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Author Vincent Goulet [cre, aut] (ORCID: <https://orcid.org/0000-0002-9315-5719>), Sébastien Auclair

[ctb], Jérémy Déraspe [ctb], Christophe Dutang [aut] (ORCID:
<https://orcid.org/0000-0001-6732-1501>), Walter Garcia-Fontes
[ctb], Nicholas Langevin [ctb], Xavier Milhaud [ctb], Tommy
Ouellet [ctb], Alexandre Parent [ctb], Mathieu Pigeon [aut],
Louis-Philippe Pouliot [ctb], Jeffrey A. Ryan [aut] (Package
API), Robert Gentleman [aut] (Parts of the R to C interface),
Ross Ihaka [aut] (Parts of the R to C interface), R Core Team
[aut] (Parts of the R to C interface), R Foundation [aut]
(Parts of the R to C interface)

Maintainer Vincent Goulet <vincent.goulet@act.ulaval.ca>

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`actuar-package` *Actuarial Functions and Heavy Tailed Distributions*

Description

Functions and data sets for actuarial science: modeling of loss distributions; risk theory and ruin theory; simulation of compound models, discrete mixtures and compound hierarchical models; credibility theory. Support for many additional probability distributions to model insurance loss size and frequency: 23 continuous heavy tailed distributions; the Poisson-inverse Gaussian discrete distribution; zero-truncated and zero-modified extensions of the standard discrete distributions. Support for phase-type distributions commonly used to compute ruin probabilities. Main reference: <doi:10.18637/jss.v025.i07>. Implementation of the Feller-Pareto family of distributions: <doi:10.18637/jss.v103.i06>.

Details

actuar provides additional actuarial science functionality and support for heavy tailed distributions to the R statistical system.

The current feature set of the package can be split into five main categories.

1. Additional probability distributions: 23 continuous heavy tailed distributions from the Feller-Pareto and Transformed Gamma families, the loggamma, the Gumbel, the inverse Gaussian and the generalized beta; phase-type distributions; the Poisson-inverse Gaussian discrete distribution; zero-truncated and zero-modified extensions of the standard discrete distributions; computation of raw moments, limited moments and the moment generating function (when it exists) of continuous distributions. See the "distributions" package vignette for details.
2. Loss distributions modeling: extensive support of grouped data; functions to compute empirical raw and limited moments; support for minimum distance estimation using three different measures; treatment of coverage modifications (deductibles, limits, inflation, coinsurance). See the "modeling" and "coverage" package vignettes for details.
3. Risk and ruin theory: discretization of the claim amount distribution; calculation of the aggregate claim amount distribution; calculation of the adjustment coefficient; calculation of the probability of ruin, including using phase-type distributions. See the "risk" package vignette for details.
4. Simulation of discrete mixtures, compound models (including the compound Poisson), and compound hierarchical models. See the "simulation" package vignette for details.
5. Credibility theory: function `cm` fits hierarchical (including Bühlmann, Bühlmann-Straub), regression and linear Bayes credibility models. See the "credibility" package vignette for details.

Author(s)

Christophe Dutang, Vincent Goulet, Mathieu Pigeon and many other contributors; use `packageDescription("actuar")` for the complete list.

Maintainer: Vincent Goulet.

References

Dutang, C., Goulet, V. and Pigeon, M. (2008). actuar: An R Package for Actuarial Science. *Journal of Statistical Software*, **25**(7), 1–37. doi:10.18637/jss.v025.i07.

Dutang, C., Goulet, V., Langevin, N. (2022). Feller-Pareto and Related Distributions: Numerical Implementation and Actuarial Applications. *Journal of Statistical Software*, **103**(6), 1–22. doi:10.18637/jss.v103.i06.

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

See Also

For probability distributions support functions, use as starting points: `FellerPareto`, `TransformedGamma`, `Loggamma`, `Gumbel`, `InverseGaussian`, `PhaseType`, `PoissonInverseGaussian` and, e.g., `ZeroTruncatedPoisson`, `ZeroModifiedPoisson`.

For loss modeling support functions: `grouped.data`, `ogive`, `emm`, `elev`, `mde`, `coverage`.

For risk and ruin theory functions: `discretize`, `aggregateDist`, `adjCoef`, `ruin`.

For credibility theory functions and datasets: `cm`, `hachemeister`.

Examples

```
## The package comes with extensive demonstration scripts;
## use the following command to obtain the list.
## Not run: demo(package = "actuar")
```

---

adjCoef *Adjustment Coefficient*

Description

Compute the adjustment coefficient in ruin theory, or return a function to compute the adjustment coefficient for various reinsurance retentions.

Usage

```
adjCoef(mgf.claim, mgf.wait = mgfexp, premium.rate, upper.bound,
        h, reinsurance = c("none", "proportional", "excess-of-loss"),
        from, to, n = 101)

## S3 method for class 'adjCoef'
plot(x, xlab = "x", ylab = "R(x)",
     main = "Adjustment Coefficient", sub = comment(x),
     type = "l", add = FALSE, ...)
```

Arguments

mgf.claim	an expression written as a function of x or of x and y, or alternatively the name of a function, giving the moment generating function (mgf) of the claim severity distribution.
mgf.wait	an expression written as a function of x, or alternatively the name of a function, giving the mgf of the claims interarrival time distribution. Defaults to an exponential distribution with mean 1.
premium.rate	if reinsurance = "none", a numeric value of the premium rate; otherwise, an expression written as a function of y, or alternatively the name of a function, giving the premium rate function.
upper.bound	numeric; an upper bound for the coefficient, usually the upper bound of the support of the claim severity mgf.
h	an expression written as a function of x or of x and y, or alternatively the name of a function, giving function h in the Lundberg equation (see below); ignored if mgf.claim is provided.
reinsurance	the type of reinsurance for the portfolio; can be abbreviated.
from, to	the range over which the adjustment coefficient will be calculated.
n	integer; the number of values at which to evaluate the adjustment coefficient.
x	an object of class "adjCoef".
xlab, ylab	label of the x and y axes, respectively.
main	main title.
sub	subtitle, defaulting to the type of reinsurance.
type	1-character string giving the type of plot desired; see plot for details.
add	logical; if TRUE add to already existing plot.
...	further graphical parameters accepted by plot or lines.

