Package 'pacotest'

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Type Package

Title Testing for Partial Copulas and the Simplifying Assumption in Vine Copulas

Version 0.4.3

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Description Routines for two different test types, the Constant Conditional Correlation (CCC) test and the Vectorial Independence (VI) test are provided (Kurz and Spanhel (2022) <doi:10.1214/22-EJS2051>). The tests can be applied to check whether a conditional copula coincides with its partial copula. Functions to test whether a regular vine copula satisfies the so-called simplifying assumption or to test a single copula within a regular vine copula to be a (j-1)-th order partial copula are available. The CCC test comes with a decision tree approach to allow testing in high-dimensional settings.

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Imports Rcpp (>= 0.11.4), VineCopula (>= 2.0.5), numDeriv, ggplot2(>= 2.0.0), gridExtra, methods

LinkingTo Rcpp, RcppArmadillo

Suggests testthat, covr

BugReports https://github.com/MalteKurz/pacotest/issues

NeedsCompilation yes

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Contents

pacotest-package *Testing for Partial Copulas and the Simplifying Assumption in Vine Copulas*

Description

The **pacotest** package provides functions, which allow to test for partial copulas and the simplifying assumption in vine copulas. The package consists of two different test types, the Constant Conditional Correlation (CCC) test and the Vectorial Independence (VI) test. The function `pacotestset` can be used to create and alter pacotest options lists and the function `pacotest` can be used to test for the partial copula and the simplifying assumption for a single bivariate conditional copula.

The function `pacotestRvineSeq` can be used with a RVineMatrix from the VineCopula-package to test all pair-copulas being building blocks in a R-vine copula to be (j-1)-th order partial copulas, which is equivalent to testing the simplifying assumption. A single building blog of a R-vine copula could be tested to be a (j-1)-th order partial copula by applying the function `pacotestRvineSingleCopula` to a RVineMatrix from the VineCopula-package.

Author(s)

Malte S. Kurz

References

Hobaek-Haff, I., K. Aas and A. Frigessi (2010), "On the simplified pair-copula construction – Simply useful or too simplistic?", Journal of Multivariate Analysis 101(5), pp. 1296-1310.

Kojadinovic, I. and M. Holmes (2009), "Tests of independence among continuous random vectors based on Cramer-von Mises functionals of the empirical copula process", Journal of Multivariate Analysis 100(6), pp. 1137-1154.

Kurz, M. S. and F. Spanhel (2022), "Testing the simplifying assumption in high-dimensional vine copulas", Electronic Journal of Statistics 16 (2), pp. 5226-5276.

Quessy, J.-F. (2010), "Applications and asymptotic power of marginal-free tests of stochastic vectorial independence", Journal of Statistical Planning and Inference 140(11), pp. 3058-3075.

Spanhel, F. and M. S. Kurz (2019), "Simplified vine copula models: Approximations based on the simplifying assumption", Electronic Journal of Statistics 13 (1), pp. 1254-1291.

Spanhel, F. and M. S. Kurz (2016), "The partial copula: Properties and associated dependence measures", Statistics & Probability Letters 119, pp. 76-83.

See Also

Development for **pacotest** can be followed via the GitHub repository at `https://github.com/MalteKurz/pacotest`.

pacotest *Testing for the Partial Copula and the Simplifying Assumption for a Single Bivariate Conditional Copula*

Description

The function can be used to test for the partial copula and the simplifying assumption for a bivariate conditional copula using different tests. Two different test types, the Constant Conditional Correlation (CCC) test and the Vectorial Independence (VI) test are implemented. For all tests different options can be set by generating a pacotest options list using the `pacotestset` function.

