Package ‘qfa’

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Description This package contains R functions for quantile-frequency analysis (QFA) of univariate or multivariate time series based on the method of trigonometric quantile regression. See Li, T.-H. (2012) Quantile periodograms, Journal of the American Statistical Association, 107, 765–776, <https://doi.org/10.1080/01621459.2012.682815>; Li, T.-H. (2014) Time Series with Mixed Spectra, CRC Press, <https://doi.org/10.1201/b15154>; Li, T.-H. (2022) Quantile Fourier transform, quantile series, and nonparametric estimation of quantile spectra, <https://doi.org/10.48550/arXiv.2211.05844>.

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`qdft` *Quantile Discrete Fourier Transform (QDFT)*

Description

This function computes quantile discrete Fourier transform (QDFT) for univariate or multivariate time series.

Usage

```
qdft(y, tau, n.cores = 1, cl = NULL)
```

Arguments

`y`	vector or matrix of time series (if matrix, `nrow(y)` = length of time series)
`tau`	sequence of quantile levels in (0,1)
`n.cores`	number of cores for parallel computing (default = 1)
`cl`	pre-existing cluster for repeated parallel computing (default = `NULL`)

Value

matrix or array of the quantile discrete Fourier transform of `y`

Examples

```
y <- stats::arima.sim(list(order=c(1,0,0), ar=0.5), n=64)
tau <- seq(0.1,0.9,0.05)
y.qdft <- qdft(y,tau)
# Make a cluster for repeated use
n.cores <- 2
cl <- parallel::makeCluster(n.cores)
parallel::clusterExport(cl, c("tqr.fit"))
doParallel::registerDoParallel(cl)
```

```
y1 <- stats::arima.sim(list(order=c(1,0,0), ar=0.5), n=64)
y.qdft <- qdft(y1,tau,n.cores=n.cores,cl=cl)
y2 <- stats::arima.sim(list(order=c(1,0,0), ar=0.5), n=64)
y.qdft <- qdft(y2,tau,n.cores=n.cores,cl=cl)
parallel::stopCluster(cl)
```

---

qdft2qacf *Quantile Autocovariance Function (QACF)*

Description

This function computes quantile autocovariance function (QACF) from QDFT.

Usage

```
qdft2qacf(y.qdft, return.qser = FALSE)
```

Arguments

`y.qdft`	matrix or array of QDFT from `qdft()` or SQDFT from `sqdft()`
`return.qser`	if `TRUE`, return quantile series (QSER) along with QACF

Value

matrix or array of quantile autocovariance function if `return.sqer = FALSE` (default), else a list with the following elements:

`qacf`	matirx or array of quantile autocovariance function
`qser`	matrix or array of quantile series

Examples

```
# single time series
y1 <- stats::arima.sim(list(order=c(1,0,0), ar=0.5), n=64)
tau <- seq(0.1,0.9,0.05)
y.qdft <- qdft(y1,tau)
qacf <- qdft2qacf(y.qdft)
plot(c(0:9),qacf[c(1:10),1],type='h',xlab="LAG",ylab="QACF")
qser <- qdft2qacf(y.qdft,return.qser=TRUE)$qser
plot(qser[,1],type='l',xlab="TIME",ylab="QSER")
# multiple time series
y2 <- stats::arima.sim(list(order=c(1,0,0), ar=-0.5), n=64)
y.qdft <- qdft(cbind(y1,y2),tau)
qacf <- qdft2qacf(y.qdft)
plot(c(0:9),qacf[1,2,c(1:10),1],type='h',xlab="LAG",ylab="QACF")
```

qdft2qper *Quantile Periodogram and Cross-Periodogram (QPER)*

Description

This function computes quantile periodogram/cross-periodogram (QPER) from QDFT.

Usage

```
qdft2qper(y.qdft)
```

Arguments

`y.qdft`	matrix or array of QDFT from `qdft()`

Value

matrix or array of quantile periodogram/cross-periodogram

Examples

```
# single time series
y1 <- stats::arima.sim(list(order=c(1,0,0), ar=0.5), n=64)
tau <- seq(0.1,0.9,0.05)
y.qdft <- qdft(y1,tau)
qper <- qdft2qper(y.qdft)
n <- length(y1)
ff <- c(0:(n-1))/n
sel.f <- which(ff > 0 & ff < 0.5)
qfa.plot(ff[sel.f],tau,Re(qper[sel.f,]))
# multiple time series
y2 <- stats::arima.sim(list(order=c(1,0,0), ar=-0.5), n=64)
y.qdft <- qdft(cbind(y1,y2),tau)
qper <- qdft2qper(y.qdft)
qfa.plot(ff[sel.f],tau,Re(qper[1,1,sel.f,]))
qfa.plot(ff[sel.f],tau,Re(qper[1,2,sel.f,]))
```

qdft2qser *Quantile Series (QSER)*

Description

This function computes quantile series (QSER) from QDFT.