Details

In the typical case reinsurance = "none", the coefficient of determination is the smallest (strictly) positive root of the Lundberg equation

$$h(x) = E[e^{xB-xcW}] = 1$$

on $[0, m)$, where m = upper.bound, B is the claim severity random variable, W is the claim interarrival (or wait) time random variable and c = premium.rate. The premium rate must satisfy the positive safety loading constraint $E[B - cW] < 0$.

With reinsurance = "proportional", the equation becomes

$$h(x, y) = E[e^{xyB-xc(y)W}] = 1,$$

where y is the retention rate and $c(y)$ is the premium rate function.

With reinsurance = "excess-of-loss", the equation becomes

$$h(x, y) = E[e^{x \min(B,y)-xc(y)W}] = 1,$$

where y is the retention limit and $c(y)$ is the premium rate function.

One can use argument h as an alternative way to provide function $h(x)$ or $h(x, y)$. This is necessary in cases where random variables B and W are not independent.

The root of $h(x) = 1$ is found by minimizing $(h(x) - 1)^2$.

Value

If `reinsurance = "none"`, a numeric vector of length one. Otherwise, a function of class `"adjCoef"` inheriting from the `"function"` class.

Author(s)

Christophe Dutang, Vincent Goulet <vincent.goulet@act.ulaval.ca>

References

Bowers, N. J. J., Gerber, H. U., Hickman, J., Jones, D. and Nesbitt, C. (1986), *Actuarial Mathematics*, Society of Actuaries.

Centeno, M. d. L. (2002), Measuring the effects of reinsurance by the adjustment coefficient in the Sparre-Anderson model, *Insurance: Mathematics and Economics* **30**, 37–49.

Gerber, H. U. (1979), *An Introduction to Mathematical Risk Theory*, Huebner Foundation.

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2008), *Loss Models, From Data to Decisions, Third Edition*, Wiley.

Examples

```
## Basic example: no reinsurance, exponential claim severity and wait
## times, premium rate computed with expected value principle and
## safety loading of 20%.
adjCoef(mgfexp, premium = 1.2, upper = 1)

## Same thing, giving function h.
h <- function(x) 1/((1 - x) * (1 + 1.2 * x))
adjCoef(h = h, upper = 1)

## Example 11.4 of Klugman et al. (2008)
mgfx <- function(x) 0.6 * exp(x) + 0.4 * exp(2 * x)
adjCoef(mgfx(x), mgfexp(x, 4), prem = 7, upper = 0.3182)

## Proportional reinsurance, same assumptions as above, reinsurer's
## safety loading of 30%.
mgfx <- function(x, y) mgfexp(x * y)
p <- function(x) 1.3 * x - 0.1
h <- function(x, a) 1/((1 - a * x) * (1 + x * p(a)))
R1 <- adjCoef(mgfx, premium = p, upper = 1, reins = "proportional",
              from = 0, to = 1, n = 11)
R2 <- adjCoef(h = h, upper = 1, reins = "p",
             from = 0, to = 1, n = 101)
R1(seq(0, 1, length = 10)) # evaluation for various retention rates
R2(seq(0, 1, length = 10)) # same
```

```
plot(R1)          # graphical representation
plot(R2, col = "green", add = TRUE) # smoother function

## Excess-of-loss reinsurance
p <- function(x) 1.3 * levgamma(x, 2, 2) - 0.1
mgfx <- function(x, l)
    mgfgamma(x, 2, 2) * pgamma(l, 2, 2 - x) +
    exp(x * l) * pgamma(l, 2, 2, lower = FALSE)
h <- function(x, l) mgfx(x, l) * mgfexp(-x * p(l))
R1 <- adjCoef(mgfx, upper = 1, premium = p, reins = "excess-of-loss",
              from = 0, to = 10, n = 11)
R2 <- adjCoef(h = h, upper = 1, reins = "e",
              from = 0, to = 10, n = 101)
plot(R1)
plot(R2, col = "green", add = TRUE)
```

---

aggregateDist *Aggregate Claim Amount Distribution*

Description

Compute the aggregate claim amount cumulative distribution function of a portfolio over a period using one of five methods.

Usage

```
aggregateDist(method = c("recursive", "convolution", "normal",
                         "npower", "simulation"),
              model.freq = NULL, model.sev = NULL, p0 = NULL,
              x.scale = 1, convolve = 0, moments, nb.simul, ...,
              tol = 1e-06, maxit = 500, echo = FALSE)

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

## S3 method for class 'aggregateDist'
plot(x, xlim, ylab = expression(F[S](x)),
     main = "Aggregate Claim Amount Distribution",
     sub = comment(x), ...)

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

## S3 method for class 'aggregateDist'
mean(x, ...)

## S3 method for class 'aggregateDist'
diff(x, ...)
```

