 1, mod = "LM", tol)
  save.image("example_SRHS.RData")
}

# *** fit the mixture latent auto-regressive model
tol <- 0.005
res <- vector("list",4)
k <- 1
q <- 51
res[[k]] <- est_lm_cov_manifest(S, X, k, q, mod = "FM", tol, output = TRUE)
for(k in 2:4) res[[k]] <- est_lm_cov_manifest(S, X, k, q = 61, mod = "FM", tol, output = TRUE)

## End(Not run)

```

---

est\_lm\_mixed

*Estimate mixed LM model*


---

## Description

Main function for estimating the mixed LM model with discrete random effect in the latent model.

**The function is no longer maintained. Please look at [lmestMixed](#) function**

## Usage

```
est_lm_mixed(S, yv = rep(1,nrow(S)), k1, k2, start = 0, tol = 10^-8, maxit = 1000,
             out_se = FALSE)
```

## Arguments

S	array of available response configurations (n x TT x r) with categories starting from 0
yv	vector of frequencies of the available configurations
k1	number of latent classes
k2	number of latent states
start	type of starting values (0 = deterministic, 1 = random)
tol	tolerance level for convergence
maxit	maximum number of iterations of the algorithm
out_se	to compute standard errors

**Value**

la	estimate of the mass probability vector (distribution of the random effects)
Piv	estimate of initial probabilities
Pi	estimate of transition probability matrices
Psi	estimate of conditional response probabilities
lk	maximum log-likelihood
W	posterior probabilities of the random effect
np	number of free parameters
bic	value of BIC for model selection
call	command used to call the function

**Author(s)**

Francesco Bartolucci, Silvia Pandolfi - University of Perugia (IT)

**References**

Bartolucci, F., Farcomeni, A. and Pennoni, F. (2013) *Latent Markov Models for Longitudinal Data*, Chapman and Hall/CRC press.

**Examples**

```
## Not run:
# Example based of criminal data

# load data
data(data_criminal_sim)
out <- long2wide(data_criminal_sim, "id", "time", "sex",
  c("y1", "y2", "y3", "y4", "y5", "y6", "y7", "y8", "y9", "y10"), aggr = T, full = 999)

XX <- out$XX
YY <- out$YY
freq <- out$freq
n1 <- sum(freq[XX[,1] == 1])
n2 <- sum(freq[XX[,1] == 2])
n <- sum(freq)

# fit mixed LM model only for females
YY <- YY[XX[,1] == 2,,]
freq <- freq[XX[,1] == 2]
k1 <- 2
k2 <- 2
res <- est_lm_mixed(YY, freq, k1, k2, tol = 10^-8)
summary(res)

## End(Not run)
```

---

 est\_mc\_basic

*Estimate basic Markov chain (MC) model*


---

**Description**

Main function for estimating the basic MC model.

**The function is no longer maintained. Please look at [lmestMc](#) function.**

**Usage**

```
est_mc_basic(S, yv, mod = 0, tol = 10^-8, maxit = 1000, out_se = FALSE)
```

**Arguments**

S	matrix (n x TT) of available configurations of the response variable with categories starting from 0
yv	vector of frequencies of the available configurations
mod	model on the transition probabilities (0 for time-heter., 1 for time-homog., from 2 to (TT-1) partial homog. of that order)
tol	tolerance level for convergence
maxit	maximum number of iterations of the algorithm
out_se	to compute the information matrix and standard errors

**Value**

lk	maximum log-likelihood
piv	estimate of initial probability vector
Pi	estimate of transition probability matrices
np	number of free parameters
aic	value of AIC for model selection
bic	value of BIC for model selection
Fy	estimated marginal distribution of the response variable for each time occasion
sepiv	standard errors for the initial probabilities
sePi	standard errors for the transition probabilities
call	command used to call the function

**Author(s)**

Francesco Bartolucci, Silvia Pandolfi, University of Perugia (IT), <http://www.stat.unipg.it/bartolucci>

## References

Bartolucci, F., Farcomeni, A. and Pennoni, F. (2013) *Latent Markov Models for Longitudinal Data*, Chapman and Hall/CRC press.

## Examples

```
# Example of drug consumption data

# load data
data(data_drug)
data_drug <- as.matrix(data_drug)
S <- data_drug[,1:5]-1
yv <- data_drug[,6]

# fit of the Basic MC model
out <- est_mc_basic(S, yv, mod = 1, out_se = TRUE)
summary(out)
```

---

est\_mc\_cov

*Estimate Markov chain (MC) model with covariates*

---

## Description

Main function for estimating the MC model with covariates.

**The function is no longer maintained. Please look at [lmestMc](#) function.**

## Usage

```
est_mc_cov(S, X1 = NULL, X2 = NULL, yv = rep(1,nrow(S)), start = 0, tol = 10^-8,
  maxit = 1000, out_se = FALSE, output = FALSE, fort = TRUE)
```

## Arguments

S	matrix of available configurations of the response variable (n x TT) with categories starting from 0
X1	matrix of covariates affecting the initial probabilities (n x nc1)
X2	array of covariates affecting the transition probabilities (n x TT-1 x nc2)
yv	vector of frequencies of the available configurations
start	type of starting values (0 = deterministic, 1 = random)
tol	tolerance level for checking convergence of the algorithm
maxit	maximum number of iterations of the algorithm
out_se	to compute the information matrix and standard errors
output	to return additional output (PI,Piv)
fort	to use fortran routine when possible (FALSE for not use fortran)

**Value**

lk	maximum log-likelihood
Be	estimated array of the parameters affecting the logit for the initial probabilities
Ga	estimated array of the parameters affecting the logit for the transition probabilities
np	number of free parameters
aic	value of AIC for model selection
bic	value of BIC for model selection
seBe	standard errors for Be
seGa	standard errors for Ga
Piv	estimate of initial probability matrix
PI	estimate of transition probability matrices
call	command used to call the function

**Author(s)**

Francesco Bartolucci, Silvia Pandolfi, University of Perugia, <http://www.stat.unipg.it/bartolucci>

**References**

Bartolucci, F., Farcomeni, A. and Pennoni, F. (2013) *Latent Markov Models for Longitudinal Data*, Chapman and Hall/CRC press.

**Examples**

```
## Not run:

# Example based on criminal data

# load criminal data
data(data_criminal_sim)

#We consider the response variable referring of crime of type 5

out <- long2wide(data_criminal_sim, "id", "time", "sex",
"y5", aggr = T, full = 999)
XX <- out$XX-1
YY <- out$YY
freq <- out$freq
TT <- 6

X1 <- as.matrix(XX[,1])
X2 <- as.matrix(XX[,2:TT])
# estimate the model
res <- est_mc_cov(S = YY, yv = freq, X1 = X1, X2 = X2, output = TRUE)
summary(res)
```

```

# Initial probability for female
Piv0 <- round(colMeans(res$Piv[X1 == 0,]), 4)

# Initial probability for male
Piv1 <- round(colMeans(res$Piv[X1 == 1,]), 4)

## End(Not run)

```

---

LMbasic-class

*Class* 'LMbasic'

---

### Description

An S3 class object created by `lmest` function for basic Latent Markov (LM) model.

### Value

lk	maximum log-likelihood at convergence of the EM algorithm
piv	estimate of initial probability vector
Pi	estimate of transition probability matrices (k x k x TT)
Psi	estimate of conditional response probabilities (mb x k x r)
np	number of free parameters
k	optimal number of latent states
aic	value of the Akaike Information Criterion for model selection
bic	value of the Bayesian Information Criterion for model selection
lkv	log-likelihood trace at every step
n	sample size (sum of the weights when weights are provided)
TT	number of time occasions
modBasic	model on the transition probabilities: default 0 for time-heterogeneous transition matrices, 1 for time-homogeneous transition matrices, 2 for partial time homogeneity based on two transition matrices one from 2 to (TT-1) and the other for TT.
sepiv	standard errors for the initial probabilities
sePi	standard errors for the transition probabilities
sePsi	standard errors for the conditional response probabilities
Lk	vector containing the values of the log-likelihood of the LM model with each k (latent states)
Bic	vector containing the values of the BIC for each k
Aic	vector containing the values of the AIC for each k
V	array containing the estimated posterior probabilities of the latent states for each response configuration and time occasion

U1	matrix containing the predicted sequence of latent states by the local decoding method
S	array containing the available response configurations
yv	vector of frequencies of the available configurations
Pmarg	matrix containing the marginal distribution of the latent states
ns	number of distinct response configurations
call	command used to call the function
data	data.frame given in input

**Author(s)**

Francesco Bartolucci, Silvia Pandolfi, Fulvia Pennoni, Alessio Farcomeni, Alessio Serafini

**See Also**

[lmest](#)

---

LMbasiccont-class      *Class* 'LMbasiccont'

---

**Description**

An S3 class object created by [lmestCont](#) function for the latent Markov (LM) model for continuous responses in long format.

**Value**

lk	maximum log-likelihood
piv	estimate of initial probability vector
Pi	estimate of transition probability matrices ( $k \times k \times TT$ )
Mu	estimate of conditional means of the response variables ( $r \times k$ )
Si	estimate of var-cov matrix common to all states ( $r \times r$ )
np	number of free parameters
k	optimal number of latent states
aic	value of the Akaike Information Criterion for model selection
bic	value of the Bayesian Information Criterion for model selection
lkv	log-likelihood trace at every step
n	number of observations in the data
TT	number of time occasions
modBasic	model on the transition probabilities: default 0 for time-heterogeneous transition matrices, 1 for time-homogeneous transition matrices, 2 for partial time homogeneity based on two transition matrices one from 2 to (TT-1) and the other for TT

sepiv	standard errors for the initial probabilities
sePi	standard errors for the transition probabilities
seMu	standard errors for the conditional means
seSi	standard errors for the var-cov matrix
sc	score vector
J	information matrix
Lk	vector containing the values of the log-likelihood of the LM model with each k (latent states)
Bic	vector containing the values of the BIC of the LM model with each k (latent states)
Aic	vector containing the values of the AIC of the LM model with each k (latent states)
V	array containing the posterior distribution of the latent states for each units and time occasion
Ul	matrix containing the predicted sequence of latent states by the local decoding method
Pmarg	matrix containing the marginal distribution of the latent states
call	command used to call the function
data	data frame given in input

**Author(s)**

Francesco Bartolucci, Silvia Pandolfi, Fulvia Pennoni, Alessio Farcomeni, Alessio Serafini

**See Also**

[lmestCont](#)

---

 lmest

*Estimate Latent Markov models for categorical responses*

---

**Description**

Main function for estimating Latent Markov (LM) models for categorical responses.

**Usage**