Usage

```
qdft2qser(y.qdft)
```

Arguments

`y.qdft`	matrix or array of QDFT from `qdft()` or SQDFT from `sqdft()`

Value

matrix or array of quantile series

Examples

```
# single time series
y1 <- stats::arima.sim(list(order=c(1,0,0), ar=0.5), n=64)
tau <- seq(0.1,0.9,0.05)
y.qdft <- qdft(y1,tau)
qser <- qdft2qser(y.qdft)
plot(qser[,1],type='l',xlab="TIME",ylab="QSER")
# multiple time series
y2 <- stats::arima.sim(list(order=c(1,0,0), ar=-0.5), n=64)
y.qdft <- qdft(cbind(y1,y2),tau)
qser <- qdft2qser(y.qdft)
plot(qser[1,,1],type='l',xlab="TIME",ylab="QSER")
```

---

qfa.plot *Quantile-Frequency Plot*

Description

This function creates an image plot of quantile spectrum.

Usage

```
qfa.plot(
  freq,
  tau,
  qper,
  rg.qper = range(qper),
  rg.tau = range(tau),
  rg.freq = c(0, 0.5),
  color = colorRamps::matlab.like2(1024),
  ylab = "QUANTILE LEVEL",
  xlab = "FREQUENCY",
  tlab = NULL,
  set.par = TRUE,
  legend.plot = TRUE
)
```

Arguments

`freq`	sequence of frequencies in (0,0.5) at which quantile spectrum is evaluated
`tau`	sequence of quantile levels in (0,1) at which quantile spectrum is evaluated
`qper`	real-valued matrix of quantile spectrum evaluated on the `freq` x `tau` grid
`rg.qper`	`zlim` for `qper` (default = `range(qper)`)
`rg.tau`	`ylim` for `tau` (default = `range(tau)`)
`rg.freq`	`xlim` for `freq` (default = `c(0,0.5)`)
`color`	colors (default = `colorRamps::matlab.like2(1024)`)

`ylab`	label of y-axis (default = "QUANTILE LEVEL")
`xlab`	label of x-axis (default = "FREQUENCY")
`tlab`	title of plot (default = NULL)
`set.par`	if TRUE, par() is set internally (single image)
`legend.plot`	if TRUE, legend plot is added

qkl.divergence — *Kullback-Leibler Divergence of Quantile Spectral Estimate*

Description

This function computes Kullback-Leibler divergence (KLD) of quantile spectral estimate.

Usage

```
qkl.divergence(qper, qspec, sel.f = NULL, sel.tau = NULL)
```

Arguments

`qper`	matrix or array of quantile spectral estimate from, e.g., qspec.lw()
`qspec`	matrix of array of true quantile spectrum/cross-spectrum (same dimension as qper)
`sel.f`	index of selected frequencies for computation (default = NULL: all frequencies)
`sel.tau`	index of selected quantile levels for computation (default = NULL: all quantile levels)

Value

real number of Kullback-Leibler divergence

qper2qcoh — *Quantile Coherence Spectrum (QCOH)*

Description

This function computes quantile coherence spectrum (QCOH) from quantile spectrum and cross-spectrum.

Usage

```
qper2qcoh(qspec, k = 1, kk = 2)
```

Arguments

`qspec`	array of quantile spectrum and cross-spectrum
`k`	index of first series (default = 1)
`kk`	index of second series (default = 2)

Value

matrix of quantile coherence evaluated at Fourier frequencies in (0,0.5)

Examples

```
y1 <- stats::arima.sim(list(order=c(1,0,0), ar=0.5), n=64)
y2 <- stats::arima.sim(list(order=c(1,0,0), ar=-0.5), n=64)
tau <- seq(0.1,0.9,0.05)
n <- length(y1)
ff <- c(0:(n-1))/n
sel.f <- which(ff > 0 & ff < 0.5)
y.qdft <- qdft(cbind(y1,y2),tau)
qacf <- qdft2qacf(y.qdft)
qper.lw <- qspec.lw(qacf,M=5)$spec
qcoh <- qper2qcoh(qper.lw,k=1,kk=2)
qfa.plot(ff[sel.f],tau,Re(qcoh))
```

---

qsmooth.qdft — *Quantile Smoothing of Quantile Discrete Fourier Transform*

Description

This function computes quantile-smoothed version of quantile discrete Fourier transform (QDFT).

