

Package ‘LMest’

June 6, 2017

Type Package

Title Latent Markov Models with and without Covariates

Version 2.4

Date 2017-06-06

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

Maintainer Francesco Bartolucci <bart@stat.unipg.it>

Description Fit certain versions of the Latent Markov model for longitudinal categorical data.

License GPL (>= 2)

Depends R (>= 2.0.0), MASS, MultiLCIRT, stats

NeedsCompilation yes

Repository CRAN

Date/Publication 2017-06-06 15:24:43 UTC

R topics documented:

LMest-package	3
blkdiag	4
bootstrap_lm_basic	4
bootstrap_lm_cov_latent	5
complk	7
data_criminal_sim	8
data_drug	9
data_SRHS_long	10
decoding	11
draw_lm_basic	12
draw_lm_cov_latent	13
draw_lm_mixed	15
est_lm_basic	16
est_lm_cov_latent	17
est_lm_cov_manifest	20
est_lm_mixed	22
est_mc_basic	24

est_mc_cov_latent	25
est_multilogit	27
expit	28
expit1	28
invglob	29
lk_ar_rho	29
lk_comp_latent	30
lk_obs	31
lk_obs_latent	32
lk_obs_manifest	33
lk_obs_mixed	34
lk_sta	35
logit1	35
long2matrices	36
long2wide	37
marg_param	38
print.LMbasic	38
print.LMlatent	39
print.LMmanifest	39
print.LMmixed	40
print.LMsearch	40
print.MCbasic	41
print.MClatent	41
prob_multilogit	42
prob_post_cov	42
prod_array	44
rec1	44
rec3	45
recursions	46
RLMSdat	47
search.model.LM	48
sq	49
stationary	50
summary.LMbasic	50
summary.LMlatent	51
summary.LMmanifest	51
summary.LMmixed	52
summary.LMsearch	53
summary.MCbasic	53
summary.MClatent	54
trans_par	54

LMest-package

Fit latent Markov models

Description

Set of functions to fit latent Markov models in the basic version and in the extended version with individual covariates.

Details

Package: LMest
Type: Package
Version: 2.4
Date: 2017-06-06
License: Unlimited

The most important functions are `est_lm_basic`, `est_lm_cov_manifest`, and `est_lm_cov_latent` which estimate the basic LM model and its extensions including covariates

Author(s)

Francesco Bartolucci, Silvia Pandolfi - University of Perugia (IT) Maintainer: Francesco Bartolucci <bart@stat.unipg.it>

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]
n = sum(yv)
# fit of the Basic LM model
k = 3
out1 = est_lm_basic(S,yv,k,mod=1,out_se=TRUE)
## Not run:
out2 = bootstrap_lm_basic(out1$piv,out1$Pi,out1$Psi,n,mod=1,B=1000)

## End(Not run)
```

blkdiag *Build a block diagonal matrix.*

Description

Function to build a block diagonal matrix (internal function).

Usage

blkdiag(A, B)

Arguments

A	The first non-empty, numeric matrix
B	The second non-empty, numeric matrix

Value

C	A numeric block diagonal matrix
---	---------------------------------

Author(s)

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

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.

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 x k x TT)
Psi	matrix of conditional response probabilities (mb x k 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

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_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.

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)

```

complk

Complete log-likelihood of the basic latent Markov model

Description

Function that computes complete log-likelihood of the basic latent Markov model (internal use).

Usage

```
complk(S, R, yv, piv, Pi, Psi, k)
```

Arguments

S	matrix of distinct response configurations (n x TT x r)
R	matrix of missing response configurations
yv	corresponding vector of frequencies
piv	vector of initial probabilities
Pi	transition probability matrix
Psi	conditional response probabilities
k	number of latent classes

Value

lk	log-likelihood
Phi	matrix of the conditional probabilities of the observed response configurations
L	matrix of the forward probabilities
pv	vector of marginal probabilities

Author(s)

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

References

Baum, L. E., Petrie, T., Soules, G., and Weiss, N. (1970). A maximization technique occurring in the statistical analysis of probabilistic functions of Markov chains. *Annals of Mathematical Statistics*, 41, 164-171.

