Package 'RMediation'

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Type Package

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Imports modelr (>= 0.1.4), doParallel (>= 1.0.0), foreach (>= 1.5.0), iterators (>= 1.0.0), stringr(>= 1.4.0), grDevices (>= 3.5)

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LazyData true

Description We provide functions to compute confidence intervals for a well-defined nonlinear function of the model parameters (e.g., product of k coefficients) in single--level and
multilevel structural equation models. It also computes a chi-square test statistic for a function of indirect effects.
'Tofighi', D. and 'MacKinnon', D. P. (2011). 'RMediation' An R package for mediation analysis confidence intervals. Behavior Research Methods, 43, 692--700. <doi:10.3758/s13428-011-0076-x>.
'Tofighi', D. (2020). Bootstrap Model-Based Constrained Optimization Tests of Indirect Effects. Frontiers in Psychology, 10, 2989. <doi:10.3389/fpsyg.2019.02989>.

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R topics documented:

`ci` *CI for a nonlinear function of coefficients estimates*

Description

This function returns a $(1-\alpha)\%$ confidence interval (CI) for a well–defined nonlinear function of the coefficients in single–level and multilevel structural equation models. The `ci` function uses the Monte Carlo (`type="MC"`) and the asymptotic normal theory (`type="asymp"`) with the multivariate delta standard error (Asymptotic–Delta) method (Sobel, 1982) to compute a CI. In addition, for each of the methods, when a user specifies `plot=TRUE` and `plotCI=TRUE`, a plot of the sampling distribution of the quantity of interest in the `quant` argument and an overlaid plot of the CI will be produced. When `type="all"` and `plot=TRUE`, two overlaid plots of the sampling distributions corresponding to each method will be produced; when `plotCI=TRUE`, then the overlaid plots of the CIs for both methods will be displayed as well.

Usage

```
ci(
  mu,
  Sigma,
  quant,
  alpha = 0.05,
  type = "MC",
  plot = FALSE,
  plotCI = FALSE,
  n.mc = 1e+06,
  H0 = FALSE,
  mu0 = NULL,
  Sigma0 = NULL,
  ...
)
```

Arguments

mu	(1) a vector of means (e.g., coefficient estimates) for the normal random variables. A user can assign a name to each mean value, e.g., mu=c(b1=.1,b2=3); otherwise, the coefficient names are assigned automatically as follows: b1,b2,.... Or, (2) a lavaan object.
Sigma	either a covariance matrix or a vector that stacks all the columns of the lower triangle variance–covariance matrix one underneath the other.
quant	quantity of interest, which is a nonlinear/linear function of the model parameters. Argument quant is a formula that **must** start with the symbol "tilde" (~): e.g., ~b1*b2*b3*b4. The names of coefficients must conform to the names provided in the argument mu or to the default names, i.e., b1,b2,....
alpha	significance level for the CI. The default value is .05.
type	method used to compute a CI. It takes on the values "MC" (default) for Monte Carlo, "asymp" for Asymptotic–Delta, or "all" that produces CIs using both methods.
plot	when TRUE, plot the approximate sampling distribution of the quantity of interest using the specified method(s) in the argument type. The default value is FALSE. When type="all", superimposed density plots generated by both methods are displayed.
plotCI	when TRUE, overlays a CI plot with error bars on the density plot of the sampling distribution of quant. When type="all", the superimposed CI plots generated by both methods are added to the density plots. Note that to obtain a CI plot, one must also specify plot="TRUE". The default value is FALSE.
n.mc	Monte Carlo sample size. The default sample size is 1e+6.
H0	False. If TRUE, it will estimate the sampling distribution of $H_0 : f(\boldsymbol{b}) = 0$. See the arguments mu0 and Sigma0.
mu0	a vector of means (e.g., coefficient estimates) for the normal random variables that satisfy the null hypothesis $H_0 : f(\boldsymbol{b}) = 0$. If it is not provided, smallest z value of mu is zet to zero.
Sigma0	either a covariance matrix or a vector that stacks all the columns of the lower triangle variance–covariance matrix one underneath the other. If it is not provided, then Sigma is used instead.
...	additional arguments.