Arguments

`U`	A (n x 2) matrix of [0,1] data (probability integral transforms), which are the arguments of the conditional copula of (Y,Z)|W for which the simplifying assumption should be tested. The first column is given by the conditional distribution function of Y|W evaluated at the observed values of Y and W. Analogously, the second column is defined as the conditional distribution function of Z|W evaluated at the observed values of Z and W. If the probability integral transforms are obtained from the partial vine copula (PVC), i.e., partial probability integral transforms (PPITs) are used, the function can be used to test for (j-1)-th order partial copulas.
`W`	A (n x K) matrix of observed values for the vector of random variables on which the conditioning is done.
`pacotestOptions`	A options list generated by the `pacotestset` function or the test type as a string, i.e., `CCC` or `VI`.

Details

Applying a test with default options (cf. `pacotestset`) and with known (i.e., not estimated) PITs (probability integral transforms) in `U`.

```
out = pacotest(U,W,'CCC')

out = pacotest(U,W,'VI')
```

Applying a test with options specified in `pacotestOptions`

```
out = pacotest(U,W,pacotestOptions)
```

Note that when calling `pacotest(U,W,'CCC')`, the default options for the CCC test are used (cf. `pacotestset`), but the two parameters `withEstUncert = FALSE` and `estUncertWithRanks = FALSE` are altered. In contrast when calling `pacotestOptions = pacotestset('CCC')`, the two parameters are set to `withEstUncert = TRUE` and `estUncertWithRanks = TRUE`. For the CCC test, under the default setting, it is assumed that estimated PPITs are provided and the test statistic is

computed under consideration of estimation uncertainty of the probability integral transforms, i.e., `withEstUncert = TRUE` and `estUncertWithRanks = TRUE`. To apply `pacotest` with `withEstUncert = TRUE`, three additional inputs have to be provided (`data`, `svcmDataFrame` and `cPitData`).

In the vine copula context, PPITs are usually estimated and not known. Therefore, in the vine copula context it is recommended to use the functions `pacotestRvineSeq` or `pacotestRvineSingleCopula` instead of `pacotest`. These functions automatically pass through the additional arguments `data`, `svcmDataFrame`, `cPitData` to the function `pacotest` and the CCC test can be applied in its default setting with consideration of estimation uncertainty of the probability integral transforms, i.e., `withEstUncert = TRUE` and `estUncertWithRanks = TRUE`.

Value

A list which can, depending on the chosen test, consist of the following elements:

`pValue`	The p-value of the test.
`testStat`	The value of the test statistic.
`decisionTree`	The decision tree used to partition the support Lambda0 of the conditioning variable W. It is provided as a list consisting of three nodes (`CentralNode`, `LeftNode` and `RightNode`) represented as lists and the variable `LeavesForFinalComparison`. Each node consists of the `Variable` used to perform the split, the corresponding `Quantile` and `Threshold`.
`S`	The bootstrapped values of the test statistic (only for the test type `VI`).

Author(s)

Malte S. Kurz

References

Kurz, M. S. and F. Spanhel (2022), "Testing the simplifying assumption in high-dimensional vine copulas", Electronic Journal of Statistics 16 (2), pp. 5226-5276.

Spanhel, F. and M. S. Kurz (2019), "Simplified vine copula models: Approximations based on the simplifying assumption", Electronic Journal of Statistics 13 (1), pp. 1254-1291.

Spanhel, F. and M. S. Kurz (2016), "The partial copula: Properties and associated dependence measures", Statistics & Probability Letters 119, pp. 76-83.

See Also

`pacotest-package`, `pacotestset`, `pacotestRvineSeq`, `pacotestRvineSingleCopula`