```
lmest(responsesFormula = NULL, latentFormula = NULL,
      data, index, k = 1:4, start = 0,
      modSel = c("BIC", "AIC"), modBasic = 0,
      modManifest = c("LM", "FM"),
      paramLatent = c("multilogit", "difflogit"),
      weights = NULL, tol = 10^-8, maxit = 1000,
```



```

out_se = FALSE, q = NULL, output = FALSE,
parInit = list(piv = NULL, Pi = NULL, Psi = NULL,
              Be = NULL, Ga = NULL, mu = NULL,
              a1 = NULL, be = NULL, si = NULL,
              rho = NULL, la = NULL, PI = NULL,
              fixPsi = FALSE),
fort = TRUE, seed = NULL, ntry = 0)

```

## Arguments

responsesFormula	a symbolic description of the model to fit. A detailed description is given in the ‘Details’ section
latentFormula	a symbolic description of the model to fit. A detailed description is given in the ‘Details’ section
data	a <code>data.frame</code> in long format
index	a character vector with two elements, the first indicating the name of the unit identifier, and the second the time occasions
k	an integer vector specifying the number of latent states (default: 1:4)
start	type of starting values (0 = deterministic, 1 = random, 2 = initial values in input)
modSel	a string indicating the model selection criteria: "BIC" for Bayesian Information Criterion and "AIC" for Akaike Information Criterion Criterion
modBasic	model on the transition probabilities (0 for time-heterogeneity, 1 for time-homogeneity, from 2 to (TT-1) partial time-homogeneity of a certain order)
modManifest	model for manifest distribution when covariates are included in the measurement model ("LM" = Latent Markov with stationary transition, "FM" = finite mixture model where a mixture of AR(1) processes is estimated with common variance and specific correlation coefficients).
paramLatent	type of parametrization for the transition probabilities ("multilogit" = standard multinomial logit for every row of the transition matrix, "difflogit" = multinomial logit based on the difference between two sets of parameters)
weights	an optional vector of weights for the available responses
tol	tolerance level for convergence
maxit	maximum number of iterations of the algorithm
out_se	to compute the information matrix and standard errors
q	number of support points for the AR(1) process (if <code>modManifest = "FM"</code> )
output	to return additional output: <code>V</code> , <code>U1</code> , <code>S</code> , <code>yv</code> , <code>Pmarg</code> for the basic LM model and for the LM with covariates on the latent model ( <a href="#">LMbasic-class</a> and <a href="#">LMlatent-class</a> ) and <code>V</code> , <code>PRED1</code> , <code>S</code> , <code>yv</code> , <code>Pmarg</code> for the LM model with covariates in the measurement model ( <a href="#">LMmanifest-class</a> )
parInit	list of initial model parameters when "start = 2". For the list of parameters look at <a href="#">LMbasic-class</a> , <a href="#">LMlatent-class</a> and <a href="#">LMmanifest-class</a>
fort	to use fortran routines when possible
seed	an integer value with the random number generator state
ntry	to set the number of random initializations

## Details

`Imest` is a general function for estimating LM models for categorical responses. The function requires data in long format and two additional columns indicating the unit identifier and the time occasions.

Covariates are allowed to affect manifest distribution (measurement model) or the initial and transition probabilities (latent model). Two different formulas are employed to specify the different LM models, `responsesFormula` and `latentFormula`:

- `responsesFormula` is used to specify the measurement model:
  - `responsesFormula = y1 + y2 ~ NULL`  
the LM model without covariates and two responses (`y1` and `y2`) is specified;
  - `responsesFormula = NULL`  
all the columns in the data except the `"id"` and `"time"` columns are used as responses to estimate the LM model without covariates;
  - `responsesFormula = y1 ~ x1 + x2`  
the univariate LM model with response (`y1`) and two covariates (`x1` and `x2`) in the measurement model is specified;
- `latentFormula` is used to specify the LM model with covariates in the latent model:
  - `responsesFormula = y1 + y2 ~ NULL`  
`latentFormula = ~ x1 + x2 | x3 + x4`  
the LM model with two responses (`y1` and `y2`) and two covariates affecting the initial probabilities (`x1` and `x2`) and other two affecting the transition probabilities (`x3` and `x4`) is specified;
  - `responsesFormula = y1 + y2 ~ NULL`  
`latentFormula = ~ 1 | x1 + x2`  
(or `latentFormula = ~ NULL | x1 + x2`)  
the covariates affect only the transition probabilities and an intercept is specified for the initial probabilities;
  - `responsesFormula = y1 + y2 ~ NULL`  
`latentFormula = ~ x1 + x2`  
the LM model with two covariates (`x1` and `x2`) affecting both the initial and transition probabilities is specified;
  - `responsesFormula = y1 + y2 ~ NULL`  
`latentFormula = ~ NULL | NULL`  
(or `latentFormula = ~ 1 | 1`)  
the LM model with only an intercept on the initial and transition probabilities is specified.

The function also allows us to deal with missing responses, including drop-out and non-monotonic missingness, under the missing-at-random assumption. Missing values for the covariates are not allowed.

The LM model with individual covariates in the measurement model is estimated only for complete univariate responses. In such a case, two possible formulations are allowed: `modManifest="LM"` is used to estimate the model illustrated in Bartolucci et al. (2017), where the latent process is of first order with initial probabilities equal to those of the stationary distribution of the chain; `modManifest="FM"` is used to estimate a model relying on the assumption that the distribution of

the latent process is a mixture of AR(1) processes with common variance and specific correlation coefficients. This model is illustrated in Bartolucci et al. (2014).

For continuous outcomes see the function `lmestCont`.

### Value

Returns an object of class 'LMbasic' for the model without covariates (see `LMbasic-class`), or an object of class 'LMmanifest' for the model with covariates on the manifest model (see `LMmanifest-class`), or an object of class 'LMlatent' for the model with covariates on the latent model (see `LMlatent-class`).

### Author(s)

Francesco Bartolucci, Silvia Pandolfi, Fulvia Pennoni, Alessio Farcomeni, Alessio Serafini

### References

Bartolucci, F., Bacci, S., and Pennoni, F. (2014). Longitudinal analysis of the self-reported health status by mixture latent autoregressive models, *Journal of the Royal Statistical Society - series C*, **63**, pp. 267-288.

Bartolucci F., Pandolfi S., and Pennoni F. (2017) LMest: An R Package for Latent Markov Models for Longitudinal Categorical Data, *Journal of Statistical Software*, **81**(4), 1-38.

Bartolucci, F., Farcomeni, A., and Pennoni, F. (2013) *Latent Markov Models for Longitudinal Data*, Chapman and Hall/CRC press.

### Examples

```
### Basic LM model

data("data_SRHS_long")
SRHS <- data_SRHS_long[1:2400,]

# Categories rescaled to vary from 0 ("poor") to 4 ("excellent")

SRHS$srhs <- 5 - SRHS$srhs

out <- lmest(responsesFormula = srhs ~ NULL,
             index = c("id", "t"),
             data = SRHS,
             k = 3,
             start = 1,
             modBasic = 1,
             seed = 123)

out
summary(out)

## Not run:
```

```

## Basic LM model with model selection using BIC

out1 <- lmest(responsesFormula = srhs ~ NULL,
             index = c("id", "t"),
             data = SRHS,
             k = 1:5,
             tol = 1e-8,
             modBasic = 1,
             seed = 123, ntry = 2)

out1
out1$Bic

# Basic LM model with model selection using AIC

out2 <- lmest(responsesFormula = srhs ~ NULL,
             index = c("id", "t"),
             data = SRHS,
             k = 1:5,
             tol = 1e-8,
             modBasic = 1,
             modSel = "AIC",
             seed = 123, ntry = 2)

out2
out2$Aic

# Criminal data

data(data_criminal_sim)
data_criminal_sim = data.frame(data_criminal_sim)

responsesFormula <- lmestFormula(data = data_criminal_sim, response = "y")$responsesFormula

out3 <- lmest(responsesFormula = responsesFormula,
             index = c("id", "time"),
             data = data_criminal_sim,
             k = 1:7,
             modBasic = 1,
             tol = 10^-4)

out3

# Example of drug consumption data

data("data_drug")
long <- data_drug[,-6]-1
long <- data.frame(id = 1:nrow(long), long)
long <- reshape(long, direction = "long",
               idvar = "id",
               varying = list(2:ncol(long)))

out4 <- lmest(index = c("id", "time"),
             k = 3,

```

```

        data = long,
        weights = data_drug[,6],
        modBasic = 1)

out4
summary(out4)

### LM model with covariates in the latent model
# Covariates: gender, race, educational level (2 columns), age and age^2

out5 <- lmest(responsesFormula = srhs ~ NULL,
              latentFormula = ~
                I(gender - 1) +
                I( 0 + (race == 2) + (race == 3)) +
                I(0 + (education == 4)) +
                I(0 + (education == 5)) +
                I(age - 50) + I((age-50)^2/100),
              index = c("id","t"),
              data = SRHS,
              k = 2,
              paramLatent = "multilogit",
              start = 0)

out5
summary(out5)

### LM model with the above covariates in the measurement model (stationary model)

out6 <- lmest(responsesFormula = srhs ~ -1 +
              I(gender - 1) +
              I( 0 + (race == 2) + (race == 3)) +
              I(0 + (education == 4)) +
              I(0 + (education == 5)) + I(age - 50) +
              I((age-50)^2/100),
              index = c("id","t"),
              data = SRHS,
              k = 2,
              modManifest = "LM",
              out_se = TRUE,
              tol = 1e-8,
              start = 1,
              seed = 123)

out6
summary(out6)

#### LM model with covariates in the measurement model (mixture latent auto-regressive model)

out7 <- lmest(responsesFormula = srhs ~ -1 +
              I(gender - 1) +
              I( 0 + (race == 2) + (race == 3)) +
              I(0 + (education == 4)) +
              I(0 + (education == 5)) + I(age - 50) +
              I((age-50)^2/100),

```

```

        index = c("id","t"),
        data = SRHS,
        k = 2,
        modManifest = "FM", q = 61,
        out_se = TRUE,
        tol = 1e-8)

out7
summary(out7)