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
y2 crime of type 2
y3 crime of type 3
y4 crime of type 4
y5 crime of type 5
y6 crime of type 6
y7 crime of type 7
y8 crime of type 8
y9 crime of type 9
y10 crime of type 10

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 about marijuana consumption measured by ordinal variables with 3 categories with increasing levels of consumption.

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_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.

id subject id

gender gender 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	<i>Perform local and global decoding</i>
----------	--

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`.

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

```
# 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)

```

draw_lm_basic

Draw samples from the basic LM model

Description

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

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

```
# 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)
```

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.

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

```
# 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)
```

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.

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

```
# 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)
```

 est_lm_basic

Estimate basic LM model

Description

Main function for estimating the basic LM model.

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

```
# 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)

## Not run:
# 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_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.

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,UI)
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
U1	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_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.

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.

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.

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_latent	<i>Estimate Markov chain (MC) model with covariates</i>
-------------------	---

Description

Main function for estimating the MC model with covariates.

Usage

```
est_mc_cov_latent(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_latent(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)
```

est_multilogit	<i>Estimate multilogit model</i>
----------------	----------------------------------

Description

The function performs maximum likelihood estimation of the multilogit model (internal function).

Usage

```
est_multilogit(Y, Xdis, label = 1:n, be = NULL, Pdis = NULL, dis = FALSE,  
              fort = TRUE, ex = FALSE)
```

Arguments

Y	matrix of all responses
Xdis	array of all covariates (two- or three-dimensional)
label	label associated to every covariate configuration
be	initial value of the parameter vector
Pdis	probability configurations as initial values
dis	to display partial results
fort	to use fortran routines when possible
ex	TRUE if the function exits without running the estimation algorithm providing the score vector and the information matrix

Value

be	estimated vector regression coefficients
P	estimated matrix of probabilities
Pdis	estimated matrix of distinct probabilities
sc	score vector
Fi	information matrix

Author(s)

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

expit *Compute the expit function.*

Description

Function to compute the inverse of the logit function.

Usage

expit(x)

Arguments

x a vector of matrix which contains the values to be transformed

Value

y The transformed sample

Author(s)

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

expit1 *Compute the expit function with respect to a reference category.*

Description

Function to compute the inverse of the logit function with respect to a reference category.

Usage

expit1(lp,ref=1)

Arguments

lp a vector which contains the values to be transformed
 ref the reference category

Value

p The transformed vector
 Der The matrix of derivatives

Author(s)

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

invglob	<i>Invert vector of global logits.</i>
---------	--

Description

Function to invert the marginal parametrization based on global logits (internal function).

Usage

```
invglob(eta)
```

Arguments

eta	vector of global logits
-----	-------------------------

Value

p	vector of joint probabilities
---	-------------------------------

Author(s)

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

lk_ar_rho	<i>Compute complete log-likelihood for AR(1) latent process</i>
-----------	---

Description

Compute the complete log-likelihood for the transition and initial probabilities under the constraint of AR(1) latent process (internal use).

Usage

```
lk_ar_rho(lrho, SUP, V, outp = FALSE)
```

Arguments

lrho	Fisher transformation of the autocorrelation coefficient
SUP	matrix of the support points
V	array containing the posterior distribution of the latent states for each response configuration and time occasion
outp	to return additional output (Wei, rho)

Value

flk	Minus the complete log-likelihood
-----	-----------------------------------

Author(s)

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

lk_comp_latent	<i>Complete log-likelihood of the latent Markov model with covariates</i>
----------------	---

Description

Function that computes complete log-likelihood of the latent Markov model with covariates in the distribution of the latent process (internal use).

Usage