Arguments

method	method to be used
model.freq	for "recursive" method: a character string giving the name of a distribution in the $(a, b, 0)$ or $(a, b, 1)$ families of distributions. For "convolution" method: a vector of claim number probabilities. For "simulation" method: a frequency simulation model (see rcomphierarc for details) or NULL. Ignored with normal and npower methods.
model.sev	for "recursive" and "convolution" methods: a vector of claim amount probabilities. For "simulation" method: a severity simulation model (see rcomphierarc for details) or NULL. Ignored with normal and npower methods.
p0	arbitrary probability at zero for the frequency distribution. Creates a zero-modified or zero-truncated distribution if not NULL. Used only with "recursive" method.
x.scale	value of an amount of 1 in the severity model (monetary unit). Used only with "recursive" and "convolution" methods.
convolve	number of times to convolve the resulting distribution with itself. Used only with "recursive" method.
moments	vector of the true moments of the aggregate claim amount distribution; required only by the "normal" or "npower" methods.
nb.simul	number of simulations for the "simulation" method.
...	parameters of the frequency distribution for the "recursive" method; further arguments to be passed to or from other methods otherwise.
tol	the resulting cumulative distribution in the "recursive" method will get less than tol away from 1.
maxit	maximum number of recursions in the "recursive" method.
echo	logical; echo the recursions to screen in the "recursive" method.
x, object	an object of class "aggregateDist".
xlim	numeric of length 2; the x limits of the plot.
ylab	label of the y axis.
main	main title.
sub	subtitle, defaulting to the calculation method.

Details

aggregateDist returns a function to compute the cumulative distribution function (cdf) of the aggregate claim amount distribution in any point.

The "recursive" method computes the cdf using the Panjer algorithm; the "convolution" method using convolutions; the "normal" method using a normal approximation; the "npower" method using the Normal Power 2 approximation; the "simulation" method using simulations. More details follow.

Value

A function of class "aggregateDist", inheriting from the "function" class when using normal and Normal Power approximations and additionally inheriting from the "ecdf" and "stepfun" classes when other methods are used.

There are methods available to summarize (summary), represent (print), plot (plot), compute quantiles (quantile) and compute the mean (mean) of "aggregateDist" objects.

For the diff method: a numeric vector of probabilities corresponding to the probability mass function evaluated at the knots of the distribution.

Recursive method

The frequency distribution must be a member of the $(a, b, 0)$ or $(a, b, 1)$ families of discrete distributions.

To use a distribution from the $(a, b, 0)$ family, model.freq must be one of "binomial", "geometric", "negative binomial" or "poisson", and p0 must be NULL.

To use a zero-truncated distribution from the $(a, b, 1)$ family, model.freq may be one of the strings above together with p0 = 0. As a shortcut, model.freq may also be one of "zero-truncated binomial", "zero-truncated geometric", "zero-truncated negative binomial", "zero-truncated poisson" or "logarithmic", and p0 is then ignored (with a warning if non NULL).

(Note: since the logarithmic distribution is always zero-truncated. model.freq = "logarithmic" may be used with either p0 = NULL or p0 = 0.)

To use a zero-modified distribution from the $(a, b, 1)$ family, model.freq may be one of standard frequency distributions mentioned above with p0 set to some probability that the distribution takes the value 0. It is equivalent, but more explicit, to set model.freq to one of "zero-modified binomial", "zero-modified geometric", "zero-modified negative binomial", "zero-modified poisson" or "zero-modified logarithmic".

The parameters of the frequency distribution must be specified using names identical to the arguments of the appropriate function dbinom, dgeom, dnbinom, dpois or dlogarithmic. In the latter case, do take note that the parametrization of dlogarithmic is different from Appendix B of Klugman et al. (2012).

If the length of p0 is greater than one, only the first element is used, with a warning.

model.sev is a vector of the (discretized) claim amount distribution X; the first element **must** be $f_X(0) = \Pr[X = 0]$.

The recursion will fail to start if the expected number of claims is too large. One may divide the appropriate parameter of the frequency distribution by 2^n and convolve the resulting distribution $n =$ convolve times.

Failure to obtain a cumulative distribution function less than tol away from 1 within maxit iterations is often due to too coarse a discretization of the severity distribution.

Convolution method

The cumulative distribution function (cdf) $F_S(x)$ of the aggregate claim amount of a portfolio in the collective risk model is

$$F_S(x) = \sum_{n=0}^{\infty} F_X^{*n}(x) p_n,$$

for $x = 0, 1, \ldots$; $p_n = \Pr[N = n]$ is the frequency probability mass function and $F_X^{*n}(x)$ is the cdf of the nth convolution of the (discrete) claim amount random variable.

`model.freq` is vector p_n of the number of claims probabilities; the first element **must** be $\Pr[N = 0]$.

`model.sev` is vector $f_X(x)$ of the (discretized) claim amount distribution; the first element **must** be $f_X(0)$.

Normal and Normal Power 2 methods

The Normal approximation of a cumulative distribution function (cdf) $F(x)$ with mean μ and standard deviation σ is

$$F(x) \approx \Phi\left(\frac{x-\mu}{\sigma}\right).$$

The Normal Power 2 approximation of a cumulative distribution function (cdf) $F(x)$ with mean μ, standard deviation σ and skewness γ is

$$F(x) \approx \Phi\left(-\frac{3}{\gamma} + \sqrt{\frac{9}{\gamma^2} + 1 + \frac{6}{\gamma}\frac{x-\mu}{\sigma}}\right).$$

This formula is valid only for the right-hand tail of the distribution and skewness should not exceed unity.

Simulation method

This methods returns the empirical distribution function of a sample of size `nb.simul` of the aggregate claim amount distribution specified by `model.freq` and `model.sev`. `rcomphierarc` is used for the simulation of claim amounts, hence both the frequency and severity models can be mixtures of distributions.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca> and Louis-Philippe Pouliot

References

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

Daykin, C.D., Pentikäinen, T. and Pesonen, M. (1994), *Practical Risk Theory for Actuaries*, Chapman & Hall.

See Also

`discretize` to discretize a severity distribution; `mean.aggregateDist` to compute the mean of the distribution; `quantile.aggregateDist` to compute the quantiles or the Value-at-Risk; `CTE.aggregateDist` to compute the Conditional Tail Expectation (or Tail Value-at-Risk); `rcomphierarc`.