## End(Not run)

```

---

lmestCont

*Estimate Latent Markov models for continuous responses*


---

## Description

Main function for estimating Latent Markov (LM) models for continuous outcomes under the assumption of (multivariate) Gaussian distribution of the response variables given the latent process.

## Usage

```

lmestCont(responsesFormula = NULL, latentFormula = NULL,
          data, index, k = 1:4, start = 0,
          modSel = c("BIC", "AIC"), modBasic = 0,
          paramLatent = c("multilogit", "difflogit"),
          weights = NULL, tol = 10^-10,
          maxit = 5000, out_se = FALSE, output = FALSE,
          parInit = list(piv = NULL, Pi = NULL,
                        Mu = NULL, Si = NULL,
                        Be = NULL, Ga = NULL),
          fort = TRUE, seed = NULL, ntry = 0, miss.imp = FALSE)

```

## Arguments

responsesFormula	a symbolic description of the model to be fitted. A detailed description is given in the ‘Details’ section
latentFormula	a symbolic description of the model to be fitted. A detailed description is given in the ‘Details’ section
data	a data.frame in long format
index	a character vector with two elements, the first indicating the name of the unit identifier, and the second the time occasions
k	an integer vector specifying the number of latent states (default: 1:4)
start	type of starting values (0 = deterministic, 1 = random, 2 = initial values in input)
modSel	a string indicating the model selection criteria: "BIC" for Bayesian Information Criterion and "AIC" for Akaike Information Criterion Criterion

modBasic	model on the transition probabilities (0 for time-heter., 1 for time-homog., from 2 to (TT-1) partial homog. of that order)
paramLatent	type of parametrization for the transition probabilities ("multilogit" = standard multinomial logit for every row of the transition matrix, "difflogit" = multinomial logit based on the difference between two sets of parameters)
weights	vector of weights
tol	tolerance level for convergence
maxit	maximum number of iterations of the algorithm
out_se	to compute the information matrix and standard errors (By default is set to FALSE)
output	to return additional output (V, UL, Pmarg) ( <a href="#">LMbasiccont-class</a> , <a href="#">LMlatentcont-class</a> , <a href="#">LMmanifestcont-class</a> )
parInit	list of initial model parameters when "start = 2". For the list of parameters look at <a href="#">LMbasiccont-class</a> , <a href="#">LMlatentcont-class</a> , and <a href="#">LMmanifestcont-class</a>
fort	to use fortran routines when possible (By default is set to TRUE)
seed	an integer value with the random number generator state
ntry	to set the number of random initializations
miss.imp	how to deal with missing values (TRUE for imputation through the imp.mix function, FALSE for missing at random assumption)

## Details

The function `lmeStCont` is a general function for estimating LM models for continuous responses. The function requires data in long format and two additional columns indicating the unit identifier and the time occasions.

Covariates are allowed on the initial and transition probabilities (latent model). Two different formulas are employed to specify the different LM models, `responsesFormula` and `latentFormula`:

- `responsesFormula` is used to specify the measurement model:
  - `responsesFormula = y1 + y2 ~ NULL`  
the LM model without covariates and two responses (`y1` and `y2`) is specified.
  - `responsesFormula = NULL`  
all the columns in the data except the "id" and "time" columns are used as responses to estimate the LM model without covariates;
  - `responsesFormula = y1 + y2 ~ x1 + x2`  
the LM model with two responses (`y1` and `y2`) and two covariates in the measurement model is specified;
- `latentFormula` is used to specify the LM model with covariates in the latent model:
  - `responsesFormula = y1 + y2 ~ NULL`  
`latentFormula = ~ x1 + x2 | x3 + x4`  
the LM model with two responses (`y1` and `y2`) and two covariates affecting the initial probabilities (`x1` and `x2`) and other two affecting the transition probabilities (`x3` and `x4`) is specified;

- responsesFormula = y1 + y2 ~ NULL  
latentFormula = ~ 1 | x1 + x2  
(or latentFormula = ~ NULL | x1 + x2)  
the covariates affect only the transition probabilities and an intercept is specified for the initial probabilities;
- responsesFormula = y1 + y2 ~ NULL  
latentFormula = ~ x1 + x2  
the LM model with two covariates (x1 and x2) affecting both the initial and transition probabilities is specified;
- responsesFormula = y1 + y2 ~ NULL  
latentFormula = ~ NULL | NULL  
(or latentFormula = ~ 1 | 1)  
the LM model with only an intercept on the initial and transition probabilities is specified.

The function also allows us to deal with missing responses using the `mix` package (Schafer, 2024) for imputing the missing values. Missing values for the covariates are not allowed.

For categorical outcomes see the function [lmest](#).

### Value

Returns an object of class 'LMbasiccont' for the model without covariates (see [LMbasiccont-class](#)), an object of class 'LMlatentcont' for the model with covariates on the latent model (see [LMlatentcont-class](#)), or an object of class 'LMmanifestcont' for the model with covariates on the measurement model (see [LMmanifestcont-class](#)).

### Author(s)

Francesco Bartolucci, Silvia Pandolfi, Fulvia Pennoni

### References

Bartolucci F., Pandolfi S., Pennoni F. (2017) LMest: An R Package for Latent Markov Models for Longitudinal Categorical Data, *Journal of Statistical Software*, **81**(4), 1-38.  
Bartolucci, F., Farcomeni, A. and Pennoni, F. (2013) *Latent Markov Models for Longitudinal Data*, Chapman and Hall/CRC press.

### See Also

[lmestFormula](#)

### Examples

```
## Not run:

data(data_long_cont)

# Basic LM model

out <- lmestCont(responsesFormula = Y1 + Y2 + Y3 ~ NULL,
                 index = c("id", "time"),
```



```
      data = data_long_cont,
      k = 3,
      modBasic = 1,
      tol = 10^-5)

out
summary(out)

# Basic LM model with model selection using BIC

out1 <- lmestCont(responsesFormula = Y1 + Y2 + Y3 ~ NULL,
  index = c("id", "time"),
  data = data_long_cont,
  k = 1:5,
  ntry = 2,
  modBasic = 1,
  tol = 10^-5)

out1
out1$Bic

# Basic LM model with model selection using AIC

out2 <- lmestCont(responsesFormula = Y1 + Y2 + Y3 ~ NULL,
  index = c("id", "time"),
  data = data_long_cont,
  k = 1:5,
  modBasic = 1,
  ntry = 2,
  modSel = "AIC",
  tol = 10^-5)

out2
out2$Aic

# LM model with covariates in the measurement model

out3 <- lmestCont(responsesFormula = Y1 + Y2 + Y3 ~ X1 + X2,
  index = c("id", "time"),
  data = data_long_cont,
  k = 3,
  output = TRUE)

out3
summary(out3)

# LM model with covariates in the latent model

out4 <- lmestCont(responsesFormula = Y1 + Y2 + Y3 ~ NULL,
  latentFormula = ~ X1 + X2,
  index = c("id", "time"),
  data = data_long_cont,
  k = 3,
```

```

                                output = TRUE)

out4
summary(out4)

# LM model with two covariates affecting the initial probabilities and one
# affecting the transition probabilities

out5 <- lmeStCont(responsesFormula = Y1 + Y2 + Y3 ~ NULL,
                  latentFormula = ~ X1 + X2 | X1,
                  index = c("id", "time"),
                  data = data_long_cont,
                  k = 3,
                  output = TRUE)

out5
summary(out5)

## End(Not run)

```

---

lmeStData

*Data for lmeSt functions*


---

### Description

An object of class `lmeStData` containing data in long format, some necessary information on the data structure and objects for the estimation functions.

### Usage

```

lmeStData(data, id = NULL, time = NULL,
           idAsFactor = TRUE, timeAsFactor = TRUE,
           responsesFormula = NULL, latentFormula = NULL,
           na.rm = FALSE, check.names = FALSE)

```

### Arguments

<code>data</code>	a matrix or data frame in long format of observation
<code>id</code>	a numeric vector or a string indicating the column with the unit identifier. If <code>NULL</code> , the first column is considered
<code>time</code>	a numeric vector or a string indicating the column with the time occasions. If <code>NULL</code> , the second column is considered, and if the <code>id</code> is not <code>NULL</code> , the function will automatically add the column with the time occasions
<code>idAsFactor</code>	a logical value indicating whether or not the column with the ids is converted to a factor. (By default is set to <code>TRUE</code> )
<code>timeAsFactor</code>	a logical value indicating whether or not the column with the time occasions is converted in a factor. (By default is set to <code>TRUE</code> )

responsesFormula	A detailed description is given in <a href="#">lmeSt</a> , <a href="#">lmeStCont</a>
latentFormula	A detailed description is given in <a href="#">lmeSt</a> , <a href="#">lmeStCont</a>
na.rm	a logical value indicating whether or not the observation with at least a missing value is removed (By default is set to FALSE)
check.names	a logical value indicating whether or not the names of the variables are syntactically valid, and adjusted if necessary. (By default is set to FALSE)

**Value**

An object of class 'lmeStData' with the following objects:

data	a data.frame object to use in the estimation functions
id	a integer vector with the unit identifier
time	a integer vector with the time occasions
n	the number of observation
TT	an integer value indicating number of time occasions
d	an interger value indicating the number of variables (columns except id and time)
Y	the response variables
Xmanifest	the variables affecting the measurement model if specified in responsesFormula
Xinitial	the variables affecting the initial probabilities of the latent model if specified in latentFormula
Xtrans	the variables affecting the transition probabilities of the latent model if specified in latentFormula

**Author(s)**

Francesco Bartolucci, Silvia Pandolfi, Fulvia Pennoni, Alessio Farcomeni, Alessio Serafini

**Examples**

```
data(data_long_cont)
str(data_long_cont)

## Data with continous resposes

dt <- lmeStData(data = data_long_cont, id = "id", time="time")
str(dt)

## Summary of each variable and for each time

summary(dt)

## Summary of each variable

summary(dt, type = "cross")
```

```

## Summary of each variable by time

summary(dt, type = "year")

plot(dt)
plot(dt, typePlot = "sh")

#####

## Not run:

data("data_criminal_sim")

dt1 <- lmestData(data = data_criminal_sim, id = "id", time = "time")
str(dt1)

summary(dt1, varType = rep("d",ncol(dt1$Y)))

dt2 <- lmestData(data = data_criminal_sim, id = "id", time = "time",
                 responsesFormula = y1 + y2 ~ y3, latentFormula = ~ y7 + y8 | y9 + y10)
str(dt2)