```
lk_comp_latent(S, R, yv, Piv, PI, Psi, k, fort = TRUE, der = FALSE,
              dPsi = NULL, dPiv = NULL, dPI = NULL)
```

Arguments

S	matrix of distinct response configurations
R	matrix of missing response configurations
yv	corresponding vector of frequencies
Piv	initial probability matrix
PI	transition probability matrices
Psi	conditional response probability matrix
k	number of latent classes
fort	to use fortran routine when possible
der	to compute derivatives
dPsi	matrix of derivatives of the logarithm of the conditional response probabilities
dPiv	matrix of derivatives of the logarithm of the initial probabilities
dPI	matrix of derivatives of the logarithm of the transition probabilities

Value

lk	log-likelihood
Phi	matrix of the conditional probabilities of the observed response configurations
L	matrix of the forward probabilities
pv	vector of marginal probabilities
dlk	derivatives of the log-likelihood
dPhi	matrix of derivatives of the log-conditional probabilities of the observed response configurations
dL	matrix of derivatives of the log-forward probabilities
dL2	matrix of second derivatives of the log-forward probabilities
dlpv	matrix of derivatives of the log-marginal probabilities

Author(s)

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

References

Baum, L. E., Petrie, T., Soules, G., and Weiss, N. (1970). A maximization technique occurring in the statistical analysis of probabilistic functions of Markov chains. *Annals of Mathematical Statistics*, 41, 164-171.

 lk_obs

Compute the observable log-likelihood of the basic LM model

Description

Function that computes the observable log-likelihood of the basic LM model (internal use).

Usage

```
lk_obs(th, m, Bm, Cm, bv, k, S, R, yv, TT, r, mod)
```

Arguments

th	vector of parameters
m	list of design matrices for the logits
Bm	design matrix for the logits
Cm	design matrix for the logits
bv	number of response categories
k	number of states
S	matrix of distinct response configurations
R	matrix of missing response configurations
yv	corresponding vector of frequencies
TT	number of times occasions
r	number of response variables
mod	type of model

Value

lk	log-likelihood
sc	score vector

Author(s)

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

lk_obs_latent	<i>Compute the observable log-likelihood of the LM model with covariates in the latent model</i>
---------------	--

Description

Function that computes the observable log-likelihood of the LM model with covariates in the latent model (internal use).

Usage

```
lk_obs_latent(th, S, R, b, yv, Am, XXdis, Xlab, ZZdis, Zlab, param, fort = TRUE)
```

Arguments

th	vector of parameters
S	matrix of distinct response configurations
R	matrix of missing response configurations
b	number of response categories
yv	corresponding vector of frequencies
Am	design matrix for the logits
XXdis	design matrix used for estimation of the initial probabilities
Xlab	list of labels used for estimation of the initial probabilities
ZZdis	design matrix used for estimation of the transition probabilities
Zlab	list of labels used for estimation of the transition probabilities
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)
fort	to use fortran routine when possible

Value

lk	log-likelihood
sc	score vector
Psi	conditional response probabilities
be	parameters on initial probabilities
Ga	parameters on transition probabilities
Piv	initial probabilities
PI	transition probabilities
dIPsi	matrix of derivatives of the logarithm of the conditional response probabilities
dIPiv	matrix of derivatives of the logarithm of the initial probabilities
dIPI	matrix of derivatives of the logarithm of the transition probabilities

Author(s)

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

lk_obs_manifest	<i>Compute the observable log-likelihood of the LM model with covariates in the measurement model</i>
-----------------	---

Description

Function that computes the observable log-likelihood of the LM model with covariates in the measurement model (internal use).

Usage