Value

When type is "MC" or "asymp", ci returns a list that contains:

$(1-\alpha)$% CI	a vector of lower and upper confidence limits,
Estimate	a point estimate of the quantity of interest,
SE	standard error of the quantity of interest,
MC Error	When type="MC", error of the Monte Carlo estimate.

When type="all", ci returns a list of two objects, each of which a list that contains the results produced by each method as described above.

Note

A shiny web application for Monte Carlo method of this function is available at https://amplab.shinyapps.io/MEDMC/

Author(s)

Davood Tofighi <dtofighi@gmail.com>

References

Tofighi, D. and MacKinnon, D. P. (2011). RMediation: An R package for mediation analysis confidence intervals. *Behavior Research Methods*, **43**, 692–700. doi:10.3758/s134280110076x

See Also

medci RMediation-package

Examples

```
ci(mu=c(b1=1,b2=.7,b3=.6, b4= .45), Sigma=c(.05,0,0,0,.05,0,0,.03,0,.03),
quant=~b1*b2*b3*b4, type="all", plot=TRUE, plotCI=TRUE)
#An Example of Conservative Null Sampling Distribution
ci(c(b1=.3,b2=.4,b3=.3), c(.01,0,0,.01,0,.02),
quant=~b1*b2*b3, type="mc", plot=TRUE, plotCI=TRUE, H0=TRUE, mu0=c(b1=.3,b2=.4,b3=0)  )
#An Example of Less Conservative Null Sampling Distribution
ci(c(b1=.3,b2=.4,b3=.3), c(.01,0,0,.01,0,.02),
quant=~b1*b2*b3, type="mc", plot=TRUE, plotCI=TRUE, H0=TRUE, mu0=c(b1=0,b2=.4,b3=0.1)  )
```

---

mbco *Model-based Constrained Optimization (MBCO) Chi-squared Test*

Description

This function computes asymptotic MBCO chi-squared test for a smooth function of model parameters including a function of indirect effects.

Usage

```
mbco(
  h0 = NULL,
  h1 = NULL,
  R = 10L,
  type = "asymp",
  alpha = 0.05,
  checkHess = "No",
  checkSE = "No",
  optim = "SLSQP",
  precision = 1e-09
)
```

Arguments

h0	An OpenMx model estimated under a null hypothesis, which is a more constrained model
h1	An OpenMx model estimated under an alternative hypothesis, which is a less constrained model. This is usually a model hypothesized by a researcher.
R	The number of bootstrap draws.
type	If 'asymp' (default), the asymptotic MBCO chi-squares test comparing fit of h0 and h1. If 'parametric', the parametric bootstrap MBCO chi-squared test is computed. If 'semi', the semi-parametric MBCO chi-squared is computed.
alpha	Significance level with the default value of .05
checkHess	If 'No' (default), the Hessian matrix would not be calculated.
checkSE	if 'No' (default), the standard errors would not be calculated.
optim	Choose optimizer available in OpenMx. The default optimizer is "SLSQP". Other optimizer choices are available. See mxOption for more details.
precision	Functional precision. The default value is set to 1e-9. See mxOption for more details.