## Summary for responses, covariates on the manifest distribution,
## covariates on intial and transition probabilities

summary(dt2, dataSummary = "responses",varType = rep("d",ncol(dt2$Y)))
summary(dt2, dataSummary = "manifest",varType = rep("d",ncol(dt2$Xmanifest)))
summary(dt2, dataSummary = "initial",varType = rep("d",ncol(dt2$Xinitial)))
summary(dt2, dataSummary = "transition",varType = rep("d",ncol(dt2$Xtrans)))

## End(Not run)

```

---

lmestDecoding

*Perform local and global decoding*


---

## Description

Function that performs local and global decoding (Viterbi algorithm) from the output of `lmest`, `lmestCont`, and `lmestMixed`.

## Usage

```

lmestDecoding(est, sequence = NULL, fort = TRUE, ...)
## S3 method for class 'LMbasic'
lmestDecoding(est, sequence = NULL,fort = TRUE, ...)
## S3 method for class 'LMmanifest'
lmestDecoding(est, sequence = NULL, fort = TRUE, ...)

```

```
## S3 method for class 'LMlatent'
lmestDecoding(est, sequence = NULL, fort = TRUE,...)
## S3 method for class 'LMbasiccont'
lmestDecoding(est, sequence = NULL, fort = TRUE,...)
## S3 method for class 'LMmixed'
lmestDecoding(est, sequence = NULL, fort = TRUE,...)
```

### Arguments

est	an object obtained from a call to <code>lmest</code> , <code>lmestCont</code> , and <code>lmestMixed</code>
sequence	an integer vector indicating the units for the decoding. If NULL the whole observations are considered. (By default is set to NULL)
fort	to use fortran routines when possible
...	further arguments

### Value

U <sub>l</sub>	matrix of local decoded states corresponding to each row of Y
U <sub>g</sub>	matrix of global decoded states corresponding to each row of Y

### Author(s)

Francesco Bartolucci, Silvia Pandolfi, Fulvia Pennoni, Alessio Farcomeni, Alessio Serafini

### References

Viterbi A. (1967) Error Bounds for Convolutional Codes and an Asymptotically Optimum Decoding Algorithm. *IEEE Transactions on Information Theory*, **13**, 260-269.

Juan B., Rabiner L. (1991) Hidden Markov Models for Speech Recognition. *Technometrics*, **33**, 251-272.

### Examples

```
# Decoding for basic LM model

data("data_drug")
long <- data_drug[,-6]-1
long <- data.frame(id = 1:nrow(long),long)
long <- reshape(long,direction = "long",
                idvar = "id",
                varying = list(2:ncol(long)))

est <- lmest(index = c("id","time"),
            k = 3,
            data = long,
            weights = data_drug[,6],
            modBasic = 1)

# Decoding for a single sequence
```

```

out1 <- lmestDecoding(est, sequence = 1)

out2 <- lmestDecoding(est, sequence = 1:4)

# Decoding for all sequences

out3 <- lmestDecoding(est)

## Not run:
# Decoding for LM model with covariates on the initial and transition probabilities

data("data_SRHS_long")

SRHS <- data_SRHS_long[1:2400,]

# Categories rescaled to vary from 0 ("poor") to 4 ("excellent")

SRHS$srhs <- 5 - SRHS$srhs

est2 <- lmest(responsesFormula = srhs ~ NULL,
              latentFormula = ~
                I(gender - 1) +
                I(0 + (race == 2) + (race == 3)) +
                I(0 + (education == 4)) +
                I(0 + (education == 5)) +
                I(age - 50) + I((age-50)^2/100),
              index = c("id", "t"),
              data = SRHS,
              k = 2,
              paramLatent = "difflogit",
              output = TRUE)

# Decoding for a single sequence

out3 <- lmestDecoding(est2, sequence = 1)

# Decoding for the first three sequences

out4 <- lmestDecoding(est2, sequence = 1:3)

# Decoding for all sequences

out5 <- lmestDecoding(est2)

## End(Not run)

```

**Description**

Building formulas for `lmeSt`, `lmeStCont`, `lmeStMixed`, and `lmeStMc`.

**Usage**

```
lmeStFormula(data,
             response, manifest = NULL,
             LatentInitial = NULL, LatentTransition = NULL,
             AddInterceptManifest = FALSE,
             AddInterceptInitial = TRUE,
             AddInterceptTransition = TRUE, responseStart = TRUE,
             manifestStart = TRUE, LatentInitialStart = TRUE,
             LatentTransitionStart = TRUE)
```

**Arguments**

<code>data</code>	a <code>data.frame</code> or a matrix of data
<code>response</code>	a numeric or character vector indicating the column indices or the names for the response variables
<code>manifest</code>	a numeric or character vector indicating the column indices or the names for the covariates affecting the measurement model
<code>LatentInitial</code>	a numeric or character vector indicating the column indices or the names for the covariates affecting the initial probabilities
<code>LatentTransition</code>	a numeric or character vector indicating the column indices or the names for the covariates affecting the transition probabilities
<code>AddInterceptManifest</code>	a logical value indicating whether the intercept is added to the covariates affecting the measurement model
<code>AddInterceptInitial</code>	a logical value indicating whether the intercept is added to covariates affecting the initial probabilities
<code>AddInterceptTransition</code>	a logical value indicating whether the intercept is added to covariates affecting the transition probabilities
<code>responseStart</code>	a logical value indicating whether the response variables names start with <code>response</code> argument
<code>manifestStart</code>	a logical value indicating whether the covariates names start with <code>manifest</code> argument
<code>LatentInitialStart</code>	a logical value indicating whether the covariates names start with <code>LatentInitial</code> argument
<code>LatentTransitionStart</code>	a logical value indicating whether the covariates names start with <code>LatentTransition</code> argument

**Details**

Generates formulas for responsesFormula and latentFormula to use in `lmest`, `lmestCont`, `lmestMixed`, and `lmestMc`.

**Value**

Returns a list with responsesFormula and latentFormula objects.

**Author(s)**

Francesco Bartolucci, Silvia Pandolfi, Fulvia Pennoni, Alessio Farcomeni, Alessio Serafini

**Examples**

```
data(data_SRHS_long)
names(data_SRHS_long)

# Formula with response srhs and covariates for both initial and transition:
# gender,race,educational,age.

## LM model with covariates on the latent model
# and with intercepts on the initial and transition probabilities

fm <- lmestFormula(data = data_SRHS_long,
                  response = "srhs",
                  LatentInitial = 3:6, LatentTransition = 3:6)
fm

## LM model with covariates on the latent model
# and without intercepts on the initial and transition probabilities

fm <- lmestFormula(data = data_SRHS_long,
                  response = "srhs",
                  LatentInitial = 3:6, LatentTransition = 3:6,
                  AddInterceptInitial = FALSE,AddInterceptTransition = FALSE)
fm

#####

data(data_criminal_sim)
str(data_criminal_sim)

# Formula with only the responses from y1 to y10

fm <- lmestFormula(data = data_criminal_sim,response = "y")$responsesFormula
fm

# Formula with only the responses from y1 to y10 and intercept for manifest

fm <- lmestFormula(data = data_criminal_sim,
                  response = "y",AddInterceptManifest = TRUE)$responsesFormula
fm
```



```
## LM model for continous responses

data(data_long_cont)
names(data_long_cont)

# Formula with response Y1, Y2, no covariate for manifest,
# X1 covariates for initail and X2 covariate for transition

fm <- lmestFormula(data = data_long_cont,
                  response = c("Y"),
                  LatentInitial = "X",
                  LatentTransition = "X2")
fm

## Wrong model specification since two variable start with X.
# Check the starts arguments.

# For the right model:

fm <- lmestFormula(data = data_long_cont,
                  response = c("Y"),
                  LatentInitial = "X1",LatentTransition = "X2")
fm

## or

fm <- lmestFormula(data = data_long_cont,
                  response = c("Y"),
                  LatentInitial = 6,LatentTransition = "X2",
                  LatentInitialStart = FALSE)
fm

## Not run:

data(data_criminal_sim)
data_criminal_sim <- data.frame(data_criminal_sim)

# Mixed LM model for females

responsesFormula <- lmestFormula(data = data_criminal_sim,
                                response = "y")$responsesFormula

out <- lmest(responsesFormula = responsesFormula,
            index = c("id","time"),
            data = data_criminal_sim,
            k = 2)

## End(Not run)
```

lmestMc

*Estimate Markov Chain models***Description**

Main function for estimating Markov Chain (MC) models for categorical responses with or without covariates.

**Usage**

```
lmestMc(responsesFormula = NULL,
        data, index, start = 0,
        modBasic = 0, weights = NULL,
        tol = 10^-8, maxit = 1000,
        out_se = FALSE, output = FALSE, fort = TRUE, seed = NULL)
```

**Arguments**

responsesFormula	a symbolic description of the model to fit. A detailed description is given in the ‘Details’ section
data	a data.frame in long format
index	a character vector with two elements, the first indicating the name of the unit identifier, and the second the time occasions
start	type of starting values (0 = deterministic, 1 = random, 2 = initial values in input)
modBasic	model on the transition probabilities (0 for time-heter., 1 for time-homog., from 2 to (TT-1) partial homog. of that order)
weights	an optional vector of weights for the available responses
tol	tolerance level for convergence
maxit	maximum number of iterations of the algorithm
out_se	to compute the information matrix and standard errors (FALSE is the default option)
output	to return additional output (PI,Piv) ( <a href="#">MCcov-class</a> )
fort	to use fortran routines when possible (By default is set to TRUE)
seed	An integer value with the random number generator state.

**Details**

The function `lmestMc` estimates the basic MC model and the MC model with covariates for categorical responses. The function requires data in long format and two additional column indicating the unit identifier and the time occasions.

`responsesFormula` is used to specify the basic MC models and the model with covariates:

- `responsesFormula = y1 + y2 ~ NULL`  
the MC model without covariates and two responses (y1 and y2) is specified;
- `responsesFormula = NULL`  
all the columns in the data except the "id" and "time" columns are used to estimate MC without covariates;
- `responsesFormula = y1 ~ x1 + x2 | x3 + x4`  
the MC model with one response (y1), two covariates affecting the initial probabilities (x1 and x2) and other two different covariates affecting the transition probabilities (x3 and x4) is specified;
- `responsesFormula = y1 ~ x1 + x2`  
the MC model with one response (y1) and two covariates (x1 and x2) affecting both the initial and transition probabilities is specified.

Missing responses are not allowed.

### Value

Returns an object of class 'MCbasic' for the basic model without covariates (see [MCbasic-class](#)), or an object of class 'MCcov' for the model with covariates (see [MCcov-class](#)).

### Author(s)

Francesco Bartolucci, Silvia Pandolfi, Fulvia Pennoni, Alessio Farcomeni, Alessio Serafini

### References

Bartolucci F., Pandolfi S., Pennoni F. (2017) LMest: An R Package for Latent Markov Models for Longitudinal Categorical Data, *Journal of Statistical Software*, **81**(4), 1-38.

Bartolucci, F., Farcomeni, A. and Pennoni, F. (2013) *Latent Markov Models for Longitudinal Data*, Chapman and Hall/CRC press.

### Examples