Usage

```
qsmooth.qdft(
  y.qdft,
  method = c("gamm", "sp"),
  spar = "GCV",
  n.cores = 1,
  cl = NULL
)
```

Arguments

`y.qdft`	matrix or array of QDFT from `qdft()`
`method`	smoothing method: `"gamm"` for `mgcv::gamm()`, `"sp"` for `stats::smooth.spline()`
`spar`	smoothing parameter in `smooth.spline()` (default = `"GCV"`)
`n.cores`	number of cores for parallel computing (default = 1)
`cl`	pre-existing cluster for repeated parallel computing (default = NULL)

Value

matrix or array of quantile-smoothed QDFT

Examples

```
y1 <- stats::arima.sim(list(order=c(1,0,0), ar=0.5), n=64)
y2 <- stats::arima.sim(list(order=c(1,0,0), ar=-0.5), n=64)
tau <- seq(0.1,0.9,0.05)
n <- length(y1)
ff <- c(0:(n-1))/n
sel.f <- which(ff > 0 & ff < 0.5)
y.qdft <- qdft(cbind(y1,y2),tau)
y.qdft <- qsmooth.qdft(y.qdft,method="sp",spar=0.9)
qacf <- qdft2qacf(y.qdft)
qper.qslw <- qspec.lw(qacf,M=5)$spec
qfa.plot(ff[sel.f],tau,Re(qper.qslw[1,1,sel.f,]))
```

---

qsmooth.qper — *Quantile Smoothing of Quantile Periodogram or Spectral Estimate*

Description

This function computes quantile-smoothed version of quantile periodogram/cross-periodogram (QPER) or other quantile spectral estimate.

Usage

```
qsmooth.qper(
  qper,
  method = c("gamm", "sp"),
  spar = "GCV",
  n.cores = 1,
  cl = NULL
)
```

Arguments

`qper`	matrix or array of quantile periodogram/cross-periodogram or spectral estimate
`method`	smoothing method: `"gamm"` for `mgcv::gamm()`, `"sp"` for `stats::smooth.spline()`
`spar`	smoothing parameter in `smooth.spline()` (default = `"GCV"`)
`n.cores`	number of cores for parallel computing (default = 1)
`cl`	pre-existing cluster for repeated parallel computing (default = `NULL`)

Value

matrix or array of quantile-smoothed quantile spectral estimate

Examples

```
y1 <- stats::arima.sim(list(order=c(1,0,0), ar=0.5), n=64)
y2 <- stats::arima.sim(list(order=c(1,0,0), ar=-0.5), n=64)
tau <- seq(0.1,0.9,0.05)
n <- length(y1)
ff <- c(0:(n-1))/n
sel.f <- which(ff > 0 & ff < 0.5)
```

```
y.qdft <- qdft(cbind(y1,y2),tau)
qacf <- qdft2qacf(y.qdft)
qper.lw <- qspec.lw(qacf,M=5)$spec
qfa.plot(ff[sel.f],tau,Re(qper.lw[1,1,sel.f,]))
qper.lwqs <- qsmooth.qper(qper.lw,method="sp",spar=0.9)
qfa.plot(ff[sel.f],tau,Re(qper.lwqs[1,1,sel.f,]))
```

---

qspec.lw *Lag-Window Estimator of Quantile Spectrum and Cross-Spectrum (QSPEC)*

Description

This function computes lag-window (LW) estimate of quantile spectrum/cross-spectrum (QSPEC) from QACF.

Usage

```
qspec.lw(qacf, M = NULL)
```

Arguments

qacf	matrix or array of QACF from `qdft2qacf()`
M	bandwidth parameter of lag window (default = `NULL`: quantile periodogram)

Value

A list with the following elements:

spec	matrix or array of LW estimate
lw	lag-window sequence

Examples

```
# single time series
y1 <- stats::arima.sim(list(order=c(1,0,0), ar=0.5), n=64)
tau <- seq(0.1,0.9,0.05)
y.qdft <- qdft(y1,tau)
qacf <- qdft2qacf(y.qdft)
qper.lw <- qspec.lw(qacf,M=5)$spec
n <- length(y1)
ff <- c(0:(n-1))/n
sel.f <- which(ff > 0 & ff < 0.5)
qfa.plot(ff[sel.f],tau,Re(qper.lw[sel.f,]))
# multiple time series
y2 <- stats::arima.sim(list(order=c(1,0,0), ar=-0.5), n=64)
y.qdft <- qdft(cbind(y1,y2),tau)
qacf <- qdft2qacf(y.qdft)
qper.lw <- qspec.lw(qacf,M=5)$spec
qfa.plot(ff[sel.f],tau,Re(qper.lw[1,2,sel.f,]))
```

`sqdft` *Spline Quantile Discrete Fourier Transform (SQDFT)*

Description

This function computes spline quantile discrete Fourier transform (SQDFT) for univariate or multivariate time series.