Examples

```
####################
# Generate an options list, e.g., the constant conditional correlation (CCC)
# test with default options. We use known PITs and don't estimate the parameters
# in the lower trees of the vine copulas and therefore additionally alter the
# two parameters withEstUncert and estUncertWithRanks to FALSE.
pacotestOptions=pacotestset(testType='CCC', withEstUncert = FALSE, estUncertWithRanks = FALSE)
```

```
######################
# Use the specified options to test for the simplifying assumption

##### Example 1: Non-simplified three-dim. C-Vine #####
# Simulate from a three-dimensional C-Vine copula with C_12 and C_13
# being product copulas and C_23|1 being a Frank copula with
# functional parameter theta(x_{1}) = (4x_{1}-2)^3
N = 500
X = matrix(runif(3*N),N,3)
theta = (4*X[,1]-2)^3

etheta = expm1(-theta);
X[,3] = -1/theta*log(1+etheta/(exp(-theta*X[,2])*(1/X[,3]-1)+1));

Result = pacotest(X[,c(2,3)],X[,1],pacotestOptions)
Result$pValue

##### Example 2: Non-simplified three-dim. C-Vine #####
# Simulate from a three-dimensional C-Vine copula with C_12 and C_13
# being product copulas and C_23|1 being a Frank copula with
# functional parameter theta(x_{1}) = 12 + 8*sin(0.4(3x_{1}+2)^2)
X = matrix(runif(3*N),N,3)
theta = 12 + 8*sin(0.4*(3*X[,1]+2)^2)

etheta = expm1(-theta);
X[,3] = -1/theta*log(1+etheta/(exp(-theta*X[,2])*(1/X[,3]-1)+1));

Result = pacotest(X[,c(2,3)],X[,1],pacotestOptions)
Result$pValue

##### Example 3: Simplified three-dim. C-Vine #####
# Simulate from a three-dimensional C-Vine copula with C_12 and C_13
# being Clayton copulas with parameter theta and C_23|1 being a Clayton copula with
# functional parameter theta(x_{1}) = theta / (1+theta)
W = matrix(runif(3*N),N,3)
X = matrix(NA,N,3)
theta = 2

X[,1] = W[,1]
X[,2] = (W[,1]^(-theta)*(W[,2]^((-theta)/(1+theta))-1)+1)^(-1/theta);
theta_23_1 = theta /(1+theta)
X[,3] = (W[,2]^(-theta_23_1)*(W[,3]^((-theta_23_1)/(1+theta_23_1))-1)+1)^(-1/theta_23_1);
X[,3] = (W[,1]^(-theta)*(X[,3]^((-theta)/(1+theta))-1)+1)^(-1/theta);

# Get pseudo-observations from the conditional copula C_23|1
U = matrix(NA,N,2)
U[,1] = (X[,1]^theta*(X[,2]^(-theta)-1)+1)^(-(1+theta)/theta);
U[,2] = (X[,1]^theta*(X[,3]^(-theta)-1)+1)^(-(1+theta)/theta);
Result = pacotest(U,X[,1],pacotestOptions)
Result$pValue
```

pacotestRvineSeq *Sequentially Testing the Simplifying Assumption for R-Vine Copulas*

Description

The function can be used to test the simplifying assumption for R-vine copulas in a sequential manner. Each pair-copula from the second tree on is tested to be a (j-1)-th order partial copula. To apply the function one needs to provide the data and a specified/estimated R-vine copula model in form of a RVineMatrix from the VineCopula-package. Additionally, a pacotest options list, which can be generated with the `pacotestset` function, needs to be provided.

Usage

```
pacotestRvineSeq(data, RVM, pacotestOptions,
  level = 0.05, illustration = 2, stopIfRejected = TRUE)
```

Arguments

`data`	A (n x d) matrix (or data frame) of [0,1] data (i.e. uniform margins).
`RVM`	An RVineMatrix object (VineCopula-package) which includes the structure, the pair-copula families and parameters of an R-vine copula.
`pacotestOptions`	A options list generated by the `pacotestset` function or the test type as string, i.e., `CCC` or `VI`.
`level`	The level of the test.
`illustration`	Either 1 or 2. If illustration = 1, the p-value for each test for a (j-1)-th order partial copula is displayed. If illustration = 2, a progress information is displayed for each tree. It consists of the individual test level and the number of H0 rejections.
`stopIfRejected`	A logical variable indicating whether the sequential test procedure should be stopped in the first tree where an H0 for one of the conditional copulas is rejected.