Examples

```
## Convolution method (example 9.5 of Klugman et al. (2012))
fx <- c(0, 0.15, 0.2, 0.25, 0.125, 0.075,
        0.05, 0.05, 0.05, 0.025, 0.025)
pn <- c(0.05, 0.1, 0.15, 0.2, 0.25, 0.15, 0.06, 0.03, 0.01)
Fs <- aggregateDist("convolution", model.freq = pn,
                    model.sev = fx, x.scale = 25)
summary(Fs)
c(Fs(0), diff(Fs(25 * 0:21))) # probability mass function
plot(Fs)

## Recursive method (example 9.10 of Klugman et al. (2012))
fx <- c(0, crossprod(c(2, 1)/3,
                     matrix(c(0.6, 0.7, 0.4, 0, 0, 0.3), 2, 3)))
Fs <- aggregateDist("recursive", model.freq = "poisson",
                    model.sev = fx, lambda = 3)
plot(Fs)
Fs(knots(Fs))        # cdf evaluated at its knots
diff(Fs)                     # probability mass function

## Recursive method (high frequency)
fx <- c(0, 0.15, 0.2, 0.25, 0.125, 0.075,
        0.05, 0.05, 0.05, 0.025, 0.025)
## Not run: Fs <- aggregateDist("recursive", model.freq = "poisson",
                    model.sev = fx, lambda = 1000)
## End(Not run)
Fs <- aggregateDist("recursive", model.freq = "poisson",
                    model.sev = fx, lambda = 250, convolve = 2, maxit = 1500)
plot(Fs)

## Recursive method (zero-modified distribution; example 9.11 of
## Klugman et al. (2012))
Fn <- aggregateDist("recursive", model.freq = "binomial",
                    model.sev = c(0.3, 0.5, 0.2), x.scale = 50,
                    p0 = 0.4, size = 3, prob = 0.3)
diff(Fn)

## Equivalent but more explicit call
aggregateDist("recursive", model.freq = "zero-modified binomial",
              model.sev = c(0.3, 0.5, 0.2), x.scale = 50,
              p0 = 0.4, size = 3, prob = 0.3)

## Recursive method (zero-truncated distribution). Using 'fx' above
## would mean that both Pr[N = 0] = 0 and Pr[X = 0] = 0, therefore
## Pr[S = 0] = 0 and recursions would not start.
fx <- discretize(pexp(x, 1), from = 0, to = 100, method = "upper")
fx[1L] # non zero
aggregateDist("recursive", model.freq = "zero-truncated poisson",
              model.sev = fx, lambda = 3, x.scale = 25, echo=TRUE)

## Normal Power approximation
Fs <- aggregateDist("npower", moments = c(200, 200, 0.5))
```

```
Fs(210)

## Simulation method
model.freq <- expression(data = rpois(3))
model.sev <- expression(data = rgamma(100, 2))
Fs <- aggregateDist("simulation", nb.simul = 1000,
                    model.freq, model.sev)
mean(Fs)
plot(Fs)

## Evaluation of ruin probabilities using Beekman's formula with
## Exponential(1) claim severity, Poisson(1) frequency and premium rate
## c = 1.2.
fx <- discretize(pexp(x, 1), from = 0, to = 100, method = "lower")
phi0 <- 0.2/1.2
Fs <- aggregateDist(method = "recursive", model.freq = "geometric",
                    model.sev = fx, prob = phi0)
1 - Fs(400)   # approximate ruin probability
u <- 0:100
plot(u, 1 - Fs(u), type = "l", main = "Ruin probability")
```

`betaint` *The "Beta Integral"*

Description

The "beta integral" is just a multiple of the non regularized incomplete beta function. This function provides an R interface to the C level routine. It is not exported by the package.

Usage

```
betaint(x, a, b)
```

Arguments

x	vector of quantiles.
a, b	parameters. See Details for admissible values.

Details

Function `betaint` computes the "beta integral"

$$B(a, b; x) = \Gamma(a + b) \int_0^x t^{a-1}(1 - t)^{b-1} dt$$

for $a > 0, b \neq -1, -2, \ldots$ and $0 < x < 1$. (Here $\Gamma(\alpha)$ is the function implemented by R's `gamma()` and defined in its help.) When $b > 0$,

$$B(a, b; x) = \Gamma(a)\Gamma(b) I_x(a, b),$$

where $I_x(a,b)$ is `pbeta(x, a, b)`. When $b < 0$, $b \neq -1, -2, \ldots$, and $a > 1 + [-b]$,

$$\begin{aligned} B(a,b;x) &= -\Gamma(a+b)\left[\frac{x^{a-1}(1-x)^b}{b} + \frac{(a-1)x^{a-2}(1-x)^{b+1}}{b(b+1)}\right. \\ &\quad \left. + \cdots + \frac{(a-1)\cdots(a-r)x^{a-r-1}(1-x)^{b+r}}{b(b+1)\cdots(b+r)}\right] \\ &\quad + \frac{(a-1)\cdots(a-r-1)}{b(b+1)\cdots(b+r)}\Gamma(a-r-1) \\ &\quad \times \Gamma(b+r+1) I_x(a-r-1, b+r+1), \end{aligned}$$

where $r = [-b]$.

This function is used (at the C level) to compute the limited expected value for distributions of the transformed beta family; see, for example, `levtrbeta`.

Value

The value of the integral.

Invalid arguments will result in return value `NaN`, with a warning.

Note

The need for this function in the package is well explained in the introduction of Appendix A of Klugman et al. (2012). See also chapter 6 and 15 of Abramowitz and Stegun (1972) for definitions and relations to the hypergeometric series.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>

References

Abramowitz, M. and Stegun, I. A. (1972), *Handbook of Mathematical Functions*, Dover.

