

Package ‘LCCR’

October 3, 2021

Type Package

Title Latent Class Capture-Recapture Models

Version 1.2

Date 2021-10-03

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Description Estimation of latent class models with individual covariates for capture-recapture data. See Forcina and Bartolucci (2021)<[arxiv:2106.03811](#)>.

License GPL (>= 2)

Depends R (>= 3.5.0)

Imports MASS

NeedsCompilation no

Repository CRAN

Date/Publication 2021-10-03 19:00:02 UTC

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LCCR-package

Latent Class Capture-Recapture Models

Description

Estimation of latent class models with individual covariates for capture-recapture data. See Forcina and Bartolucci (2021)<arxiv:2106.03811>.

Details

The package provides functions to specify latent class models for capture-recapture data with individual covariates, simulate data from the specified model and estimate it on the basis of observed data, including the possibility to obtain a profile confidence interval for the population size.

The latent class models may be specified by a log-linear or a recursive logit parametrization of the conditional distribution of the capture configurations given the latent class. The log-linear parametrization is based on main effects that may depend on some covariates and may include bivariate interaction terms. The recursive logit parametrization allows us to model the dependence of capture probabilities on previous capture history. Linear constraints on the model parameters may be assumed to make the model more parsimonious. Covariates may also affect the latent class weights by a Multinomial logit parametrization.

Estimation of the specified model is based on the unconditional likelihood method following the approach formalized in Forcina and Bartolucci (2021), which may be seen as a refinement of the one in Liu et al. (2017). The approach uses as additional parameters the weights associated to the different strata that are estimated together with the model parameters and the population size. Functions for constructing a profile confidence interval for the population size are provided; this procedure is recommended as an alternative to using the normal approximation.

Author(s)

Francesco Bartolucci [aut, cre], Antonio Forcina [aut]

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References

Forcina, A. and Bartolucci, F. (2021). Estimating the size of a closed population by modeling latent and observed heterogeneity, *arXiv:2106.03811*.

Liu, Y., Li, P., and Qin, J. (2017). Maximum empirical likelihood estimation for abundance in a closed population from capture-recapture data. *Biometrika*, **104**, 527-543.

Examples

```
data(data_sim2)
# estimate latent class model with 2 classes, same main log-linear effect across lists,
# one covariate affecting the weights, and bivariate interaction between consecutive lists
est = estLCCR(Y=data_sim2$Y,H=2,W=data_sim2$W,biv=matrix(c(1,2,3,4,2,3,4,5),4),main="same")
est
# compute profile confidence interval
conf = confint(est)
conf
plot(conf)
```

aggr_data

Aggregate capture-recapture data

Description

Given a matrix of individual capture configurations, and the corresponding matrix and array of covariates (affecting the class weights and the conditional capture probabilities given the latent class), the function aggregates data, providing a stratified capture-recapture format.

Usage

```
aggr_data(Y, W = NULL, X = NULL)
```

Arguments

Y	matrix of frequencies of capture configurations
W	matrix of covariates affecting the class weights
X	array of covariates affecting the conditional capture probabilities

Value

Ya	matrix of aggregated frequencies of capture configurations
Wa	matrix of aggregated covariates affecting the class weights
Xa	array of aggregated covariates affecting the conditional capture probabilities

Author(s)

Francesco Bartolucci, Antonio Forcina

See Also

[freq_data](#)

Examples

```
# case without covariates
Y = rbind(c(0,1,0,0,0,0,0,0),c(0,0,0,1,0,0,0,0),c(0,0,0,0,0,0,1,0))
aggr_data(Y)

# case with covariates
W = c(1,1,2); X = as.matrix(c(0,0,2))
aggr_data(Y,W,X)
```

confint.estLCCR	<i>Confidence interval</i>
-----------------	----------------------------

Description

Profile confidence interval for a latent class model with covariates.

Usage

```
## S3 method for class 'estLCCR'
confint(object, parm, level = 0.95, ...)
```

Arguments

object	output from estLCCR
parm	step of the grid of values of the population size
level	the confidence level required
...	additional argument(s) for methods

Value

No return value

Author(s)

Francesco Bartolucci, Antonio Forcina

References

Forcina, A. and Bartolucci, F. (2021). Estimating the size of a closed population by modeling latent and observed heterogeneity, *arXiv:2106.03811*.