Value

A list consisting of the following elements:

`pacotestResultLists`
: A matrix in the same structure like the `Matrix`, `family`, `par`, etc. entries in the RVineMatrix object from the VineCopula-package. Each entry of the matrix is a list containing the test result from a test for a (j-1)-th order partial copula obtained from a call to `pacotest`. Depending on the chosen test, it could consist of different elements. A documentation of the `pacotestResultLists` can be found in the documentation of `pacotest`.

`pValues` A matrix in the same structure like the `Matrix`, `family`, `par`, etc. entries in the RVineMatrix object from the VineCopula-package. Each entry of the matrix is a p-value corresponding to the test result from a test for a (j-1)-th order partial copula.

`testResultSummary`
A data.frame summarizing the test results. The first column, `Tree`, is the tree number. The second column, `NumbOfRejections`, is the number of of rejections in the corresponding tree. The third column, `IndividualTestLevel`, is the level at which each individual test has been performed. The fourth column, `Interpretation`, provides an interpretation of the test result.

Author(s)

Malte S. Kurz

References

Kurz, M. S. and F. Spanhel (2022), "Testing the simplifying assumption in high-dimensional vine copulas", Electronic Journal of Statistics 16 (2), pp. 5226-5276.

Spanhel, F. and M. S. Kurz (2019), "Simplified vine copula models: Approximations based on the simplifying assumption", Electronic Journal of Statistics 13 (1), pp. 1254-1291.

See Also

pacotest-package, pacotest, pacotestset, pacotestRvineSingleCopula

Examples

```
# Sample data and R-vine copula selection are taken
# from the documentation of RVineStructureSelect
# of the VineCopula package.

# Obtain sample data
data(daxreturns, package ="VineCopula")
dataSet = daxreturns[1:750,1:4]

# Specify an R-vine copula model
# (can be obtained by calling: RVM = VineCopula::RVineStructureSelect(dataSet))
vineStructure = matrix(c(3,4,1,2,0,2,4,1,0,0,1,4,0,0,0,4),4,4)
families = matrix(c(0,5,2,2,0,0,2,14,0,0,0,14,0,0,0,0),4,4)
par = matrix(c(0,0.8230664,0.1933472,0.6275062,
             0,0,0.2350109,1.6619945,
             0,0,0,1.599363,
             0,0,0,0),4,4)
par2 = matrix(c(0,0,11.757700,4.547847,
             0,0,17.15717,0,
             0,0,0,0,0,0,0,0),4,4)
RVM = VineCopula::RVineMatrix(vineStructure, families, par, par2)


# Specify a pacotestOptions list:
```

```
pacotestOptions = pacotestset('CCC')

# Test for the simplifying assumption.
pacotestResultList = pacotestRvineSeq(dataSet, RVM,
                                      pacotestOptions)
```

---

pacotestRvineSingleCopula

Testing for a Single (j-1)-th Order Partial Copula in a R-Vine Copula

---

Description

The function can be used to test a single copula in a R-vine copula to be a (j-1)-th order partial copula. To apply the function one needs to provide the data and a specified/estimated R-vine copula model in form of a RVineMatrix from the VineCopula-package. Additionally, a pacotest options list, which can be generated with the `pacotestset` function, needs to be provided.

Usage

```
pacotestRvineSingleCopula(data, RVM, pacotestOptions, tree, copulaNumber)
```

Arguments

`data`	A (n x d) matrix (or data frame) of [0,1] data (i.e. uniform margins).
`RVM`	An RVineMatrix object (VineCopula-package) which includes the structure, the pair-copula families and parameters of an R-vine copula.
`pacotestOptions`	A options list generated by the `pacotestset` function or the test type as string, i.e., `CCC` or `VI`.
`tree`	The tree number (j>=2) of the copula which should be tested to be a (j-1)-th order partial copula.
`copulaNumber`	The number (1<= copulaNumber <= j-1) of the copula in the normalized RVineMatrix which should be tested to be a (j-1)-th order partial copula.