Value

A list that contains

chisq	asymptotic chi-squared test statistic value
df	chi-squared df
p	chi-squared p-value computed based on the method specified by the argument type

Author(s)

Davood Tofighi <dtofighi@gmail.com>

References

Tofighi, D., & Kelley, K. (2020). Indirect effects in sequential mediation models: Evaluating methods for hypothesis testing and confidence interval formation. *Multivariate Behavioral Research*, **55**, 188–210. doi:10.1080/00273171.2019.1618545

Tofighi, D. (2020). Bootstrap Model-Based Constrained Optimization Tests of Indirect Effects. *Frontiers in Psychology*, **10**, 2989. doi:10.3389/fpsyg.2019.02989

Examples

```
data(memory_exp)
memory_exp$x <- as.numeric(memory_exp$x)-1 # manually creating dummy codes
endVar <- c('x', 'repetition', 'imagery', 'recall')
manifests <- c('x', 'repetition', 'imagery', 'recall')
full_model <- mxModel(
 "memory_example",
```

```
 type = "RAM",
 manifestVars = manifests,
 mxPath(
   from = "x",
   to = endVar,
   arrows = 1,
   free = TRUE,
   values = .2,
   labels = c("a1", "a2", "cp")
 ),
 mxPath(
   from = 'repetition',
  to = 'recall',
  arrows = 1,
   free = TRUE,
   values = .2,
   labels = 'b1'
 ),
 mxPath(
   from = 'imagery',
 to = 'recall',
 arrows = 1,
 free = TRUE,
 values = .2,
 labels = "b2"
),
mxPath(
 from = manifests,
 arrows = 2,
 free = TRUE,
 values = .8
),
mxPath(
 from = "one",
 to = endVar,
 arrows = 1,
 free = TRUE,
 values = .1
),
mxAlgebra(a1 * b1, name = "ind1"),
mxAlgebra(a2 * b2, name = "ind2"),
mxCI("ind1", type = "both"),
mxCI("ind2", type = "both"),
mxData(observed = memory_exp, type = "raw")
)
## Reduced  Model for indirect effect: a1*b1
null_model1 <- mxModel(
model= full_model,
name = "Null Model 1",
mxConstraint(ind1 == 0, name = "ind1_eq0_constr")
)
full_model <- mxTryHard(full_model, checkHess=FALSE, silent = TRUE )
null_model1 <- mxTryHard(null_model1, checkHess=FALSE, silent = TRUE )
```

```
mbco(null_model1,full_model)
```

`medci` *Confidence Interval for the Mediated Effect*

Description

Produces confidence intervals for the mediated effect and the product of two normal random variables

Usage

```
medci(
  mu.x,
  mu.y,
  se.x,
  se.y,
  rho = 0,
  alpha = 0.05,
  type = "dop",
  plot = FALSE,
  plotCI = FALSE,
  n.mc = 1e+05,
  ...
)
```

Arguments

`mu.x`	mean of x
`mu.y`	mean of y
`se.x`	standard error (deviation) of x
`se.y`	standard error (deviation) of y
`rho`	correlation between x and y, where -1 <`rho` < 1. The default value is 0.
`alpha`	significance level for the confidence interval. The default value is .05.
`type`	method used to compute confidence interval. It takes on the values `"dop"` (default), `"MC"`, `"asymp"` or `"all"`
`plot`	when `TRUE`, plots the distribution of `n.mc` data points from the distribution of product of two normal random variables using the density estimates provided by the function `density`. The default value is `FALSE`.
`plotCI`	when `TRUE`, overlays a confidence interval with error bars on the plot for the mediated effect. Note that to obtain the CI plot, one must also specify `plot="TRUE"`. The default value is `FALSE`.
`n.mc`	when `type="MC"`, `n.mc` determines the sample size for the Monte Carlo method. The default sample size is 1E5.
`...`	additional arguments to be passed on to the function.

Details

This function returns a $(1-\alpha)\%$ confidence interval for the mediated effect (product of two normal random variables). To obtain a confidence interval using a specific method, the argument `type` should be specified. The default is `type="dop"`, which uses the code we wrote in R to implement the distribution of product of the coefficients method described by Meeker and Escobar (1994) to evaluate the CDF of the distribution of product. `type="MC"` uses the Monte Carlo approach to compute the confidence interval (Tofighi & MacKinnon, 2011). `type="asymp"` produces the asymptotic normal confidence interval. Note that except for the Monte Carlo method, the standard error for the indirect effect is based on the analytical results by Craig (1936):

$$\sqrt{(se.y^2\mu.x^2 + se.x^2\mu.y^2 + 2\mu.x\mu.y\rho se.x se.y + se.x^2 se.y^2 + se.x^2 se.y^2\rho^2)}$$

. In addition, the estimate of indirect effect is $\mu.x\mu.y+\sigma.xy$; `type="all"` prints confidence intervals using all four options.