Liu, Y., Li, P., and Qin, J. (2017). Maximum empirical likelihood estimation for abundance in a closed population from capture-recapture data. *Biometrika*, **104**, 527-543.

See Also

[estLCCR](#), [plot.confLCCR](#)

Examples

```
data(data_sim2)
est = estLCCR(Y=data_sim2$Y,H=2,W=data_sim2$W,biv=matrix(c(1,2,3,4,2,3,4,5),4),main="same")
conf = confint(est)
plot(conf)
```

data_sim1	<i>Simulated data 1</i>
-----------	-------------------------

Description

Simulated capture-recapture data from a latent class model with 2 classes having the same weight on 5 lists.

Usage

```
data(data_sim1)
```

Format

A matrix containing the capture configurations at individual level.

References

Forcina, A. and Bartolucci, F. (2021). Estimating the size of a closed population by modeling latent and observed heterogeneity, *arXiv:2106.03811*.

Examples

```
data(data_sim1)
est = estLCCR(Y=data_sim1,H=2)
```

data_sim2	<i>Simulated data 2</i>
-----------	-------------------------

Description

Simulated capture-recapture data from a latent class model with 2 classes, one covariate affecting the class weights, and bivariate loglinear interactions between consecutive lists.

Usage

```
data(data_sim2)
```

Format

A list containing capture configurations at individual level and corresponding covariates.

Y capture configurations

W values of the covariate affecting the class weights

References

Forcina, A. and Bartolucci, F. (2021). Estimating the size of a closed population by modeling latent and observed heterogeneity, *arXiv:2106.03811*.

Examples

```
data(data_sim2)
est = estLCCR(Y=data_sim2$Y,H=2,W=data_sim2$W,biv=matrix(c(1,2,3,4,2,3,4,5),4),main="same")
```

data_sim3

Simulated data 3

Description

Simulated capture-recapture data from a latent class model with 3 classes, one covariate affecting the logits of each response, and lag dependence.

Usage

```
data(data_sim3)
```

Format

A list containing capture configurations at individual level and corresponding covariates.

Y capture configurations

X values of the covariate affecting the conditional capture probabilities given the latent class

References

Forcina, A. and Bartolucci, F. (2021). Estimating the size of a closed population by modeling latent and observed heterogeneity, *arXiv:2106.03811*.

Examples

```
data(data_sim3)
est = estLCCR(Y=data_sim3$Y,H=3,model="logit",X=data_sim3$X,flag="atleast")
```

 data_sim4

Simulated data 4

Description

Simulated stratified capture-recapture data from a latent class model with 2 classes and covariates affecting both the class weights and the conditional capture probabilities given the latent class.

Usage

```
data(data_sim4)
```

Format

A list containing capture configurations at individual level and corresponding covariates.

Y capture configurations

W values of the covariate affecting the class weights

X values of the covariate affecting the conditional capture probabilities given the latent class

References

Forcina, A. and Bartolucci, F. (2021). Estimating the size of a closed population by modeling latent and observed heterogeneity, *arXiv:2106.03811*.

Examples

```
data(data_sim4)
est = estLCCR(Y=data_sim4$Y,H=2,X=data_sim4$X,W=data_sim4$W)
```

 design_matrix_logit

Design matrix for recursive logit parametrization

Description

For a latent class model for capture-recapture data, it provides design matrices for the recursive logit parametrization used to formulate the conditional distribution of capture configurations given the latent class. It is possible to include the effect of covariates and of previous captures.