Value

A list which can, depending on the chosen test, consist of the following elements:

`pValue`	The p-value of the test.
`testStat`	The value of the test statistic.
`decisionTree`	The decision tree used to partition the support Lmabda0 of the conditioning variable W. It is provided as a list consisting of three nodes (`CentralNode`, `LeftNode` and `RightNode`) represented as lists and the variable `LeavesForFinalComparison`. Each node consists of the `Variable` used to perform the split, the corresponding `Quantile` and `Threshold`.
`S`	The bootstrapped values of the test statistic (only for the test type `VI`).

Author(s)

Malte S. Kurz

References

Kurz, M. S. and F. Spanhel (2022), "Testing the simplifying assumption in high-dimensional vine copulas", Electronic Journal of Statistics 16 (2), pp. 5226-5276.

Spanhel, F. and M. S. Kurz (2019), "Simplified vine copula models: Approximations based on the simplifying assumption", Electronic Journal of Statistics 13 (1), pp. 1254-1291.

See Also

pacotest-package, pacotest, pacotestset, pacotestRvineSeq

Examples

```
# Sample data and R-vine copula selection are taken
# from the documentation of RVineStructureSelect
# of the VineCopula package.

# Obtain sample data
data(daxreturns, package ="VineCopula")
dataSet = daxreturns[1:750,1:4]

# Specify an R-vine copula model
# (can be obtained by calling: RVM = VineCopula::RVineStructureSelect(dataSet))
vineStructure = matrix(c(3,4,1,2,0,2,4,1,0,0,1,4,0,0,0,4),4,4)
families = matrix(c(0,5,2,2,0,0,2,14,0,0,0,14,0,0,0,0),4,4)
par = matrix(c(0,0.8230664,0.1933472,0.6275062,
             0,0,0.2350109,1.6619945,
             0,0,0,1.599363,
             0,0,0,0),4,4)
par2 = matrix(c(0,0,11.757700,4.547847,
             0,0,17.15717,0,
             0,0,0,0,0,0,0,0),4,4)
RVM = VineCopula::RVineMatrix(vineStructure, families, par, par2)

# Specify a pacotestOptions list:
# For illustrating the functioning of the decision tree,
# grouped scatterplots and a decision tree plot are activated.
pacotestOptions = pacotestset(testType='CCC',
                              groupedScatterplots = TRUE,
                              decisionTreePlot = TRUE)

# Test for a 2-nd order partial copula
# corresponding to the variables BAYN.DE,BMW.DE
# and conditioning set ALV.DE,BAS.DE
tree = 3
copulaNumber = 1

pacotestResultList = pacotestRvineSingleCopula(dataSet, RVM,
```

```
pacotestOptions, tree, copulaNumber)
```

`pacotestset` *Create and Alter a Pacotest Options List*

Description

The function creates or updates a list object, which is required for applying the `pacotest` function.

Arguments

`pacotestOptions`
: A options list for the `pacotest` function generated by the `pacotestset` function.

`testType`
: A string which specifies the type of the test for testing the simplifying assumption.

  Possible values: `CCC` | `VI`

`grouping`
: For `testType` = `CCC`:

  The grouping method which is used to obtain a partitioning of the support of the conditioning variable W.

  Possible values: `TreeCCC` | `SumMedian` | `SumThirdsI` | `SumThirdsII` | `SumThirdsIII` | `SumQuartiles` | `ProdMedian` | `ProdThirdsI` | `ProdThirdsII` | `ProdThirdsIII` | `ProdQuartiles` | `TreeEC`

`expMinSampleSize`
: For `testType` = `CCC` with `grouping` = `TreeCCC` | `TreeEC`:

  The minimum number of observations which are allocated to a group in the decision tree learning process. The default value is `100`.