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

Examples

```
x <- 0.3
a <- 7

## case with b > 0
b <- 2
actuar:::betaint(x, a, b)
gamma(a) * gamma(b) * pbeta(x, a, b)    # same

## case with b < 0
b <- -2.2
r <- floor(-b)        # r = 2
actuar:::betaint(x, a, b)
```

```
## "manual" calculation
s <- (x^(a-1) * (1-x)^b)/b +
    ((a-1) * x^(a-2) * (1-x)^(b+1))/(b * (b+1)) +
    ((a-1) * (a-2) * x^(a-3) * (1-x)^(b+2))/(b * (b+1) * (b+2))
-gamma(a+b) * s +
    (a-1)*(a-2)*(a-3) * gamma(a-r-1)/(b*(b+1)*(b+2)) *
    gamma(b+r+1)*pbeta(x, a-r-1, b+r+1)
```

BetaMoments *Raw and Limited Moments of the Beta Distribution*

Description

Raw moments and limited moments for the (central) Beta distribution with parameters shape1 and shape2.

Usage

```
mbeta(order, shape1, shape2)
levbeta(limit, shape1, shape2, order = 1)
```

Arguments

order	order of the moment.
limit	limit of the loss variable.
shape1, shape2	positive parameters of the Beta distribution.

Details

The kth raw moment of the random variable X is $E[X^k]$ and the kth limited moment at some limit d is $E[\min(X, d)^k]$, $k > -\alpha$.

The noncentral beta distribution is not supported.

Value

mbeta gives the kth raw moment and levbeta gives the kth moment of the limited loss variable.

Invalid arguments will result in return value NaN, with a warning.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca> and Mathieu Pigeon

References

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

See Also

Beta for details on the beta distribution and functions [dpqr]beta.

Examples

```
mbeta(2, 3, 4) - mbeta(1, 3, 4)^2
levbeta(10, 3, 4, order = 2)
```

Burr *The Burr Distribution*

Description

Density function, distribution function, quantile function, random generation, raw moments and limited moments for the Burr distribution with parameters shape1, shape2 and scale.

Usage

```
dburr(x, shape1, shape2, rate = 1, scale = 1/rate,
      log = FALSE)
pburr(q, shape1, shape2, rate = 1, scale = 1/rate,
      lower.tail = TRUE, log.p = FALSE)
qburr(p, shape1, shape2, rate = 1, scale = 1/rate,
      lower.tail = TRUE, log.p = FALSE)
rburr(n, shape1, shape2, rate = 1, scale = 1/rate)
mburr(order, shape1, shape2, rate = 1, scale = 1/rate)
levburr(limit, shape1, shape2, rate = 1, scale = 1/rate,
        order = 1)
```

Arguments

x, q	vector of quantiles.
p	vector of probabilities.
n	number of observations. If length(n) > 1, the length is taken to be the number required.
shape1, shape2, scale	parameters. Must be strictly positive.
rate	an alternative way to specify the scale.
log, log.p	logical; if TRUE, probabilities/densities p are returned as $\log(p)$.
lower.tail	logical; if TRUE (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.
order	order of the moment.
limit	limit of the loss variable.

Details

The Burr distribution with parameters `shape1` $= \alpha$, `shape2` $= \gamma$ and `scale` $= \theta$ has density:

$$f(x) = \frac{\alpha\gamma(x/\theta)^\gamma}{x[1+(x/\theta)^\gamma]^{\alpha+1}}$$

for $x > 0$, $\alpha > 0$, $\gamma > 0$ and $\theta > 0$.

The Burr is the distribution of the random variable

$$\theta\left(\frac{X}{1-X}\right)^{1/\gamma},$$

where X has a beta distribution with parameters 1 and α.

The Burr distribution has the following special cases:

- A Loglogistic distribution when `shape1 == 1`;
- A Paralogistic distribution when `shape2 == shape1`;
- A Pareto distribution when `shape2 == 1`.

The kth raw moment of the random variable X is $E[X^k]$, $-\gamma < k < \alpha\gamma$.

The kth limited moment at some limit d is $E[\min(X,d)^k]$, $k > -\gamma$ and $\alpha - k/\gamma$ not a negative integer.

Value

`dburr` gives the density, `pburr` gives the distribution function, `qburr` gives the quantile function, `rburr` generates random deviates, `mburr` gives the kth raw moment, and `levburr` gives the kth moment of the limited loss variable.

Invalid arguments will result in return value `NaN`, with a warning.

Note

`levburr` computes the limited expected value using `betaint`.

Distribution also known as the Burr Type XII or Singh-Maddala distribution. See also Kleiber and Kotz (2003) for alternative names and parametrizations.

The `"distributions"` package vignette provides the interrelations between the continuous size distributions in **actuar** and the complete formulas underlying the above functions.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca> and Mathieu Pigeon

References

Kleiber, C. and Kotz, S. (2003), *Statistical Size Distributions in Economics and Actuarial Sciences*, Wiley.

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

See Also

dpareto4 for an equivalent distribution with a location parameter.

Examples

```
exp(dburr(1, 2, 3, log = TRUE))
p <- (1:10)/10
pburr(qburr(p, 2, 3, 2), 2, 3, 2)

## variance
mburr(2, 2, 3, 1) - mburr(1, 2, 3, 1) ^ 2

## case with shape1 - order/shape2 > 0
levburr(10, 2, 3, 1, order = 2)

## case with shape1 - order/shape2 < 0
levburr(10, 1.5, 0.5, 1, order = 2)
```

ChisqSupp *Moments and Moment Generating Function of the (non-central) Chi-Squared Distribution*

Description

Raw moments, limited moments and moment generating function for the chi-squared (χ^2) distribution with df degrees of freedom and optional non-centrality parameter ncp.

Usage

```
mchisq(order, df, ncp = 0)
levchisq(limit, df, ncp = 0, order = 1)
mgfchisq(t, df, ncp = 0, log= FALSE)
```

Arguments

order	order of the moment.
limit	limit of the loss variable.
df	degrees of freedom (non-negative, but can be non-integer).
ncp	non-centrality parameter (non-negative).
t	numeric vector.
log	logical; if TRUE, the cumulant generating function is returned.