Usage

```
design_matrix_logit(J, H = 1, main = c("LC", "same", "Rasch"), X = NULL,
  free_cov = c("no", "class", "resp", "both"),
  flag = c("no", "prev", "sum", "atleast"),
  free_flag = c("no", "class", "resp", "both"))
```

Arguments

J	number of capture occasions
H	number of latent classes
main	"LC" for the latent class model in which there is a separate main effect for each capture occasion and latent class; "same" for the constrained model in which the main effect is the same across capture occasions but different across latent classes; "Rasch" for the constrained model in which each main effect is expressed in an additive form with a parameter related to the latent class and another parameter related to the capture occasion
X	array of covariates (n. strata x n. covariates x n. responses)
free_cov	"no" for constant effect of the covariates across capture occasions and latent classes; "class" for effect of covariates varying only with the latent class; "resp" for effect of covariates varying only with the capture occasion; "both" for effect of covariates varying with the capture occasion and the latent class
flag	"no" for no lag effect; "prev" for effect of the previous capture occasion only; "sum" for the effect of the sum of the previous capture occasions; "atleast" for the effect of at least one capture at the previous occasions
free_flag	"no" for constant effect of the previous capture occasions with respect to the occasion and the latent class; "class" for free effect only with respect to the latent class; "int" for free effect only with respect to the occasion; "both" for free effect with respect to capture occasion and latent class

Value

M	design matrices
par_list	list of parameter names
Main	list of capture configurations

Author(s)

Francesco Bartolucci, Antonio Forcina

References

Forcina, A. and Bartolucci, F. (2021). Estimating the size of a closed population by modeling latent and observed heterogeneity, *arXiv:2106.03811*.

See Also

[design_matrix_loglin](#), [matrix_logit](#), [estLCCR](#)

design_matrix_loglin *Design matrix for loglinear parametrization*

Description

For a latent class model for capture-recapture data, it provides design matrices for the loglinear parametrization used to formulate the conditional distribution of the capture configurations given the latent class. It is possible to include the effect of covariates and bivariate interactions.

Usage

```
design_matrix_loglin(J, H = 1, main = c("LC", "same", "Rasch"), X = NULL,
                   free_cov = c("no", "class", "resp", "both"),
                   biv = NULL, free_biv = c("no", "class", "int", "both"))
```

Arguments

J	number of capture occasions
H	number of latent classes
main	"LC" for the latent class model in which there is a separate main effect for each capture occasion and latent class; "same" for the constrained model in which the main effect is the same across capture occasions but different across latent classes; "Rasch" for the constrained model in which each main effect is expressed in an additive form with a parameter related to the latent class and another parameter related to the capture occasion
X	array of covariates (n. strata x n. covariates x n. responses)
free_cov	"no" for constant effect of the covariates across capture occasions and latent classes; "class" for effect of covariates varying only with the latent class; "resp" for effect of covariates varying only with the capture occasion; "both" for effect of covariates varying with the capture occasion and the latent class
biv	matrix with two columns containing the list of bivariate interactions
free_biv	"no" for constant bivariate interaction effect with respect to the occasion and the latent class; "class" for free interaction with respect to the latent class; "int" for free effect only with respect to the interaction; "both" for free effect with respect to interaction and latent class

Value

M	design matrices
par_list	list of parameter names
Main	list of capture configurations

Author(s)

Francesco Bartolucci, Antonio Foricna

References

Forcina, A. and Bartolucci, F. (2021). Estimating the size of a closed population by modeling latent and observed heterogeneity, *arXiv:2106.03811*.

See Also

[design_matrix_logit](#), [estLCCR](#)

estLCCR	<i>Estimate latent class models for capture-recapture data with individual covariates</i>
---------	---

Description

For a latent class model for stratified capture-recapture data with individual covariates, it estimates the model on the basis of observed data by the unconditional likelihood method, exploiting weights associated to the different strata. Estimation of the model parameters, included the population size, is based on an EM algorithm.

Usage

```
estLCCR(Y, H, model = c("loglin", "logit"), W = NULL, X = NULL, N = NULL, biv = NULL,
        flag = c("no", "prev", "sum", "atleast"),
        main = c("LC", "same", "Rasch"),
        free_cov = c("no", "class", "resp", "both"),
        free_biv = c("no", "class", "int", "both"),
        free_flag = c("no", "class", "resp", "both"),
        N0 = NULL, be0 = NULL, la0 = NULL, maxit = 5000,
        verb = TRUE, init_rand = FALSE, se_out = FALSE)
```