```
## Not run:
# Basic Markov Chain model

data("RLMSlong")

# Categories rescaled from 1 "absolutely unsatisfied" to 5 "absolutely satisfied"

RLMSlong$value <- 5 - RLMSlong$value

out <- lmestMc(responsesFormula = value ~ NULL,
              index = c("id", "time"),
              modBasic = 1,
              data = RLMSlong)

out
summary(out)
```

```

# Example of drug consumption data

data("data_drug")
long <- data_drug[,-6]
long <- data.frame(id = 1:nrow(long),long)
long <- reshape(long,direction = "long",
                idvar = "id",
                varying = list(2:ncol(long)))

out1 <- lmestMc(index = c("id","time"), data = long,
                weights = data_drug[,6], modBasic = 1, out_se = TRUE)

out1

### MC model with covariates
### Covariates: gender, race, educational level (2 columns), age and age^2

data("data_SRHS_long")
SRHS <- data_SRHS_long[1:2400,]

# Categories of the responses rescaled from 1 "poor" to 5 "excellent"

SRHS$srhs <- 5 - SRHS$srhs

out2 <- lmestMc(responsesFormula = srhs ~
                I( 0 + (race==2) + (race == 3)) +
                I(0 + (education == 4)) +
                I(0 + (education == 5)) +
                I(age - 50) +
                I((age-50)^2/100),
                index = c("id","t"),
                data = SRHS)

out2
summary(out2)

# Criminal data

data(data_criminal_sim)
data_criminal_sim = data.frame(data_criminal_sim)

out3 <- lmestMc(responsesFormula = y5~sex,
                index = c("id","time"),
                data = data_criminal_sim,
                output = TRUE)

out3

## End(Not run)

```

---

 lmestMixed

*Estimate mixed Latent Markov models*


---

### Description

Main function for estimating the mixed latent Markov (LM) models for categorical responses with discrete random effects in the latent model.

### Usage

```
lmestMixed(responsesFormula = NULL,
           data, index, k1, k2, start = 0,
           weights = NULL, tol = 10^-8, maxit = 1000,
           out_se = FALSE, seed = NULL)
```

### Arguments

responsesFormula	a symbolic description of the model to fit. A detailed description is given in the ‘Details’ section
data	a data.frame in long format
index	a character vector with two elements, the first indicating the name of the unit identifier, and the second the time occasions
k1	number of latent classes
k2	number of latent states
start	type of starting values (0 = deterministic, 1 = random, 2 = initial values in input)
weights	an optional vector of weights for the available responses
tol	tolerance level for convergence
maxit	maximum number of iterations of the algorithm
out_se	to compute the information matrix and standard errors (FALSE is the default option)
seed	an integer value with the random number generator state

### Details

The function `lmestMixed` estimates the mixed LM for categorical data. The function requires data in long format and two additional columns indicating the unit identifier and the time occasions.

`responsesFormula` is used to specify the responses of the mixed LM model:

- `responsesFormula = y1 + y2 ~ NULL`  
the mixed LM model with two categorical responses (`y1` and `y2`) is specified;
- `responsesFormula = NULL`  
all the columns in the data except the `"id"` and `"time"` columns are used as responses to estimate the mixed LM.

Missing responses are not allowed.

**Value**

Returns an object of class 'LMmixed' (see [LMmixed-class](#)).

**Author(s)**

Francesco Bartolucci, Silvia Pandolfi, Fulvia Pennoni, Alessio Farcomeni, Alessio Serafini

**References**

Bartolucci F., Pandolfi S., Pennoni F. (2017) LMest: An R Package for Latent Markov Models for Longitudinal Categorical Data, *Journal of Statistical Software*, **81**(4), 1-38.

Bartolucci, F., Farcomeni, A. and Pennoni, F. (2013) *Latent Markov Models for Longitudinal Data*, Chapman and Hall/CRC press.

**Examples**

```
## Not run:

# Example based on criminal data

data(data_criminal_sim)
data_criminal_sim <- data.frame(data_criminal_sim)

# Estimate mixed LM model for females

responsesFormula <- lmestFormula(data = data_criminal_sim,
                                response = "y")$responsesFormula

# fit mixed LM model only for females
out <- lmestMixed(responsesFormula = responsesFormula,
                 index = c("id", "time"),
                 k1 = 2,
                 k2 = 2,
                 data = data_criminal_sim[data_criminal_sim$sex == 2,])

out
summary(out)

## End(Not run)
```

**Description**

Function that searches for the global maximum of the log-likelihood of different models and selects the optimal number of states.

**Usage**

```
lmestSearch(responsesFormula = NULL, latentFormula = NULL,
            data, index, k,
            version = c("categorical", "continuous"),
            weights = NULL, nrep = 2, tol1 = 10^-5,
            tol2 = 10^-10, out_se = FALSE, miss.imp = FALSE, seed = NULL, ...)
```

**Arguments**

<code>responsesFormula</code>	a symbolic description of the model to fit. A detailed description is given in the ‘Details’ section of <a href="#">lmest</a>
<code>latentFormula</code>	a symbolic description of the model to fit. A detailed description is given in the ‘Details’ section of <a href="#">lmest</a>
<code>data</code>	a <code>data.frame</code> in long format
<code>index</code>	a character vector with two elements, the first indicating the name of the unit identifier, and the second the time occasions
<code>k</code>	a vector of integer values for the number of latent states
<code>weights</code>	an optional vector of weights for the available responses
<code>version</code>	type of responses for the LM model: "categorical" and "continuous"
<code>nrep</code>	number of repetitions of each random initialization
<code>tol1</code>	tolerance level for checking convergence of the algorithm in the random initializations
<code>tol2</code>	tolerance level for checking convergence of the algorithm in the last deterministic initialization
<code>out_se</code>	to compute the information matrix and standard errors (FALSE is the default option)
<code>miss.imp</code>	Only for continuous responses: how to deal with missing values (TRUE for imputation through the <code>imp.mix</code> function, FALSE for missing at random assumption)
<code>seed</code>	an integer value with the random number generator
<code>...</code>	additional arguments to be passed to functions <a href="#">lmest</a> or <a href="#">lmestCont</a>

**Details**

The function combines deterministic and random initializations strategy to reach the global maximum of the model log-likelihood. It uses one deterministic initialization (`start=0`) and a number of random initializations (`start=1`) proportional to the number of latent states. The tolerance level is set equal to  $10^{-5}$ . Starting from the best solution obtained in this way, a final run is performed (`start=2`) with a default tolerance level equal to  $10^{-10}$ .

Missing responses are allowed according to the model to be estimated.

**Value**

Returns an object of class 'LMsearch' with the following components:

<code>out.single</code>	Output of every LM model estimated for each number of latent states given in input
<code>Aic</code>	Values the Akaike Information Criterion for each number of latent states given in input
<code>Bic</code>	Values of the Bayesian Information Criterion for each number of latent states given in input
<code>lkv</code>	Values of log-likelihood for each number of latent states given in input.

**Author(s)**

Francesco Bartolucci, Silvia Pandolfi, Fulvia Pennoni, Alessio Farcomeni, Alessio Serafini

**References**

Bartolucci F., Pandolfi S., Pennoni F. (2017) LMest: An R Package for Latent Markov Models for Longitudinal Categorical Data, *Journal of Statistical Software*, **81**(4), 1-38.

Bartolucci, F., Farcomeni, A. and Pennoni, F. (2013) *Latent Markov Models for Longitudinal Data*, Chapman and Hall/CRC press.

**Examples**

```
### Example with data on drug use in wide format

data("data_drug")
long <- data_drug[,-6]

# add labels referred to the identifier

long <- data.frame(id = 1:nrow(long),long)

# reshape data from the wide to the long format

long <- reshape(long,direction = "long",
                idvar = "id",
                varying = list(2:ncol(long)))

out <- lmestSearch(data = long,
                  index = c("id","time"),
                  version = "categorical",
                  k = 1:3,
                  weights = data_drug[,6],
                  modBasic = 1,
                  seed = 123)

out
summary(out$out.single[[3]])
```



```

## Not run:

### Example with data on self rated health

# LM model with covariates in the measurement model

data("data_SRHS_long")
SRHS <- data_SRHS_long[1:1000,]

# Categories rescaled to vary from 1 ("poor") to 5 ("excellent")

SRHS$srhs <- 5 - SRHS$srhs

out1 <- lmestSearch(data = SRHS,
                    index = c("id","t"),
                    version = "categorical",
                    responsesFormula = srhs ~ -1 +
                    I(gender - 1) +
                    I(0 + (race == 2) + (race == 3)) +
                    I(0 + (education == 4)) +
                    I(0 + (education == 5)) + I(age - 50) +
                    I((age-50)^2/100),
                    k = 1:2,
                    out_se = TRUE,
                    seed = 123)

summary(out1)
summary(out1$out.single[[2]])