Details

The kth raw moment of the random variable X is $E[X^k]$, the kth limited moment at some limit d is $E[\min(X, d)]$ and the moment generating function is $E[e^{tX}]$.

Only integer moments are supported for the non central Chi-square distribution (ncp > 0).

The limited expected value is supported for the centered Chi-square distribution (ncp = 0).

Value

mchisq gives the kth raw moment, levchisq gives the kth moment of the limited loss variable, and mgfchisq gives the moment generating function in t.

Invalid arguments will result in return value NaN, with a warning.

Author(s)

Christophe Dutang, Vincent Goulet <vincent.goulet@act.ulaval.ca>

References

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

Johnson, N. L. and Kotz, S. (1970), *Continuous Univariate Distributions, Volume 1*, Wiley.

See Also

Chisquare

Examples

```
mchisq(2, 3, 4)
levchisq(10, 3, order = 2)
mgfchisq(0.25, 3, 2)
```

---

cm *Credibility Models*

Description

Fit the following credibility models: Bühlmann, Bühlmann-Straub, hierarchical, regression (Hachemeister) or linear Bayes.

Usage

```
cm(formula, data, ratios, weights, subset,
   regformula = NULL, regdata, adj.intercept = FALSE,
   method = c("Buhlmann-Gisler", "Ohlsson", "iterative"),
   likelihood, ...,
   tol = sqrt(.Machine$double.eps), maxit = 100, echo = FALSE)

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

## S3 method for class 'cm'
predict(object, levels = NULL, newdata, ...)
```

```
## S3 method for class 'cm'
summary(object, levels = NULL, newdata, ...)

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

Arguments

formula	character string "bayes" or an object of class "formula": a symbolic description of the model to be fit. The details of model specification are given below.
data	a matrix or a data frame containing the portfolio structure, the ratios or claim amounts and their associated weights, if any.
ratios	expression indicating the columns of data containing the ratios or claim amounts.
weights	expression indicating the columns of data containing the weights associated with ratios.
subset	an optional logical expression indicating a subset of observations to be used in the modeling process. All observations are included by default.
regformula	an object of class "formula": symbolic description of the regression component (see lm for details). No left hand side is needed in the formula; if present it is ignored. If NULL, no regression is done on the data.
regdata	an optional data frame, list or environment (or object coercible by as.data.frame to a data frame) containing the variables in the regression model.
adj.intercept	if TRUE, the intercept of the regression model is located at the barycenter of the regressor instead of the origin.
method	estimation method for the variance components of the model; see Details.
likelihood	a character string giving the name of the likelihood function in one of the supported linear Bayes cases; see Details.
tol	tolerance level for the stopping criteria for iterative estimation method.
maxit	maximum number of iterations in iterative estimation method.
echo	logical; whether to echo the iterative procedure or not.
x, object	an object of class "cm".
levels	character vector indicating the levels to predict or to include in the summary; if NULL all levels are included.
newdata	data frame containing the variables used to predict credibility regression models.
...	parameters of the prior distribution for cm; additional attributes to attach to the result for the predict and summary methods; further arguments to format for the print.summary method; unused for the print method.

Details

cm is the unified front end for credibility models fitting. The function supports hierarchical models with any number of levels (with Bühlmann and Bühlmann-Straub models as special cases) and the regression model of Hachemeister. Usage of cm is similar to lm for these cases. cm can also fit linear Bayes models, in which case usage is much simplified; see the section on linear Bayes below.

When not "bayes", the formula argument symbolically describes the structure of the portfolio in the form $terms$. Each term is an interaction between risk factors contributing to the total variance of the portfolio data. Terms are separated by + operators and interactions within each term by :. For a portfolio divided first into sectors, then units and finally contracts, formula would be ~ sector + sector:unit + sector:unit:contract, where sector, unit and contract are column names in data. In general, the formula should be of the form ~ a + a:b + a:b:c + a:b:c:d + ...

If argument regformula is not NULL, the regression model of Hachemeister is fit to the data. The response is usually time. By default, the intercept of the model is located at time origin. If argument adj.intercept is TRUE, the intercept is moved to the (collective) barycenter of time, by orthogonalization of the design matrix. Note that the regression coefficients may be difficult to interpret in this case.

Arguments ratios, weights and subset are used like arguments select, select and subset, respectively, of function subset.

Data does not have to be sorted by level. Nodes with no data (complete lines of NA except for the portfolio structure) are allowed, with the restriction mentioned above.

The print methods use the option deparse.cutoff to control the printing of the call to cm.

Value

Function cm computes the structure parameters estimators of the model specified in formula. The value returned is an object of class cm.

An object of class "cm" is a list with at least the following components:

means	a list containing, for each level, the vector of linearly sufficient statistics.
weights	a list containing, for each level, the vector of total weights.
unbiased	a vector containing the unbiased variance components estimators, or NULL.
iterative	a vector containing the iterative variance components estimators, or NULL.
cred	for multi-level hierarchical models: a list containing, the vector of credibility factors for each level. For one-level models: an array or vector of credibility factors.
nodes	a list containing, for each level, the vector of the number of nodes in the level.
classification	the columns of data containing the portfolio classification structure.
ordering	a list containing, for each level, the affiliation of a node to the node of the level above.

Regression fits have in addition the following components:

adj.models	a list containing, for each node, the credibility adjusted regression model as obtained with lm.fit or lm.wfit.
transition	if adj.intercept is TRUE, a transition matrix from the basis of the orthogonal design matrix to the basis of the original design matrix.
terms	the terms object used.