Value

A vector of lower confidence limit and upper confidence limit. When `type` is `"prodclin"` (default), `"DOP"`, `"MC"` or `"asymp"`, `medci` returns a list that contains:

$(1-\alpha)\%$ `CI`	a vector of lower and upper confidence limits,
`Estimate`	a point estimate of the quantity of interest,
`SE`	standard error of the quantity of interest,
`MC Error`	When `type="MC"`, error of the Monte Carlo estimate.

Note that when `type="all"`, `medci` returns a list of *four* objects, each of which a list that contains the results produced by each method as described above.

Author(s)

Davood Tofighi <dtofighi@gmail.com>

References

Craig, C. C. (1936). On the frequency function of xy. *The Annals of Mathematical Statistics*, **7**, 1–15.

MacKinnon, D. P., Fritz, M. S., Williams, J., and Lockwood, C. M. (2007). Distribution of the product confidence limits for the indirect effect: Program PRODCLIN. *Behavior Research Methods*, **39**, 384–389.

Meeker, W. and Escobar, L. (1994). An algorithm to compute the CDF of the product of two normal random variables. *Communications in Statistics: Simulation and Computation*, **23**, 271–280.

Tofighi, D. and MacKinnon, D. P. (2011). RMediation: An R package for mediation analysis confidence intervals. *Behavior Research Methods*, **43**, 692–700. doi:10.3758/s134280110076x

See Also

`qprodnormal` `pprodnormal` `ci` `RMediation-package`

Examples

```
## Example 1
 res <- medci(mu.x=.2, mu.y=.4, se.x=1, se.y=1, rho=0, alpha=.05,
 type="dop", plot=TRUE, plotCI=TRUE)
 ## Example 2
res <- medci(mu.x=.2, mu.y=.4, se.x=1, se.y=1, rho=0, alpha=.05, type="all", plot=TRUE, plotCI=TRUE)
```

`memory_exp` *Memory Experiment Data Description from MacKinnon et al., 2018*

Description

Data were obtained from eight replicated experiments. The data were collected on the first day of class as part of the first Dr. MacKinnon's (2018) classroom teaching. The pedagogical value of the experiment was that students would have first-hand knowledge of the experiment thereby increasing their understanding of course concepts. Permission to use the data was obtained from the university Institutional Review Board.

Usage

```
data(memory_exp)
```

Format

A data frame with 369 rows and 5 variables:

study Replication ID, ranges from 1 to 8

repetition Use of repetition rehearsal technique on a 1 to 9 scale

recall Total words recalled out of 20 words

imagery Use of imagery rehearsal technique on a 1 to 9 scale

x A factor with two levels: repetition or primary rehearsal = 0, imagery or secondary rehearsal = 1

Note

If you use the data set, please cite the original article by MacKinnon et al. (2018) cited below.

Source

doi:10.1037/met0000174.supp

References

MacKinnon, D. P., Valente, M. J., & Wurpts, I. C. (2018). Benchmark validation of statistical models: Application to mediation analysis of imagery and memory. Psychological Methods, 23, 654–671. doi:10.1037/met0000174

pMC *Probability (percentile) for the Monte Carlo Sampling Distribution of a nonlinear function of coefficients estimates*

Description

This function returns a probability corresponding to the quantile q.