Arguments

Y	matrix of frequencies for each stratum (by row)
H	number of latent classes
model	"loglin" for loglinear parametrization; "logit" for recursive logit parametrization
W	matrix of covariates on the class weights
X	array of covariates (n. strata x n. covariates x n. responses)
N	fixed population size
biv	matrix with two columns containing the list of bivariate interactions (for loglinear parametrization)
flag	"no" for no lag effect; "prev" for effect of the previous capture occasion only; "sum" for the effect of the sum of the previous capture occasions; "atleast" for the effect of at least one capture at the previous occasions (for recursive logit parametrization)

main	"LC" for the latent class model in which there is a separate main effect for each capture occasion and latent class; "same" for the constrained model in which the main effect is the same across capture occasions but different across latent classes; "Rasch" for the constrained model in which each main effect is expressed in an additive form with a parameter related to the latent class and another parameter related to the capture occasion
free_cov	"no" for constant effect of the covariates across capture occasions and latent classes; "class" for effect of covariates varying only with the latent class; "resp" for effect of covariates varying only with the capture occasion; "both" for effect of covariates varying with the capture occasion and the latent class
free_biv	"no" for constant bivariate interaction effect with respect to the occasion and the latent class; "class" for free interaction with respect to the latent class; "int" for free effect only with respect to the interaction; "both" for free effect with respect to interaction and latent class (for loglinear parametrization)
free_flag	"no" for constant effect of the previous capture occasions with respect to the occasion and the latent class; "class" for free effect only with respect to the latent class; "int" for free effect only with respect to the occasion; "both" for free effect with respect to capture occasion and latent class (for recursive logit parametrization)
N0	initial value of the population size
be0	initial value of the parameters affecting the class weights
la0	initial value of the parameters affecting the conditional distribution of capture configurations given the latent class
maxit	maximum number of iterations of the EM algorithm
verb	to have partial output during the model fitting
init_rand	to use a random initialization of the parameters
se_out	to require computation of the standard errors

Value

be	estimate of the parameters affecting the class weights
la	estimate of the parameters affecting the conditional distribution of capture configurations given the latent class
lk	final log-likelihood value
N	estimate of the population size
np	number of free parameters
AIC	value of AIC for model selection
BIC	value of BIC for model selection
M	design matrices used for the recursive logit or loglinear parametrization of the conditional distribution of capture configurations given the latent class
tauv	estimate of the weights of each stratum
phiv	estimate of the probability of being never captured for each stratum
seN	standard error for the estimate of N

sebe	standard error for the estimate of beta
sela	standard error for the estimate of lambda
lk1	component of the log-likelihood based on the binomial factor in N
lk2	component of the log-likelihood involving N and the overall probability of being never captured
lk3	component of the log-likelihood involving the capture probabilities
lk4	component of the log-likelihood involving the stratum weights

Author(s)

Francesco Bartolucci, Antonio Forcina

References

Forcina, A. and Bartolucci, F. (2021). Estimating the size of a closed population by modeling latent and observed heterogeneity, *arXiv:2106.03811*.

Liu, Y., Li, P., and Qin, J. (2017). Maximum empirical likelihood estimation for abundance in a closed population from capture-recapture data. *Biometrika*, **104**, 527-543.

See Also

[design_matrix_logit](#), [design_matrix_loglin](#), [simLCCR](#)

Examples

```
# estimate latent class model with 2 classes having the same weight on 5 lists
data(data_sim1)
est = estLCCR(Y=data_sim1,H=2)
est

# estimate latent class model with 2 classes, one covariate affecting the weights and bivariate
# loglinear interactions between consecutive lists
data(data_sim2)
est = estLCCR(Y=data_sim2$Y,H=2,W=data_sim2$W,biv=matrix(c(1,2,3,4,2,3,4,5),4),main="same")
est

# estimate latent class model with 3 classes, one covariate affecting the logits of each response,
# and lag dependence
data(data_sim3)
est = estLCCR(Y=data_sim3$Y,H=3,model="logit",X=data_sim3$X,flag="atleast")
est

# estimate latent class model with 2 classes and covariates affecting both the class weights and
# conditional capture probabilities given the latent class
data(data_sim4)
est = estLCCR(Y=data_sim4$Y,H=2,X=data_sim4$X,W=data_sim4$W)
est
```

freq_data	<i>Convert capture-recapture configurations into frequency data</i>
-----------	---

Description

Given a matrix of observed capture-recapture configurations, convert the data to a matrix of frequencies having the same number of rows and a number of columns equal to the number of possible configurations.