The method of predict for objects of class "cm" computes the credibility premiums for the nodes of every level included in argument levels (all by default). Result is a list the same length as levels or the number of levels in formula, or an atomic vector for one-level models.

Hierarchical models

The credibility premium at one level is a convex combination between the linearly sufficient statistic of a node and the credibility premium of the level above. (For the first level, the complement of credibility is given to the collective premium.) The linearly sufficient statistic of a node is the credibility weighted average of the data of the node, except at the last level, where natural weights are used. The credibility factor of node i is equal to

$$\frac{w_i}{w_i + a/b},$$

where w_i is the weight of the node used in the linearly sufficient statistic, a is the average within node variance and b is the average between node variance.

Regression models

The credibility premium of node i is equal to

$$y' b_i^a,$$

where y is a matrix created from `newdata` and b_i^a is the vector of credibility adjusted regression coefficients of node i. The latter is given by

$$b_i^a = Z_i b_i + (I - Z_I)m,$$

where b_i is the vector of regression coefficients based on data of node i only, m is the vector of collective regression coefficients, Z_i is the credibility matrix and I is the identity matrix. The credibility matrix of node i is equal to

$$A^{-1}(A + s^2 S_i),$$

where S_i is the unscaled regression covariance matrix of the node, s^2 is the average within node variance and A is the within node covariance matrix.

If the intercept is positioned at the barycenter of time, matrices S_i and A (and hence Z_i) are diagonal. This amounts to use Bühlmann-Straub models for each regression coefficient.

Argument `newdata` provides the "future" value of the regressors for prediction purposes. It should be given as specified in `predict.lm`.

Variance components estimation

For hierarchical models, two sets of estimators of the variance components (other than the within node variance) are available: unbiased estimators and iterative estimators.

Unbiased estimators are based on sums of squares of the form

$$B_i = \sum_j w_{ij}(X_{ij} - \bar{X}_i)^2 - (J-1)a$$

and constants of the form

$$c_i = w_i - \sum_j \frac{w_{ij}^2}{w_i},$$

where X_{ij} is the linearly sufficient statistic of level (ij); $\bar{X}_i$ is the weighted average of the latter using weights w_{ij}; $w_i = \sum_j w_{ij}$; J is the effective number of nodes at level (ij); a is the within variance of this level. Weights w_{ij} are the natural weights at the lowest level, the sum of the natural weights the next level and the sum of the credibility factors for all upper levels.

The Bühlmann-Gisler estimators (`method = "Buhlmann-Gisler"`) are given by

$$b = \frac{1}{I} \sum_i \max\left(\frac{B_i}{c_i}, 0\right),$$

that is the average of the per node variance estimators truncated at 0.

The Ohlsson estimators (`method = "Ohlsson"`) are given by

$$b = \frac{\sum_i B_i}{\sum_i c_i},$$

that is the weighted average of the per node variance estimators without any truncation. Note that negative estimates will be truncated to zero for credibility factor calculations.

In the Bühlmann-Straub model, these estimators are equivalent.

Iterative estimators `method = "iterative"` are pseudo-estimators of the form

$$b = \frac{1}{d} \sum_i w_i (X_i - \bar{X})^2,$$

where X_i is the linearly sufficient statistic of one level, $\bar{X}$ is the linearly sufficient statistic of the level above and d is the effective number of nodes at one level minus the effective number of nodes of the level above. The Ohlsson estimators are used as starting values.

For regression models, with the intercept at time origin, only iterative estimators are available. If `method` is different from `"iterative"`, a warning is issued. With the intercept at the barycenter of time, the choice of estimators is the same as in the Bühlmann-Straub model.

Linear Bayes

When `formula` is `"bayes"`, the function computes pure Bayesian premiums for the following combinations of distributions where they are linear credibility premiums:

- $X|\Theta = \theta \sim \text{Poisson}(\theta)$ and $\Theta \sim \text{Gamma}(\alpha, \lambda)$;
- $X|\Theta = \theta \sim \text{Exponential}(\theta)$ and $\Theta \sim \text{Gamma}(\alpha, \lambda)$;
- $X|\Theta = \theta \sim \text{Gamma}(\tau, \theta)$ and $\Theta \sim \text{Gamma}(\alpha, \lambda)$;
- $X|\Theta = \theta \sim \text{Normal}(\theta, \sigma_2^2)$ and $\Theta \sim \text{Normal}(\mu, \sigma_1^2)$;
- $X|\Theta = \theta \sim \text{Bernoulli}(\theta)$ and $\Theta \sim \text{Beta}(a, b)$;
- $X|\Theta = \theta \sim \text{Binomial}(\nu, \theta)$ and $\Theta \sim \text{Beta}(a, b)$;
- $X|\Theta = \theta \sim \text{Geometric}(\theta)$ and $\Theta \sim \text{Beta}(a, b)$.
- $X|\Theta = \theta \sim \text{Negative Binomial}(r, \theta)$ and $\Theta \sim \text{Beta}(a, b)$.

The following combination is also supported: $X|\Theta = \theta \sim$ Single Parameter Pareto(θ) and $\Theta \sim$ Gamma(α, λ). In this case, the Bayesian estimator not of the risk premium, but rather of parameter θ is linear with a "credibility" factor that is not restricted to $(0, 1)$.

Argument `likelihood` identifies the distribution of $X|\Theta = \theta$ as one of `"poisson"`, `"exponential"`, `"gamma"`, `"normal"`, `"bernoulli"`, `"binomial"`, `"geometric"`, `"negative binomial"` or `"pareto"`.

The parameters of the distributions of $X|\Theta = \theta$ (when needed) and Θ are set in `...` using the argument names (and default values) of `dgamma`, `dnorm`, `dbeta`, `dbinom`, `dnbinom` or `dpareto1`, as appropriate. For the Gamma/Gamma case, use `shape.lik` for the shape parameter τ of the Gamma likelihood. For the Normal/Normal case, use `sd.lik` for the standard error σ_2 of the Normal likelihood.

Data for the linear Bayes case may be a matrix or data frame as usual; an atomic vector to fit the model to a single contract; missing or `NULL` to fit the prior model. Arguments `ratios`, `weights` and `subset` are ignored.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>, Xavier Milhaud, Tommy Ouellet, Louis-Philippe Pouliot

References

Bühlmann, H. and Gisler, A. (2005), *A Course in Credibility Theory and its Applications*, Springer.

Belhadj, H., Goulet, V. and Ouellet, T. (2009), On parameter estimation in hierarchical credibility, *Astin Bulletin* **39**.

Goulet, V. (1998), Principles and application of credibility theory, *Journal of Actuarial Practice* **6**, ISSN 1064-6647.

Goovaerts, M. J. and Hoogstad, W. J. (1987), *Credibility Theory*, Surveys of Actuarial Studies, No. 4, Nationale-Nederlanden N.V.

See Also

`subset`, `formula`, `lm`, `predict.lm`.

Examples