```
lk_obs_manifest(par, Y, Xd, yv, indn, lev, k, sup, G2, IPI, mod, outp = FALSE)
```

Arguments

par	vector of regression parameters
Y	matrix of response variables
Xd	matrix of covariates
yv	vector of frequencies of response configurations
indn	index of the design matrix for each unit
lev	vector containing the number of levels of each variable
k	number of latent states
sup	support points
G2	design matrix
IPI	index of the transition matrix elements
mod	model (0 = LM with stationary transition, 1 = finite mixture)
outp	to compute the score of the observable log-likelihood

Value

lk	log-likelihood
U	array containing the posterior distribution of the latent states for each response configuration and each pair of consecutive time occasions
s	score of the observable log-likelihood

Author(s)

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

lk_obs_mixed

*Compute the observable log-likelihood of the mixed LM model***Description**

Function that computes the observable log-likelihood of the mixed LM model with discrete random effect in the latent model (internal use).

Usage

```
lk_obs_mixed(th, nla, nPiv, nPi, nPsi, S, yv, r, k1, k2)
```

Arguments

th	vector of parameters
nla	number of logits for the mass probability vector
nPiv	number of logits for the initial probabilities
nPi	number of logits for the transition probabilities
nPsi	number of logits for the conditional response probabilities
S	matrix of distinct response configurations
yv	corresponding vector of frequencies
r	number of response variables
k1	number of latent classes
k2	number of latent states

Value

lk	log-likelihood
sc	score vector

Author(s)

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

lk_sta *Compute the stationary log-likelihood*

Description

Function that computes the stationary log-likelihood (internal use).

Usage

```
lk_sta(tau, u, V, G2, out1 = TRUE)
```

Arguments

tau	vector of parameters
u	vector of initial posterior probabilities
V	sum of the posterior probabilities
G2	design matrix
out1	to return additional output (la,PI)

Value

flk	log-likelihood
-----	----------------

Author(s)

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

logit1 *Compute the logit function with respect to a reference category.*

Description

Function to compute the logit function with respect to a reference category.

Usage

```
logit1(p, ref = 1)
```

Arguments

p	a vector which contains the values to be transformed
ref	the reference category

Value

lp The transformed vector

Author(s)

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

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

id vector of subjects id
time vector of time occasions
X matrix of covariates in long format
Y matrix of responses in long format

Value

XX array of covariates (n x TT x nc)
YY 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)
```

marg_param	<i>Compute marginal parametrization</i>
------------	---

Description

Function that creates matrices C and M for the marginal parametrization of the probability vector for a vector of categorical variables (internal use)

Usage

```
marg_param(lev, type)
```

Arguments

lev	vector containing the number of levels of each variable
type	vector with elements "l", "g", "c", "r" indicating the type of logit

Value

C	matrix of constrats (the first sum(lev)-length(r) elements are referred to univariate logits)
M	marginalization matrix with elements 0 and 1
G	corresponding design matrix for the corresponding log-linear model

Author(s)

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

print.LMbasic	<i>Print the output of LMbasic object</i>
---------------	---

Description

Given the output from LMbasic, it is written in a readable form

Usage

```
## S3 method for class 'LMbasic'
print(x, ...)
```

Arguments

x	output from LMbasic
...	further arguments passed to or from other methods

Author(s)

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

print.LMlatent *Print the output of LMlatent object*

Description

Given the output from LMlatent, it is written in a readable form

Usage

```
## S3 method for class 'LMlatent'  
print(x, ...)
```

Arguments

x output from LMlatent
... further arguments passed to or from other methods

Author(s)

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

print.LMmanifest *Print the output of LMmanifest object*

Description

Given the output from LMmanifest, it is written in a readable form

Usage

```
## S3 method for class 'LMmanifest'  
print(x, ...)
```

Arguments

x output from LMmanifest
... further arguments passed to or from other methods

Author(s)

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

print.LMmixed *Print the output of LMmixed object*

Description

Given the output from LMmixed, it is written in a readable form

Usage

```
## S3 method for class 'LMmixed'  
print(x, ...)
```

Arguments

x output from LMmixed
... further arguments passed to or from other methods

Author(s)