`aggInfo`
: For `testType` = `CCC` with `grouping` = `TreeCCC` | `TreeEC`:

  The method used for aggregating information in the conditioning set. The information in the conditioning set can be aggregated by either taking the mean of all variables or the pairwise mean. The result is added as an additional variable which can be used by the decision tree to partition the support of the conditioning variable W.

  Possible values: `none` | `meanAll` | `meanPairwise`

`withEstUncert`
: For `testType` = `CCC`:

  A logical variable indicating whether the asymptotic-variance covariance matrix of the estimated correlations should be corrected for the estimation uncertainty of the probability integral transforms.

`estUncertWithRanks`
: For `testType` = `CCC`:

  A logical variable indicating whether the asymptotic-variance covariance matrix of the estimated correlations should be corrected for the estimation uncertainty induced by using a semiparametric estimator for the vine copula, i.e., empirical cdf's for the univariate margins and parametric copula families as building blocks of the R-vine copula.

`finalComparison`

For `testType = CCC` with `grouping = TreeCCC | TreeEC`:

A variable specifying whether at the end of the decision tree all subsets being part of the partition are compared against each other or whether only the pair with the highest value of the test statistic is used.

Possible values: `pairwiseMax | all`

`penaltyParams` For `testType = CCC` with `grouping = TreeCCC | TreeEC`:

A vector of length two, specifying the functional form of the penalty. The penalty is a function of the sample size n and chosen to be lambda(n) = cn^(-beta). The first entry of the vector is specifying the level c of the penalty and needs to be a positive real number. The second entry of the vector is specifying the power beta of the penalty and needs to be chosen from the interval (0,1).

`gamma0Partition`

For `testType = CCC` with `grouping = TreeCCC | TreeEC`:

The gamma0 partition. I.e., the partition which is favoured via the penalty under the H0.

Possible values: `SumMedian | SumThirdsI | SumThirdsII | SumThirdsIII | SumQuartiles | ProdMedian | ProdThirdsI | ProdThirdsII | ProdThirdsIII | ProdQuartiles`

`groupedScatterplots`

For `testType = CCC`:

A logical whether grouped scatterplots should be produced.

`decisionTreePlot`

For `testType = CCC`:

A logical whether the partition of the support of W should be illustrated as a decision tree plot.

`numbBoot` For `testType = VI`:

The number of bootstrap replications for computing p-values using the multiplier bootstrap approach.

Details

Calling without any arguments prints all possible options.

```
pacotestset()
```

Calling with a string, that specifies the test type, gives back a option list with the default values corresponding to each test.

```
pacotestOptions = pacotestset('CCC')
```

```
pacotestOptions = pacotestset('VI')
```

Calling with pairs of parameter names and values creates an `pacotestOptions` list in which the named parameters have the specified values.

```
pacotestOptions = pacotestset('Name1',Value1,'Name2',Value2,...)
```

Calling with an existing `pacotestOptions` list checks the list for consistency.

```
pacotestset(pacotestOptions)
```

Calling with an existing `pacotestOptions` list and pairs of parameter names and values creates a copy of the existing list, where the named parameters are updated with the provided values.

```
pacotestOptionsNew = pacotestset(pacotestOptions,'Name1',Value1,'Name2',Value2,...)
```

Value

The function returns a `pacotestOptions` list which can be used as input argument for the functions `pacotest`, `pacotestRvineSeq` and `pacotestRvineSingleCopula`.

Author(s)

Malte S. Kurz

References

Kurz, M. S. and F. Spanhel (2022), "Testing the simplifying assumption in high-dimensional vine copulas", Electronic Journal of Statistics 16 (2), pp. 5226-5276.

See Also

`pacotest-package`, `pacotest`, `pacotestRvineSeq`, `pacotestRvineSingleCopula`

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