## End(Not run)

```

---

LMlatent-class	<i>Class 'LMlatent'</i>
----------------	-------------------------

---

### Description

An S3 class object created by `lmest` for Latent Markov (LM) model with covariates in the latent model.

### Value

lk	maximum log-likelihood
Be	estimated array of the parameters affecting the logit for the initial probabilities
Ga	estimated array of the parameters affecting the logit for the transition probabilities
Piv	estimate of initial probability matrix. The first state is used as reference category when <code>param = "multilogit"</code>
PI	estimate of transition probability matrices. State u is used as reference category when <code>paramLatent = "multilogit"</code>

Psi	estimate of conditional response probabilities (mb x k x r)
np	number of free parameters
k	optimal number of latent states
aic	value of the Akaike Information Criterion for model selection
bic	value of the Bayesian Information Criterion for model selection
lkv	log-likelihood trace at every step of the EM algorithm
n	number of observations in the data
TT	number of time occasions
paramLatent	type of parametrization for the transition probabilities ("multilogit" = standard multinomial logit for every row of the transition matrix, "difflogit" = multinomial logit based on the difference between two sets of parameters)
sePsi	standard errors for the conditional response matrix
seBe	standard errors for Be
seGa	standard errors for Ga
Lk	vector containing the values of the log-likelihood of the LM model with each k (latent states)
Bic	vector containing the values of the BIC for each k
Aic	vector containing the values of the AIC for each k
V	array containing the posterior distribution of the latent states for each response configuration and time occasion
U1	matrix containing the predicted sequence of latent states by the local decoding method
S	array containing the available response configurations
yv	vector of frequencies of the available configurations
Pmarg	matrix containing the marginal distribution of the latent states
call	command used to call the function
data	Data frame given in input

**Author(s)**

Francesco Bartolucci, Silvia Pandolfi, Fulvia Pennoni, Alessio Farcomeni, Alessio Serafini

**See Also**

[lmest](#)

---

 LMlatentcont-class      *Class 'LMlatentcont'*


---

**Description**

An S3 class object created by `lmestCont` for the Latent Markov (LM) model for continuous responses in long format with covariates in the latent model.

**Value**

lk	maximum log-likelihood
Be	estimated array of the parameters affecting the logit for the initial probabilities
Ga	estimated array of the parameters affecting the logit for the transition probabilities
Mu	estimate of conditional means of the response variables
Si	estimate of var-cov matrix common to all states
np	number of free parameters
k	optimal number of latent states
aic	value of the Akaike Information Criterion for model selection
bic	value of the Bayesian Information Criterion for model selection
lkv	log-likelihood trace at every step
n	number of observations in the data
TT	number of time occasions
paramLatent	type of parametrization for the transition probabilities ("multilogit" = standard multinomial logit for every row of the transition matrix, "difflogit" = multinomial logit based on the difference between two sets of parameters)
seMu	standard errors for the conditional means
seSi	standard errors for the var-cov matrix
seBe	standard errors for Be
seGa	standard errors for Ga
sc	score vector
J	information matrix
PI	estimate of transition probability matrices
Piv	estimate of initial probability matrix
Lk	vector containing the values of the log-likelihood of the LM model with each k (latent states)
Bic	vector containing the values of the BIC of the LM model with each k (latent states)
Aic	vector containing the values of the AIC of the LM model with each k (latent states)

V	array containing the posterior distribution of the latent states for each units and time occasion
U1	matrix containing the predicted sequence of latent states by the local decoding method
Pmarg	matrix containing the marginal distribution of the latent states
call	command used to call the function
data	data frame given in input

**Author(s)**

Francesco Bartolucci, Silvia Pandolfi, Fulvia Pennoni, Alessio Farcomeni, Alessio Serafini

**See Also**

[lmestCont](#)

---

LMmanifest-class	Class 'LMmanifest'
------------------	--------------------

---

**Description**

An S3 class object created by [lmest](#) for Latent Markov (LM) model with covariates in the measurement model.

**Value**

mu	vector of cut-points
al	support points for the latent states
be	estimate of the vector of regression parameters
si	sigma of the AR(1) process (mod = "FM")
rho	parameter vector for AR(1) process (mod = "FM")
la	vector of initial probabilities
PI	transition matrix
lk	maximum log-likelihood
np	number of parameters
k	optimal number of latent states
aic	value of the Akaike Information Criterion
bic	value of Bayesian Information Criterion
n	number of observations in the data
TT	number of time occasions

modManifest	for LM model with covariates on the manifest model: "LM" = Latent Markov with stationary transition, "FM" = finite mixture model where a mixture of AR(1) processes is estimated with common variance and specific correlation coefficients
sebe	standard errors for the regression parameters be
selrho	standard errors for logit type transformation of rho
J1	information matrix
V	array containing the posterior distribution of the latent states for each units and time occasion
PRED1	prediction of the overall latent effect
S	array containing the available response configurations
yv	vector of frequencies of the available configurations
Pmarg	matrix containing the marginal distribution of the latent states
Lk	vector containing the values of the log-likelihood of the LM model with each k (latent states)
Bic	vector containing the values of the BIC for each k
Aic	vector containing the values of the AIC for each k
call	command used to call the function
data	data frame given in input

**Author(s)**

Francesco Bartolucci, Silvia Pandolfi, Fulvia Pennoni, Alessio Farcomeni, Alessio Serafini

**See Also**

[lmest](#)

---

LMmanifestcont-class    *Class* 'LMmanifestcont'

---

**Description**

An S3 class object created by [lmestCont](#) for Latent Markov (LM) model for continuous responses in long format with covariates in the measurement model.

**Value**

Al	support points for the latent states
Be	estimate of the vector of regression parameters
Si	estimate of var-cov matrix common to all states
piv	vector of initial probabilities

Pi	transition matrix
lk	maximum log-likelihood
np	number of parameters
k	optimal number of latent states
aic	value of the Akaike Information Criterion
bic	value of Bayesian Information Criterion
n	number of observations in the data
TT	number of time occasions
modBasic	model on the transition probabilities (0 for time-heter., 1 for time-homog., from 2 to (TT-1) partial homog. of that order)
lkv	log-likelihood trace at every step
seAl	standard errors for the support points Al
seBe	standard errors regression parameters Be
sepiv	standard errors for the initial probabilities
sePi	standard errors for the transition probabilities
seSi	standard errors for the var-cov matrix
Lk	vector containing the values of the log-likelihood of the LM model for each k (latent states)
Np	vector containing the number of parameters for each k (latent states)
Bic	vector containing the values of the BIC for each k
Aic	vector containing the values of the AIC for each k
J	information matrix
sc	score vector
V	array containing the posterior distribution of the latent states for each units and time occasion
Ul	matrix containing the predicted sequence of latent states by the local decoding method
Pmarg	matrix containing the marginal distribution of the latent states
call	command used to call the function
data	data frame given in input

**Author(s)**

Francesco Bartolucci, Silvia Pandolfi, Fulvia Pennoni

**See Also**

[lmestCont](#)

---

LMmixed-class	Class 'LMmixed'
---------------	-----------------

---

**Description**

An S3 class object created by [lmestMixed](#) for the mixed latent Markov (LM) models for categorical data in long format.

**Value**

la	estimate of the mass probability vector (distribution of the random effects)
Piv	estimate of initial probabilities
Pi	estimate of transition probability matrices
Psi	estimate of conditional response probabilities
lk	maximum log-likelihood
W	posterior probabilities of the random effect
np	number of free parameters
k1	number of support points (latent classes) of the latent variable defining the unobserved clusters
k2	number of support points (latent states) of the latent variable defining the first-order Markov process
bic	value of the Akaike Information Criterion for model selection
aic	value of the Akaike Information Criterion for model selection
n	number of observations in the data
TT	number of time occasions
sela	standard errors for la
sePiv	estimate of initial probability matrix
sePi	standard errors for the transition probabilities
sePsi	standard errors for the conditional response matrix
call	command used to call the function
data	the input data

**Author(s)**

Francesco Bartolucci, Silvia Pandolfi, Fulvia Pennoni, Alessio Farcomeni, Alessio Serafini

**See Also**

[lmestMixed](#)

---

`long2matrices`*From data in the long format to data in array format*

---

**Description**

Function that transforms data in the long format to data in array format.

**Usage**

```
long2matrices(id, time = NULL, X = NULL, Y)
```

**Arguments**

<code>id</code>	vector of subjects id
<code>time</code>	vector of time occasions
<code>X</code>	matrix of covariates in long format
<code>Y</code>	matrix of responses in long format

**Value**

<code>XX</code>	array of covariates (n x TT x nc)
<code>YY</code>	array of responses (n x TT x r)

**Author(s)**

Francesco Bartolucci, Silvia Pandolfi, University of Perugia (IT), <http://www.stat.unipg.it/bartolucci>

**Examples**

```
# Example based on SRHS data

# load SRHS data
data(data_SRHS_long)
dataSRHS <- data_SRHS_long[1:1600,]
head(dataSRHS)
X <- cbind(dataSRHS$gender-1, dataSRHS$race == 2 | dataSRHS$race == 3,
dataSRHS$education == 4, dataSRHS$education == 5, dataSRHS$age-50,
(dataSRHS$age-50)^2/100)
Y <- dataSRHS$srhs
res <- long2matrices(dataSRHS$id, X = X, Y = Y)
```



---

long2wide	<i>From data in the long format to data in the wide format</i>
-----------	--

---

**Description**

Function that transforms data in the long format to data in the wide format.

**Usage**

```
long2wide(data, nameid, namet, colx, coly, aggr = T, full = 999)
```

**Arguments**

data	matrix of data
nameid	name of the id column
namet	name of the t column
colx	vector of the names of the columns of the covariates
coly	vector of the names of the columns of the responses
aggr	if wide aggregated format is required
full	number to use for missing data

**Value**

listid	list of id for every unit
listt	list of the time occasions
data_wide	data in wide format
XX	array of the covariates
YY	array of the responses
freq	vector of the corresponding frequencies

**Author(s)**

Francesco Bartolucci, Silvia Pandolfi, University of Perugia (IT), <http://www.stat.unipg.it/bartolucci>

**Examples**

```
# Example based on criminal data
# load criminal data
data(data_criminal_sim)
# consider only the first 1000 records to shorten time
out <- long2wide(data_criminal_sim[1:1000,], "id", "time", "sex",
c("y1", "y2", "y3", "y4", "y5", "y6", "y7", "y8", "y9", "y10"), aggr = TRUE, full = 999)
```

---

matrices2long                      *From data in array format to data in long format*

---

**Description**

Function to convert data with array format in data with long format.

**Usage**