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

print.LMsearch *Print the output of LMsearch object*

Description

Given the output from LMsearch, it is written in a readable form

Usage

```
## S3 method for class 'LMsearch'  
print(x, ...)
```

Arguments

x output from LMsearch
... further arguments passed to or from other methods

Author(s)

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

print.MCbasic	<i>Print the output of MCbasic object</i>
---------------	---

Description

Given the output from MCbasic, it is written in a readable form

Usage

```
## S3 method for class 'MCbasic'  
print(x, ...)
```

Arguments

x	output from MCbasic
...	further arguments passed to or from other methods

Author(s)

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

print.MClatent	<i>Print the output of MClatent object</i>
----------------	--

Description

Given the output from MClatent, it is written in a readable form

Usage

```
## S3 method for class 'MClatent'  
print(x, ...)
```

Arguments

x	output from MClatent
...	further arguments passed to or from other methods

Author(s)

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

prob_multilogit *Compute multinomial probabilities*

Description

The function computes multinomial probabilities (internal function).

Usage

```
prob_multilogit(Xdis, be, label, fort = TRUE, der = FALSE)
```

Arguments

Xdis	array of all covariates (two- or three-dimensional)
be	initial value of the parameter vector
label	label associated to every covariate configuration
fort	to use fortran routines when possible
der	to compute derivatives

Value

P	estimated matrix of probabilities
Pdis	estimated matrix of distinct probabilities
dP	derivatives of the estimated matrix of probabilities
dPdis	derivatives of the estimated matrix of distinct probabilities

Author(s)

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

prob_post_cov *Compute posterior probabilities.*

Description

Function that uses backward recursion to compute posterior probabilities (internal function).

Usage

```
prob_post_cov(S, yv, Psi, Piv, PI, Phi, L, pv, der = FALSE, fort = TRUE,
             d1Phi = NULL, d1Piv = NULL, d1PI = NULL, d1L = NULL, d1L2 = NULL, d1pv = NULL)
```

Arguments

S	matrix of distinct response configurations
yv	corresponding vector of frequencies
Psi	conditional response probabilities
Piv	initial probability matrix
PI	transition probability matrices
Phi	matrix of the conditional probabilities of the observed response configurations
L	matrix of the forward probabilities
pv	vector of marginal probabilities
der	to compute derivatives
fort	to use fortran routine when possible
d1Phi	matrix of derivatives of the log-conditional probabilities of the observed response configurations
d1Piv	matrix of derivatives of the logarithm of the initial probabilities
d1PI	matrix of derivatives of the logarithm of the transition probabilities
d1L	matrix of derivatives of the log-forward probabilities
d1L2	matrix of second derivatives of the log-forward probabilities
d1pv	matrix of derivatives of the log-marginal probabilities

Value

U	array containing the posterior distribution of the latent states for each response configuration and each pair of consecutive time occasions
V	array containing the posterior distribution of the latent states for each response configuration and time occasion
d1U	matrix of derivatives of the logarithm of U
d1V	matrix of derivatives of the logarithm of V

Author(s)

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

prod_array	<i>Compute the product of array and vector</i>
------------	--

Description

Function that compute the product of each matrix in X by the vector y (internal funtion).

Usage

```
prod_array(X, y)
```

Arguments

X	a given array
y	a given vector

Value

Z	the resulting matrix
---	----------------------

Author(s)

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

rec1	<i>Recursions used by est_lm_cov_manifest</i>
------	---

Description

Implementation of the forward recursions to compute posterior distribution of the latent states (internal function).

Usage

```
rec1(Pio, las, PI)
```

Arguments

Pio	matrix of manifest probabilities
las	stationary initial probability
PI	transition probability matrices

Value

Q	matrices of posterior probabilities
---	-------------------------------------

Author(s)

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

References

Baum, L. E., Petrie, T., Soules, G., and Weiss, N. (1970). A maximization technique occurring in the statistical analysis of probabilistic functions of Markov chains. *Annals of Mathematical Statistics*, 41, 164-171.

 rec3

Recursions used by est_lm_cov_manifest

Description

Implementation of the backward recursions to compute posterior distribution of the latent states (internal function).