Usage

```
pMC(q, mu, Sigma, quant, lower.tail = TRUE, n.mc = 1e+06, ...)
```

Arguments

q	quantile
mu	a vector of means (e.g., coefficient estimates) for the normal random variables. A user can assign a name to each mean value, e.g., mu=c(b1=.1,b2=3); otherwise, the coefficient names are assigned automatically as follows: b1,b2,....
Sigma	either a covariance matrix or a vector that stacks all the columns of the lower triangle variance–covariance matrix one underneath the other.
quant	quantity of interest, which is a nonlinear/linear function of the model parameters. Argument quant is a formula that **must** start with the symbol "tilde" (~): e.g., ~b1*b2*b3*b4. The names of coefficients must conform to the names provided in the argument mu or to the default names, i.e., b1,b2,....
lower.tail	logical; if TRUE (default), the probability is $P[quant < q]$; otherwise, $P[quant > q]$
n.mc	Monte Carlo sample size. The default sample size is 1e+6.
...	additional arguments.

Value

scalar probability value.

Author(s)

Davood Tofighi <dtofighi@gmail.com>

References

Tofighi, D. and MacKinnon, D. P. (2011). RMediation: An R package for mediation analysis confidence intervals. *Behavior Research Methods*, **43**, 692–700. doi:10.3758/s13428-011-0076-x

See Also

medci RMediation-package

Examples

```
pMC(.2,mu=c(b1=1,b2=.7,b3=.6, b4= .45), Sigma=c(.05,0,0,0,.05,0,0,.03,0,.03),
quant=~b1*b2*b3*b4)
```

`pprodnormal` *Percentile for the Distribution of Product of Two Normal Variables*

Description

Generates percentiles (100 based quantiles) for the distribution of product of two normal random variables and the mediated effect

Usage

```
pprodnormal(
  q,
  mu.x,
  mu.y,
  se.x = 1,
  se.y = 1,
  rho = 0,
  lower.tail = TRUE,
  type = "dop",
  n.mc = 1e+05
)
```

Arguments

`q`	quantile or value of the product
`mu.x`	mean of x
`mu.y`	mean of y
`se.x`	standard error (deviation) of x
`se.y`	standard error (deviation) of y
`rho`	correlation between x and y, where -1 <`rho` < 1. The default value is 0.
`lower.tail`	logical; if `TRUE` (default), the probability is $P[X*Y < q]$; otherwise, $P[X*Y > q]$
`type`	method used to compute confidence interval. It takes on the values `"dop"` (default), `"MC"`, `"asymp"` or `"all"`
`n.mc`	when `type="MC"`, `n.mc` determines the sample size for the Monte Carlo method. The default sample size is 1E5.

Details

This function returns the percentile (probability) and the associated error for the distribution of product of mediated effect (two normal random variables). To obtain a percentile using a specific method, the argument type should be specified. The default method is type="dop", which is based on the method described by Meeker and Escobar (1994) to evaluate the CDF of the distribution of product of two normal random variables. type="MC" uses the Monte Carlo approach (Tofighi & MacKinnon, 2011). type="all" prints percentiles using all three options. For the method type="dop", the error is the modulus of absolute error for the numerical integration (for more information see Meeker and Escobar, 1994). For type="MC", the error refers to the Monte Carlo error.

Value

An object of the type list that contains the following values:

p	probability (percentile) corresponding to quantile q
error	estimate of the absolute error

Author(s)

Davood Tofighi <dtofighi@gmail.com>

References

Tofighi, D. and MacKinnon, D. P. (2011). RMediation: An R package for mediation analysis confidence intervals. *Behavior Research Methods*, **43**, 692–700. doi:10.3758/s13428-011-0076-x

See Also

medci RMediation-package

Examples

```
pprodnormal(q=0, mu.x=.5, mu.y=.3, se.x=1, se.y=1, rho= 0, type="all")
```

---

qMC *Quantile for the Monte Carlo Sampling Distribution of a nonlinear function of coefficients estimates*

Description

This function returns a quantile corresponding to the probability p.