Usage

```
sqdft(y, tau, c0 = 0.02, d = 4, weighted = FALSE, n.cores = 1, cl = NULL)
```

Arguments

`y`	vector or matrix of time series (if matrix, `nrow(y)` = length of time series)
`tau`	sequence of quantile levels in (0,1)
`c0`	penalty parameter
`d`	subsampling rate of quantile levels (default = 1)
`weighted`	if `TRUE`, penalty function is weighted (default = `FALSE`)
`n.cores`	number of cores for parallel computing (default = 1)
`cl`	pre-existing cluster for repeated parallel computing (default = `NULL`)

Value

matrix or array of the spline quantile discrete Fourier transform of `y`

Examples

```
y <- stats::arima.sim(list(order=c(1,0,0), ar=0.5), n=64)
tau <- seq(0.1,0.9,0.05)
y.sqdft <- sqdft(y,tau,c0=0.02,d=4)
n <- length(y)
ff <- c(0:(n-1))/n
sel.f <- which(ff > 0 & ff < 0.5)
qacf <- qdft2qacf(y.sqdft)
qper.sqrlw <- qspec.lw(qacf,M=5)$spec
qfa.plot(ff[sel.f],tau,Re(qper.sqrlw[sel.f,]))
```

`sqr.fit` *Spline Quantile Regression (SQR)*

Description

This function computes the spline quantile regression (SQR) solution given response vector and design matrix. It uses the code `rqfnb.f` in the "quantreg" package with the permission of Dr. R. Koenker.

Usage

```
sqr.fit(y, X, tau, c0, d = 1, weighted = FALSE, mthreads = FALSE)
```

Arguments

`y`	response vector
`X`	design matrix (`nrow(X) = length(y)`)
`tau`	sequence of quantile levels in (0,1)
`c0`	penalty parameter
`d`	subsampling rate of quantile levels (default = 1)
`weighted`	if `TRUE`, penalty function is weighted (default = `FALSE`)
`mthreads`	if `TRUE`, multithread BLAS is enabled when available (default = `FALSE`, required for parallel computing)

Value

A list with the following elements:

`coefficients`	matrix of regression coefficients
`nit`	number of iterations

`tqr.fit` *Trigonometric Quantile Regression (TQR)*

Description

This function computes trigonometric quantile regression (TQR) for univariate time series at a single frequency.

Usage

```
tqr.fit(y, f0, tau, prepared = TRUE)
```

Arguments

`y`	vector of time series
`f0`	frequency in [0,1)
`tau`	sequence of quantile levels in (0,1)
`prepared`	if `TRUE`, intercept is removed and coef of cosine is doubled when `f0 = 0.5`

Value

object of `rq()` (coefficients in `$coef`)

Examples

```
y <- stats::arima.sim(list(order=c(1,0,0), ar=0.5), n=64)
tau <- seq(0.1,0.9,0.05)
fit <- tqr.fit(y,f0=0.1,tau=tau)
plot(tau,fit$coef[1,],type='o',pch=0.75,xlab='QUANTILE LEVEL',ylab='TQR COEF')
```

tsqr.fit *Trigonometric Spline Quantile Regression (TSQR)*

Description

This function computes trigonometric spline quantile regression (TSQR) for univariate time series at a single frequency.

Usage

```
tsqr.fit(y, f0, tau, c0, d = 1, weighted = FALSE, prepared = TRUE)
```

Arguments

y	vector of time series
f0	frequency in [0,1)
tau	sequence of quantile levels in (0,1)
c0	penalty parameter
d	subsampling rate of quantile levels (default = 1)
weighted	if TRUE, penalty function is weighted (default = FALSE)
prepared	if TRUE, intercept is removed and coef of cosine is doubled when f0 = 0.5

Value

object of sqr.fit() (coefficients in $coef)

Examples

```
y <- stats::arima.sim(list(order=c(1,0,0), ar=0.5), n=64)
tau <- seq(0.1,0.9,0.05)
fit <- tqr.fit(y,f0=0.1,tau=tau)
fit.sqr <- tsqr.fit(y,f0=0.1,tau=tau,c0=0.02,d=4)
plot(tau,fit$coef[1,],type='p',xlab='QUANTILE LEVEL',ylab='TQR COEF')
lines(tau,fit.sqr$coef[1,],type='l')
```

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