Usage

```
rec3(Q, yv, PI, Pio, pim)
```

Arguments

Q	posterior probabilities from the forward recursion
yv	vector of frequencies of response configurations
PI	transition probability matrices
Pio	matrix of manifest probabilities
pim	vector of marginal probabilities

Value

U	array containing the posterior distribution of the latent states for each response configuration and time occasion
V	matrix containing the posterior distribution of the latent states

Author(s)

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

References

Baum, L. E., Petrie, T., Soules, G., and Weiss, N. (1970). A maximization technique occurring in the statistical analysis of probabilistic functions of Markov chains. *Annals of Mathematical Statistics*, 41, 164-171.

recursions *Recursions used by est_lm_basic*

Description

Implementation of the recursions to compute manifest probability of the responses and posterior distribution of the latent states (internal function).

Usage

```
recursions(S, R, yv, Psi, piv, Pi, k, lth, matr, Bm, Cm, bv, mod)
```

Arguments

S	matrix of distinct response configurations
R	matrix of missing response configurations
yv	corresponding vector of frequencies
Psi	matrix of conditional response probabilities
piv	initial probability vector
Pi	transition probability matrices
k	number of latent states
lth	internal argument
matr	internal argument
Bm	internal argument
Cm	internal argument
bv	internal argument
mod	model on the transition probabilities (0 for time-heter., 1 for time-homog., from 2 to (TT-1) partial homog. of that order)

Value

lk	log-likelihood
sc	score vector
F1	internal argument
F2	internal argument
F1d	internal argument
F2d	internal argument

Author(s)

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

References

Baum, L. E., Petrie, T., Soules, G., and Weiss, N. (1970). A maximization technique occurring in the statistical analysis of probabilistic functions of Markov chains. *Annals of Mathematical Statistics*, 41, 164-171.

RLMSdat	<i>Dataset about job satisfaction</i>
---------	---------------------------------------

Description

Longitudinal dataset deriving from the Russia Longitudinal Monitoring Survey (RLMS) about job satisfaction measured by an ordinal variable with 5 categories.

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>, <http://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)
```

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

Usage

```
search.model.LM(version = c("basic", "latent", "manifest"), 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))
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 or est_lm_cov_manifest.

Value

out.single	output of each single model (as from est_lm_basic, est_lm_cov_latent or est_lm_cov_manifest) 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

```
# 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)
```

sq

Create a matrix with the combination of vectors of (1,0)

Description

Function that creates a matrix with the combination of all possible row vectors with 't' elements equal to 1 and 'J-t' elements equal to 0. If 't' is NULL the function generates all the possible combinations of vectors of length 'J' with elements (1,0).

Usage

```
sq(J, t = NULL)
```

Arguments

J	an integer
t	an integer

Value

M	the resulting matrix
---	----------------------

Author(s)

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

stationary	<i>Stationary</i>
------------	-------------------

Description

Function that computes the derivatives of the log-likelihood of a stationary model (internal function).

Usage

```
stationary(tau, k, G2, IPI)
```

Arguments

tau	regression parameters
k	number of latent states
G2	internal argument
IPI	index of the transition matrix elements

Value

d0	first derivatives of the log-likelihood
d1	second derivatives of the log-likelihood

Author(s)

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

summary.LMbasic	<i>Print the output of LMbasic object</i>
-----------------	---

Description

Given the output from LMbasic, it is written in a readable form

Usage

```
## S3 method for class 'LMbasic'
summary(object, ...)
```

Arguments

object	output from LMbasic
...	further arguments passed to or from other methods

Value

table summary of all the results

Author(s)

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

summary.LMlatent *Print the output of LMlatent object*

Description

Given the output from LMlatent, it is written in a readable form

Usage

```
## S3 method for class 'LMlatent'  
summary(object, ...)
```

Arguments

object output from LMlatent
... further arguments passed to or from other methods