Usage

```
freq_data(R)
```

Arguments

R	Matrix of size n (sample size) x J (number of capture occasions) of observed capture-recapture configurations
---	---

Value

Y	Matrix of frequency of each capture configuration of size n x (2 ^J)
---	---

Author(s)

Francesco Bartolucci, Antonio Forcina

See Also

[aggr_data](#)

Examples

```
R = rbind(c(0,0,0,1),c(0,1,0,0),c(0,0,1,1),c(1,1,1,1))
Y = freq_data(R)
```

matrix_logit	<i>Design matrices of saturated logit parametrization</i>
--------------	---

Description

For J binary responses, it provides design matrices A and B used to express the saturated recursive logit parametrization of type $\log(p) = [A*\eta - B*\log(1+\exp(\eta))]$.

Usage

```
matrix_logit(J)
```

Arguments

J number of capture occasions

Value

A first matrix involved in the recursive logit parametrization
 B second matrix involved in the recursive logit parametrization

Author(s)

Francesco Bartolucci, Antonio Forcina

References

Forcina, A. and Bartolucci, F. (2021). Estimating the size of a closed population by modeling latent and observed heterogeneity, *arXiv:2106.03811*.

See Also

[matrix_logit](#), [estLCCR](#)

plot	<i>Plot profile confidence interval</i>
------	---

Description

Plot for output from `confint.estLCCR`.

Usage

```
## S3 method for class 'confLCCR'
plot(x, ...)
```

Arguments

x an object of class `condLCCR`
 ... further possible arguments

Value

M matrix of binary configurations

Author(s)

Francesco Bartolucci, Antonio Forcina

Examples

```
data(data_sim2)
est = estLCCR(Y=data_sim2$Y,H=2,W=data_sim2$W,biv=matrix(c(1,2,3,4,2,3,4,5),4),main="same")
conf = confint(est)
plot(conf)
```

print	<i>Print the output</i>
-------	-------------------------

Description

Given the output, it is written in a readable form.

Usage

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

Arguments

x	output from <code>estLCCR</code> or <code>confint.estLCCR</code>
...	further arguments passed to or from other methods

Value

No return value

Author(s)

Francesco Bartolucci, Antonio Forcina

simLCCR	<i>Simulate capture-recapture data from a latent class model with individual covariates</i>
---------	---

Description

The function simulates capture-recapture data from a latent class model with individual covariates that may affect the class weights and/or the conditional distribution of capture configurations given the latent class. The data may be in disaggregated form (with each stratum having unitary dimension) or aggregated form (with strata having generic dimension).

Usage

```
simLCCR(H, J, be, la, N, model = c("loglin", "logit"), Wc = NULL, Xc = NULL, biv = NULL,
        flag = c("no", "prev", "sum", "atleast"),
        main = c("LC", "same", "Rasch"),
        free_cov = c("no", "class", "resp", "both"),
        free_biv = c("no", "class", "int", "both"),
        free_flag = c("no", "class", "resp", "both"))
```