```
matrices2long(Y, X1 = NULL, X2 = NULL)
```

**Arguments**

Y	array of responses (n x TT x r)
X1	array of covariates (n x TT x nc1)
X2	array of covariates (n x TT x nc2)

**Details**

Y, X1 and X2 must have the same number of observations.

**Value**

Returns a data.frame with data in long format. The first column indicates the name of the unit identifier, and the second column indicates the time occasions.

**Author(s)**

Francesco Bartolucci, Silvia Pandolfi, Fulvia Pennoni, Alessio Farcomeni, Alessio Serafini

**Examples**

```
### Example with data on self rated health

data(data_SRHS_long)
SRHS <- data_SRHS_long[1:1600,]

# Covariates

X <- cbind(SRHS$gender-1,
           SRHS$race == 2 | SRHS$race == 3,
           SRHS$education == 4,
           SRHS$education == 5,
           SRHS$age-50,
           (SRHS$age-50)^2/100)

# Responses

Y <- SRHS$srhs
```

```
res <- long2matrices(SRHS$id, X = X, Y = Y)
long <- matrices2long(Y = res$YY, X1 = res$XX)
```

---

MCbasic-class	Class 'MCbasic'
---------------	-----------------

---

### Description

An S3 class object created by [lmestMc](#) function for the Markov chain (MC) model without covariates.

### Value

lk	maximum log-likelihood
piv	estimate of initial probability vector
Pi	estimate of transition probability matrices
np	number of free parameters
aic	value of the Akaike Information Criterion for model selection
bic	value of the Bayesian Information Criterion for model selection
Fy	estimated marginal distribution of the response variable at each time occasion
n	number of observations in the data
TT	number of time occasions
modBasic	model on the transition probabilities: default 0 for time-heterogeneous transition matrices, 1 for time-homogeneous transition matrices, 2 for partial time homogeneity based on two transition matrices one from 2 to (TT-1) and the other for TT
sepiv	standard errors for the initial probabilities
sePi	standard errors for the transition probabilities
call	command used to call the function
data	data frame given in input

### Author(s)

Francesco Bartolucci, Silvia Pandolfi, Fulvia Pennoni, Alessio Farcomeni, Alessio Serafini

### See Also

[lmestMc](#)

---

MCcov-class	<i>Class 'MCcov'</i>
-------------	----------------------

---

### Description

An S3 class object created by [lmestMc](#) function for Markov chain (MC) model for categorical responses in long format with covariates.

### Value

lk	maximum log-likelihood
Be	estimated array of the parameters affecting the logit for the initial probabilities
Ga	estimated array of the parameters affecting the logit for the transition probabilities
np	number of free parameters
aic	value of the Akaike Information Criterion (AIC) for model selection
bic	value of the Bayesian Information Criterion (BIC) for model selection
n	number of observations in the data
TT	number of time occasions
seBe	standard errors for Be
seGa	standard errors for Ga
Piv	estimate of initial probability matrix
PI	estimate of transition probability matrices
call	command used to call the function
data	data frame given in input

### Author(s)

Francesco Bartolucci, Silvia Pandolfi, Fulvia Pennoni, Alessio Farcomeni, Alessio Serafini

### See Also

[lmestMc](#)

---

NLSYlong

*National Longitudinal Survey of Youth data*

---

**Description**

Longitudinal dataset in long format deriving from the National Longitudinal Survey of Youth with information about 581 individuals followed from 1990 to 1994.

**Usage**

```
data(NLSYlong)
```

**Format**

A data frame with 1743 observations on the following 12 variables.

momage mother's age at birth.

gender 0 if male, 1 if female.

childage child's age at first interview.

hispanic 1 if child is Hispanic, 0 if not.

black 1 if child is black, 0 if not.

momwork 1 if mother works, 0 if not.

married 1 if parents are married, 0 if not.

time occasion of observation.

anti a measure of antisocial behavior measured on a scale from 0 to 6.

self a measure of self-esteem measured on a scale from 6 to 24.

pov a time varying variable assuming value 1 if family is in poverty, 0 if not.

id subject id.

**Source**

<https://www.nlsinfo.org/content/cohorts/nlsy79>

**References**

The wide format of this dataset is downloadable from the package 'panelr'.

**Examples**

```
data(NLSYlong)
```

plot

*Plots for Generalized Latent Markov Models***Description**

Plots for outputs of LMest objects: LMbasic, LMbasiccont, LMlatent, LMlatentcont, and LMsearch

**Usage**

```
## S3 method for class 'LMbasic'
plot(x,
      what = c("modSel", "CondProb", "transitions", "marginal"),
      verbose=interactive(),...)
## S3 method for class 'LMlatent'
plot(x,
      what = c("modSel", "CondProb", "transitions", "marginal"),
      verbose=interactive(),...)
## S3 method for class 'LMbasiccont'
plot(x,
      what = c("modSel", "density", "transitions", "marginal"),
      components, verbose=interactive(),...)
## S3 method for class 'LMlatentcont'
plot(x,
      what = c("modSel", "density", "transitions", "marginal"),
      components, verbose=interactive(),...)
## S3 method for class 'LMsearch'
plot(x,...)
```

**Arguments**

x	an object of class LMbasic, LMlatent, LMbasiccont, LMlatentcont or LMsearch
what	a string indicating the type of plot. A detailed description is provided in the 'Details' section.
components	An integer or a vector of integers specifying the components (latent states) to be selected for the "density" plot.
verbose	A logical controlling if a text progress bar is displayed during the fitting procedure. By default is TRUE if the session is interactive, and FALSE otherwise.
...	Unused argument.

**Details**

The type of plots are the following:

"modSel"	plot of values of the Bayesian Information Criterion and of the Akaike Information Criterion for model selection
"CondProb"	plot of the estimated conditional response probabilities

"density"	plot of the overall estimated density for continuous responses, with weights given by the estimated marginal distribution of the latent variable. For multivariate continuous responses a contour plot is provided. If the argument components is specified, the density plot for the selected components results
"transitions"	path diagram of the estimated transition probabilities
"marginal"	plot of the estimated marginal distribution of the latent variable

If argument what is not specified, a menu of choices is proposed in an interactive session.

### Author(s)

Francesco Bartolucci, Silvia Pandolfi, Fulvia Pennoni, Alessio Farcomeni, Alessio Serafini

### Examples

```
## Not run:
### Plot of basic LM model

data("data_SRHS_long")
SRHS <- data_SRHS_long[1:2400,]

# Categories rescaled to vary from 0 ("poor") to 4 ("excellent")

SRHS$srhs <- 5 - SRHS$srhs

out <- lmest(responsesFormula = srhs ~ NULL,
            index = c("id", "t"),
            data = SRHS,
            k = 1:3,
            start = 1,
            modBasic = 1,
            seed = 123)

out
summary(out)
plot(out)

### Plot of basic LM model for continuous responses

data(data_long_cont)

out1 <- lmestCont(responsesFormula = Y1 + Y2 + Y3 ~ NULL,
                 index = c("id", "time"),
                 data = data_long_cont,
                 k = 1:5,
                 modBasic=1,
                 tol=10^-5)

plot(out1, what="modSel")

plot(out1, what="density")
plot(out1, what="density", components=c(1,3))
```

```
## End(Not run)
```

---

```
print          Print the output
```

---

## Description

Given the output, it is written in a readable form

## Usage

```
## S3 method for class 'LMbasic'
print(x, ...)
## S3 method for class 'LMbasiccont'
print(x, ...)
## S3 method for class 'LMlatent'
print(x, ...)
## S3 method for class 'LMlatentcont'
print(x, ...)
## S3 method for class 'LMmanifest'
print(x, ...)
## S3 method for class 'LMmixed'
print(x, ...)
## S3 method for class 'MCbasic'
print(x, ...)
## S3 method for class 'MCcov'
print(x, ...)
## S3 method for class 'LMsearch'
print(x, modSel = "BIC",...)
```

## Arguments

x	output from <code>lmest</code> , <code>lmestCont</code> , <code>lmestMixed</code> , and <code>lmestMc</code>
modSel	a string indicating the model selection criteria: "BIC" (default) for Bayesian Information Criterion and "AIC" for Akaike Information Criterion Criterion
...	further arguments passed to or from other methods

## Author(s)

Francesco Bartolucci, Silvia Pandolfi, Fulvia Pennoni, Alessio Farcomeni, Alessio Serafini



---

PSIDlong	<i>Dataset about income dynamics</i>
----------	--------------------------------------

---

**Description**

Longitudinal dataset deriving from the Panel Study of Income Dynamics (PSID) from 1987 to 1993.

**Usage**

```
data(PSIDlong)
```

**Format**

A data frame with 1446 observations on the following variables.

id subject id.

**time** occasion of observation.

Y1Fertility indicating whether a woman had given birth to a child in a certain year 1 for "yes", 0 for "no".

Y2Employment indicating whether she was employed 1 for "yes", 0 for "no".

X1Race dummy variable equal to 1 for a "black" woman, 0 for "other".

X2Age age in 1986, rescaled by its maximum value.

X3Age2 squared age.

X4Education number of years of schooling.

X5Child1\_2 number of children in the family aged between 1 and 2 years, referred to the previous year.

X6Child3\_5 number of children in the family aged between 3 and 5 years, referred to the previous year.

X7Child6\_13 number of children in the family aged between 6 and 13 years, referred to the previous year.

X8Child14 number of children in the family aged over 14 years, referred to the previous year.

X9Income income of the husband (in dollars, referred to the previous year, divided by 1,000).

**Source**

<https://psidonline.isr.umich.edu>

**References**

This dataset is downloadable through the package 'psidR'.

**Examples**

```
data(PSIDlong)
```

---

RLMSdat

*Dataset about job satisfaction*

---

### **Description**

Longitudinal dataset deriving from the Russia Longitudinal Monitoring Survey (RLMS) about job satisfaction measured by an ordinal variable at seven different occasions with five categories, 1 for “absolutely satisfied”, 2 for “mostly satisfied”, 3 for “neutral”, 4 for “not very satisfied”, and 5 for “absolutely unsatisfied”.

### **Usage**

```
data(RLMSdat)
```

### **Format**

A data frame with 1718 observations on the following 7 variables.

IKSJQ reported job satisfaction at the 1st occasion

IKSJR reported job satisfaction at the 2nd occasion

IKSJS reported job satisfaction at the 3rd occasion

IKSJT reported job satisfaction at the 4th occasion

IKSJU reported job satisfaction at the 5th occasion

IKSJV reported job satisfaction at the 6th occasion

IKSJW reported job satisfaction at the 7th occasion

### **Source**

<http://www.cpc.unc.edu/projects/rlms-hse>, <https://www.hse.ru/org/hse/rlms>

### **References**

Russia Longitudinal Monitoring survey, RLMS-HSE, conducted by Higher School of Economics and ZAO "Demoscope" together with Carolina Population Center, University of North Carolina at Chapel Hill and the Institute of Sociology RAS

### **Examples**