Value

table summary of all the results

Author(s)

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

summary.LMmanifest *Print the output of LMmanifest object*

Description

Given the output from LMmanifest, it is written in a readable form

Usage

```
## S3 method for class 'LMmanifest'  
summary(object, ...)
```

Arguments

object output from LMmanifest
 ... further arguments passed to or from other methods

Value

table summary of all the results

Author(s)

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

summary.LMmixed *Print the output of LMmixed object*

Description

Given the output from LMmixed, it is written in a readable form

Usage

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

Arguments

object output from LMmixed
 ... further arguments passed to or from other methods

Value

table summary of all the results

Author(s)

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

summary.LMsearch *Print the output of LMsearch object*

Description

Given the output from LMsearch, it is written in a readable form

Usage

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

Arguments

object	output from LMsearch
...	further arguments passed to or from other methods

Value

table	summary of all the results
-------	----------------------------

Author(s)

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

summary.MCbasic *Print the output of MCbasic object*

Description

Given the output from MCbasic, it is written in a readable form

Usage

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

Arguments

object	output from MCbasic
...	further arguments passed to or from other methods

Value

table summary of all the results

Author(s)

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

summary.MClatent *Print the output of MClatent object*

Description

Given the output from MClatent, it is written in a readable form

Usage

```
## S3 method for class 'MClatent'
summary(object, ...)
```

Arguments

object output from MClatent
 ... further arguments passed to or from other methods

Value

table summary of all the results

Author(s)

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

trans_par *Convert matrix parametrization*

Description

Function that converts matrix parametrization (internal function).

Usage

```
trans_par(par, lev, k, sup, G2, IPI, mod)
```

Arguments

par	regression parameters
lev	vector containing the number of levels of each variable
k	number of latent states
sup	vectors of support points
G2	internal argument
IPI	internal argument
mod	model (0 = LM with stationary transition, 1 = finite mixture)

Value

la	vector of initial probabilities
PI	transition matrix
rho	parameter vector for AR
si	sigma of the AR process
par	regression parameters
lrho	Fisher transformation of the autocorrelation coefficient
tau	regression parameters

Author(s)

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

Index

*Topic **datasets**

data_criminal_sim, 8
data_drug, 9
data_SRHS_long, 10
RLMSdat, 47

*Topic **package**

LMest-package, 3

blkdiag, 4
bootstrap_lm_basic, 4
bootstrap_lm_cov_latent, 5

complk, 7

data_criminal_sim, 8
data_drug, 9
data_SRHS_long, 10
decoding, 11
draw_lm_basic, 12
draw_lm_cov_latent, 13
draw_lm_mixed, 15

est_lm_basic, 16
est_lm_cov_latent, 17
est_lm_cov_manifest, 20
est_lm_mixed, 22
est_mc_basic, 24
est_mc_cov_latent, 25
est_multilogit, 27
expit, 28
expit1, 28

invglob, 29

lk_ar_rho, 29
lk_comp_latent, 30
lk_obs, 31
lk_obs_latent, 32
lk_obs_manifest, 33
lk_obs_mixed, 34
lk_sta, 35

LMest (LMest-package), 3
LMest-package, 3
logit1, 35
long2matrices, 36
long2wide, 37

marg_param, 38

print.LMbasic, 38
print.LMlatent, 39
print.LMmanifest, 39
print.LMmixed, 40
print.LMsearch, 40
print.MCbasic, 41
print.MClatent, 41
prob_multilogit, 42
prob_post_cov, 42
prod_array, 44

rec1, 44
rec3, 45
recursions, 46
RLMSdat, 47

search.model.LM, 48
sq, 49
stationary, 50
summary.LMbasic, 50
summary.LMlatent, 51
summary.LMmanifest, 51
summary.LMmixed, 52
summary.LMsearch, 53
summary.MCbasic, 53
summary.MClatent, 54

trans_par, 54