Arguments

H	number of latent classes
J	number of capture occasions
be	value of the parameters affecting the class weights
la	value of the parameters affecting the conditional distribution of capture configurations given the latent
N	population size (with individual data); vector containing the size of any stratum (with aggregated data)
model	population size (with individual data); vector containing the size of any stratum (with aggregated data)
Wc	matrix of covariates affecting the class weights at population level
Xc	array of covariates at population level (n. strata x n. covariates x n. responses)
biv	matrix with two columns containing the list of bivariate interactions (for loglinear parametrization)
flag	"no" for no lag effect; "prev" for effect of the previous capture occasion only; "sum" for the effect of the sum of the previous capture occasions; "atleast" for the effect of at least one capture at the previous occasions (for recursive logit parametrization)
main	"LC" for the latent class model in which there is a separate main effect for each capture occasion and latent class; "same" for the constrained model in which the main effect is the same across capture occasions but different across latent classes; "Rasch" for the constrained model in which each main effect is expressed in an additive form with a parameter related to the latent class and another parameter related to the capture occasion
free_cov	"no" for constant effect of the covariates across capture occasions and latent classes; "class" for effect of covariates varying only with the latent class; "resp" for effect of covariates varying only with the capture occasion; "both" for effect of covariates varying with the capture occasion and the latent class
free_biv	"no" for constant bivariate interaction effect with respect to the occasion and the latent class; "class" for free interaction with respect to the latent class; "int" for free effect only with respect to the interaction; "both" for free effect with respect to interaction and latent class (for loglinear parametrization)
free_flag	"no" for constant effect of the previous capture occasions with respect to the occasion and the latent class; "class" for free effect only with respect to the latent class; "int" for free effect only with respect to the occasion; "both" for free effect with respect to capture occasion and latent class (for recursive logit parametrization)

Value

Y	matrix of frequencies for each stratum (by row), only for captured individuals
Yc	matrix of frequencies for each stratum (by row), for all individuals
Piv	matrix of class weights for each stratum
Q	matrix of the conditional distribution of capture configurations given the latent class
Pm	matrix of the distribution of the capture configurations (with aggregated data)
R	matrix of single capture occasions (with individual data), only for captured individuals
U	vector of latent classes (with individual data)
Rc	matrix of single capture occasions (with individual data), for all individuals
W	matrix of covariates affecting the class weights, only for captured individuals
X	array of covariates affecting the conditional distribution of capture configurations given the latent class, only for captured individuals

Author(s)

Francesco Bartolucci, Antonio Forcina

References

Forcina, A. and Bartolucci, F. (2021). Estimating the size of a closed population by modeling latent and observed heterogeneity, *arXiv:2106.03811*.

See Also

[design_matrix_logit](#), [design_matrix_loglin](#), [estLCCR](#)

Examples

```
# simulate data from latent class model with 2 classes having the same weight on 5 lists
out = simLCCR(2,5,be=0,la=c(rep(-1,5),rep(1,5)),N=200)

# simulate data from a latent class model with 2 classes, one covariate affecting the weights and
# bivariate loglinear interactions between consecutive lists
Wc = rnorm(200)
out = simLCCR(2,6,be=c(0,1),la=c(-1,1,1),N=200,Wc=Wc,biv=matrix(c(1,2,3,4,2,3,4,5),4),main="same")

# simulate data from a latent class model with 3 classes, one covariate affecting the logits of
# each response, and lag dependence
Xc = rnorm(200)
out = simLCCR(3,6,model="logit",be=c(0,0),la=c(rep(-1,6),rep(0,6),rep(1,6),1,1),N=200,Xc=Xc,
             flag="atleast")

# simulate data from latent class model with 2 classes and covariates affecting both class weights
# and conditional probabilities of capture configurations given the latent class
Wc = c(-1,0,1); Xc = rnorm(3)
out = simLCCR(2,5,be=c(0,0),la=c(rep(-1,5),rep(1,5),1),N=c(100,100,100),Wc=Wc,Xc=Xc)
```

sq	<i>Build matrix of binary vectors of a fixed length</i>
----	---

Description

It creates all possible binary (with elements equal to 0 or 1) vectors of a specified length; these vectors are casted in a matrix having a number of columns equal to the vector length. If required, the binary vectors are constrained to have the same total (sum of their elements).

Usage

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

Arguments

J	length of binary vectors
t	possible fixed total

Value

M	matrix containing all binary vectors
---	--------------------------------------

Author(s)

Francesco Bartolucci, Antonio Forcina

Examples

```
# build matrix of all possible binary vectors of length 5
M = sq(5)

# build matrix of all possible binary vectors of length 5 with total equal 2
M = sq(5,2)
```

summary	<i>Summary of output</i>
---------	--------------------------

Description

Summary of output from fitting latent class models for capture-recapture data with covariates.

Usage

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

Arguments

object output from [estLCCR](#) or [confint.estLCCR](#)
... further arguments passed to or from other methods

Value

No return value

Author(s)

Francesco Bartolucci, Antonio Forcina

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