```
data(RLMSdat)
```

---

RLMSlong

*Dataset about job satisfaction*

---

## Description

Longitudinal dataset in long format deriving from the Russia Longitudinal Monitoring Survey (RLMS, from Round XVII to Round XXIII, collected from 2008 to 2014) about job satisfaction measured by an ordinal variable at seven different occasions with five categories, 1 for “absolutely satisfied”, 2 for “mostly satisfied”, 3 for “neutral”, 4 for “not very satisfied”, and 5 for “absolutely unsatisfied”.

## Usage

```
data(RLMSlong)
```

## Format

A data frame with 1718 observations on the following 7 variables.

`time` occasion of observation.

`id` subject id.

`rlms` see [RLMSdat](#).

`value` reported job satisfaction at different time occasions coded as 1 for “absolutely satisfied”, 2 for “mostly satisfied”, 3 for “neutral”, 4 for “not very satisfied”, 5 for “absolutely unsatisfied”.

## Source

<http://www.cpc.unc.edu/projects/rlms-hse>, <https://www.hse.ru/org/hse/rlms>

## References

Russia Longitudinal Monitoring survey, RLMS-HSE, conducted by Higher School of Economics and ZAO "Demoscope" together with Carolina Population Center, University of North Carolina at Chapel Hill and the Institute of Sociology RAS

## Examples

```
data(RLMSlong)
```

---

se	<i>Standard errors</i>
----	------------------------

---

### Description

Function to compute standard errors for the parameter estimates.

### Usage

```
se(est, ...)
## S3 method for class 'LMbasic'
se(est, ...)
## S3 method for class 'LMbasiccont'
se(est, ...)
## S3 method for class 'LMlatent'
se(est, ...)
## S3 method for class 'LMlatentcont'
se(est, ...)
```

### Arguments

est	an object obtained from a call to <code>lmest</code> and <code>lmestCont</code>
...	further arguments

### Value

Standard errors for estimates in est object.

### Author(s)

Francesco Bartolucci, Silvia Pandolfi, Fulvia Pennoni, Alessio Farcomeni, Alessio Serafini

### Examples

```
## Not run:

# LM model for categorical responses without covariates

data("data_SRHS_long")
SRHS <- data_SRHS_long[1:2400,]

# Categories rescaled to vary from 0 ("poor") to 4 ("excellent")

SRHS$srhs <- 5 - SRHS$srhs

out <- lmest(responsesFormula = srhs ~ NULL,
            index = c("id", "t"),
            data = SRHS,
            k = 3,
```

```

        modBasic = 1,
        out_se = FALSE)

out.se <- se(out)

out1 <- lmest(responsesFormula = srhs ~ NULL,
             index = c("id", "t"),
             data = SRHS,
             k = 3,
             modBasic = 1,
             out_se = TRUE)

out1.se <- se(out1)

# LM model for categorical responses with covariates on the latent model

out2 <- lmest(responsesFormula = srhs ~ NULL,
             latentFormula = ~
             I(gender - 1) +
             I(0 + (race == 2) + (race == 3)) +
             I(0 + (education == 4)) +
             I(0 + (education == 5)) +
             I(age - 50) + I((age-50)^2/100),
             index = c("id", "t"),
             data = SRHS,
             k = 2,
             paramLatent = "multilogit",
             start = 0)

out2.se <- se(out2)

# LM model for continuous responses without covariates

data(data_long_cont)

out3 <- lmestCont(responsesFormula = Y1 + Y2 + Y3 ~ NULL,
                 index = c("id", "time"),
                 data = data_long_cont,
                 k = 3,
                 modBasic = 1,
                 tol = 10^-5)

out3.se <- se(out3)

# LM model for continuous responses with covariates

out4 <- lmestCont(responsesFormula = Y1 + Y2 + Y3 ~ NULL,
                 latentFormula = ~ X1 + X2 | X1 + X2,
                 index = c("id", "time"),
                 data = data_long_cont,
                 k = 3,
                 output = TRUE)

```

```
out4.se <- se(out4)

## End(Not run)
```

---

```
search.model.LM      Search for the global maximum of the log-likelihood
```

---

## Description

Function that searches for the global maximum of the log-likelihood of different models given a vector of possible number of states to try for.

**The function is no longer maintained. Please look at [lmestSearch](#) function.**

## Usage

```
search.model.LM(version = c("basic", "latent", "manifest", "basic.cont", "latent.cont"),
  kv, ..., nrep = 2, tol1 = 10^-5, tol2 = 10^-10, out_se = FALSE)
```

## Arguments

version	model to be estimated ("basic" = basic LM model (est_lm_basic function); "latent" = LM model with covariates in the distribution of the latent process (est_lm_cov_latent function); "manifest" = LM model with covariates in the measurement model (est_lm_cov_maifest function), "basic.cont" = basic LM model for continuous outcomes (est_lm_basic_cont function); "latent.cont" = LM model for continuous outcomes with covariates in the distribution of the latent process (est_lm_cov_latent_cont function))
kv	vector of possible number of latent states
...	additional arguments to be passed based on the model to be estimated (see details)
nrep	number of repetitions of each random initialization
tol1	tolerance level for checking convergence of the algorithm in the random initializations
tol2	tolerance level for checking convergence of the algorithm in the last deterministic initialization
out_se	TRUE for computing information matrix and standard errors

## Details

The function combines deterministic and random initializations strategy to reach the global maximum of the model log-likelihood. It uses one deterministic initialization (start=0) and a number of random initializations (start=1) proportional to the number of latent states. The tolerance level is set equal to  $10^{-5}$ . Starting from the best solution obtained in this way, a final run is performed (start=2) with a default tolerance level equal to  $10^{-10}$ .

Arguments in ... depend on the model to be estimated. They match the arguments to be passed to functions est\_lm\_basic, est\_lm\_cov\_latent, est\_lm\_cov\_manifest, est\_lm\_basic\_cont, or est\_lm\_cov\_latent\_cont.

**Value**

out.single	output of each single model (as from <code>est_lm_basic</code> , <code>est_lm_cov_latent</code> or <code>est_lm_cov_manifest</code> ) for each k in kv
aicv	value of AIC index for each k in kv
bicv	value of BIC index for each k in kv
lkv	value of log-likelihood for each k in kv

**Author(s)**

Francesco Bartolucci, Silvia Pandolfi, University of Perugia (IT), <http://www.stat.unipg.it/bartolucci>

**Examples**

```
## Not run:

# example for est_lm_basic
data(data_drug)
data_drug <- as.matrix(data_drug)
S <- data_drug[,1:5]-1
yv <- data_drug[,6]
n <- sum(yv)
# Search Basic LM model

res <- search.model.LM("basic", kv = 1:4, S, yv, mod = 1)
summary(res)

## End(Not run)
```

---

summary

*Summary of LM fits*


---

**Description**

Summary methods

**Usage**

```
## S3 method for class 'LMbasic'
summary(object, ...)
## S3 method for class 'LMbasiccont'
summary(object, ...)
## S3 method for class 'LMlatent'
summary(object, ...)
## S3 method for class 'LMlatentcont'
summary(object, ...)
## S3 method for class 'LMmanifest'
```

```
summary(object, ...)
## S3 method for class 'LMmixed'
summary(object, ...)
## S3 method for class 'MCbasic'
summary(object, ...)
## S3 method for class 'MCcov'
summary(object, ...)
## S3 method for class 'LMsearch'
summary(object,...)
```

### Arguments

object            output from `lmest`, `lmestCont`, `lmestMixed`, and `lmestMc`  
 ...              further arguments passed to or from other methods

### Author(s)

Francesco Bartolucci, Silvia Pandolfi, Fulvia Pennoni, Alessio Farcomeni, Alessio Serafini

---

summary.lmestData      *Summary and plot of lmestData*

---

### Description

Methods for `lmestData` object providing basic descriptive statistics (summary) and plots.

### Usage

```
## S3 method for class 'lmestData'
summary(object, type = c("all", "cross", "year"),
        dataSummary = c("all", "responses", "manifest", "initial", "transition"),
        varType = rep("c", x$d), digits = getOption("digits"),
        maxsum = 10, maxobs = 20, ...)
## S3 method for class 'lmestData'
plot(x, typePlot = c("s", "sh"),
     dataPlots = c("all", "responses", "manifest", "initial", "transition"),
     ...)
## S3 method for class 'lmestData'
print(x, ...)
```

### Arguments

object            an object of class `lmestData`  
 x                an object of class `lmestData`



type	type of summary to print. <code>all</code> prints a summary for each variable, and a summary for each variables by time. <code>cross</code> prints a summary for each variable. <code>year</code> prints a summary for each variable by time. The summary is adapted according to <code>varType</code> (By default is set to <code>all</code> )
dataSummary	a string indicating whether summary is returned: <code>all</code> for the entire data, <code>responses</code> for the responses, <code>manifest</code> for covariates on the manifest distribution, <code>initial</code> for the covariate affecting the initial probabilities, and <code>transition</code> for the covariates affecting the transition probabilities. (By default is set to <code>all</code> )
varType	a string vector of length equal to the number of variables, "c" for continuous and "d" for discrete, indicating which variables are continuous and which are discrete
digits	the number of significant digits
maxsum	an integer value indicating the maximum number of levels to print
maxobs	an integer value indicating the maximum number of observation in which the summary statistics are reported for each observation
typePlot	a string indicating the type of plot. "s" plots a scatterplot matrix. "sh" plots a scatterplot matrix with the histogram for each variable in the diagonal
dataPlots	a string indicating whether the plot is returned: <code>all</code> for the entire data, <code>responses</code> for the responses, <code>manifest</code> for covariates on the manifest distribution, <code>initial</code> for the covariate affecting the initial probabilities, <code>transition</code> for the covariates affecting the transition probabilities. (By default is set to <code>all</code> )
...	further arguments

**Author(s)**

Francesco Bartolucci, Silvia Pandolfi, Fulvia Pennoni, Alessio Farcomeni, Alessio Serafini

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