Usage

```
qMC(p, mu, Sigma, quant, n.mc = 1e+06, ...)
```

Arguments

p	probability.
mu	a vector of means (e.g., coefficient estimates) for the normal random variables. A user can assign a name to each mean value, e.g., `mu=c(b1=.1,b2=3)`; otherwise, the coefficient names are assigned automatically as follows: `b1,b2,...`.
Sigma	either a covariance matrix or a vector that stacks all the columns of the lower triangle variance–covariance matrix one underneath the other.
quant	quantity of interest, which is a nonlinear/linear function of the model parameters. Argument `quant` is a formula that **must** start with the symbol "tilde" (~): e.g., `~b1*b2*b3*b4`. The names of coefficients must conform to the names provided in the argument `mu` or to the default names, i.e., `b1,b2,...`.
n.mc	Monte Carlo sample size. The default sample size is 1e+6.
...	additional arguments.

Value

scalar quantile value.

Author(s)

Davood Tofighi <dtofighi@gmail.com>

References

Tofighi, D. and MacKinnon, D. P. (2011). RMediation: An R package for mediation analysis confidence intervals. *Behavior Research Methods*, **43**, 692–700. doi:10.3758/s13428-011-0076-x

See Also

medci RMediation-package

Examples

```
qMC(.05,mu=c(b1=1,b2=.7,b3=.6, b4= .45), Sigma=c(.05,0,0,0,.05,0,0,.03,0,.03),
quant=~b1*b2*b3*b4)
```

---

qprodnormal *Quantile for the Distribution of Product of Two Normal Variables*

Description

Generates quantiles for the distribution of product of two normal random variables

Usage

```
qprodnormal(
  p,
  mu.x,
  mu.y,
  se.x,
  se.y,
  rho = 0,
  lower.tail = TRUE,
  type = "dop",
  n.mc = 1e+05
)
```

Arguments

p	probability
mu.x	mean of x
mu.y	mean of y
se.x	standard error (deviation) of x
se.y	standard error (deviation) of y
rho	correlation between x and y, where -1 <rho < 1. The default value is 0.
lower.tail	logical; if TRUE (default), the probability is $P[X*Y < q]$; otherwise, $P[X*Y > q]$
type	method used to compute confidence interval. It takes on the values "dop" (default), "MC", "asymp" or "all"
n.mc	when type="MC", n.mc determines the sample size for the Monte Carlo method. The default sample size is 1E5.

Details

This function returns a quantile and the associated error (accuracy) corresponding the requested percentile (probability) p of the distribution of product of mediated effect (product of two normal random variables). To obtain a quantile using a specific method, the argument type should be specified. The default method is type="dop", which uses the method described by Meeker and Escobar (1994) to evaluate the CDF of the distribution of product of two normal variables. type="MC" uses the Monte Carlo approach (Tofighi & MacKinnon, 2011). type="all" prints quantiles using all three options. For the method type="dop", the error is the modulus of absolute error for the numerical integration (for more information see Meeker and Escobar, 1994). For type="MC", the error refers to the Monte Carlo error.

Value

An object of the type list that contains the following values:

q	quantile corresponding to probability p
error	estimate of the absolute error

Author(s)

Davood Tofighi <dtofighi@gmail.com>

References

Tofighi, D. and MacKinnon, D. P. (2011). RMediation: An R package for mediation analysis confidence intervals. *Behavior Research Methods*, **43**, 692–700. doi:10.3758/s13428-011-0076-x

See Also

medci RMediation-package

Examples

```
##lower tail
qprodnormal(p=.1, mu.x=.5, mu.y=.3, se.x=1, se.y=1, rho=0,
lower.tail = TRUE, type="all")
##upper tail
qprodnormal(p=.1, mu.x=.5, mu.y=.3, se.x=1, se.y=1, rho=0,
lower.tail = FALSE, type="all")
```

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