```
data(hachemeister)

## Buhlmann-Straub model
fit <- cm(~state, hachemeister,
          ratios = ratio.1:ratio.12, weights = weight.1:weight.12)
fit    # print method
predict(fit)   # credibility premiums
summary(fit)   # more details

## Two-level hierarchical model. Notice that data does not have
## to be sorted by level
X <- data.frame(unit = c("A", "B", "A", "B", "B"), hachemeister)
fit <- cm(~unit + unit:state, X, ratio.1:ratio.12, weight.1:weight.12)
predict(fit)
```

```
predict(fit, levels = "unit") # unit credibility premiums only
summary(fit)
summary(fit, levels = "unit") # unit summaries only

## Regression model with intercept at time origin
fit <- cm(~state, hachemeister,
          regformula = ~time, regdata = data.frame(time = 12:1),
          ratios = ratio.1:ratio.12, weights = weight.1:weight.12)
fit
predict(fit, newdata = data.frame(time = 0))
summary(fit, newdata = data.frame(time = 0))

## Same regression model, with intercept at barycenter of time
fit <- cm(~state, hachemeister, adj.intercept = TRUE,
          regformula = ~time, regdata = data.frame(time = 12:1),
          ratios = ratio.1:ratio.12, weights = weight.1:weight.12)
fit
predict(fit, newdata = data.frame(time = 0))
summary(fit, newdata = data.frame(time = 0))

## Poisson/Gamma pure Bayesian model
fit <- cm("bayes", data = c(5, 3, 0, 1, 1),
          likelihood = "poisson", shape = 3, rate = 3)
fit
predict(fit)
summary(fit)

## Normal/Normal pure Bayesian model
cm("bayes", data = c(5, 3, 0, 1, 1),
   likelihood = "normal", sd.lik = 2,
   mean = 2, sd = 1)
```

---

coverage *Density and Cumulative Distribution Function for Modified Data*

Description

Compute probability density function or cumulative distribution function of the payment per payment or payment per loss random variable under any combination of the following coverage modifications: deductible, limit, coinsurance, inflation.

Usage

```
coverage(pdf, cdf, deductible = 0, franchise = FALSE,
         limit = Inf, coinsurance = 1, inflation = 0,
         per.loss = FALSE)
```

Arguments

pdf, cdf	function object or character string naming a function to compute, respectively, the probability density function and cumulative distribution function of a probability law.
deductible	a unique positive numeric value.
franchise	logical; TRUE for a franchise deductible, FALSE (default) for an ordinary deductible.
limit	a unique positive numeric value larger than deductible.
coinsurance	a unique value between 0 and 1; the proportion of coinsurance.
inflation	a unique value between 0 and 1; the rate of inflation.
per.loss	logical; TRUE for the per loss distribution, FALSE (default) for the per payment distribution.

Details

coverage returns a function to compute the probability density function (pdf) or the cumulative distribution function (cdf) of the distribution of losses under coverage modifications. The pdf and cdf of unmodified losses are pdf and cdf, respectively.

If pdf is specified, the pdf is returned; if pdf is missing or NULL, the cdf is returned. Note that cdf is needed if there is a deductible or a limit.

Value

An object of mode "function" with the same arguments as pdf or cdf, except "lower.tail", "log.p" and "log", which are not supported.

Note

Setting arguments of the function returned by coverage using formals may very well not work as expected.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca> and Mathieu Pigeon

References

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

See Also

vignette("coverage") for the exact definitions of the per payment and per loss random variables under an ordinary or franchise deductible.

Examples

```
## Default case: pdf of the per payment random variable with
## an ordinary deductible
coverage(dgamma, pgamma, deductible = 1)

## Add a limit
f <- coverage(dgamma, pgamma, deductible = 1, limit = 7)
f <- coverage("dgamma", "pgamma", deductible = 1, limit = 7) # same
f(0, shape = 3, rate = 1)
f(2, shape = 3, rate = 1)
f(6, shape = 3, rate = 1)
f(8, shape = 3, rate = 1)
curve(dgamma(x, 3, 1), xlim = c(0, 10), ylim = c(0, 0.3))    # original
curve(f(x, 3, 1), xlim = c(0.01, 5.99), col = 4, add = TRUE) # modified
points(6, f(6, 3, 1), pch = 21, bg = 4)

## Cumulative distribution function
F <- coverage(cdf = pgamma, deductible = 1, limit = 7)
F(0, shape = 3, rate = 1)
F(2, shape = 3, rate = 1)
F(6, shape = 3, rate = 1)
F(8, shape = 3, rate = 1)
curve(pgamma(x, 3, 1), xlim = c(0, 10), ylim = c(0, 1))    # original
curve(F(x, 3, 1), xlim = c(0, 5.99), col = 4, add = TRUE)  # modified
curve(F(x, 3, 1), xlim = c(6, 10), col = 4, add = TRUE)    # modified

## With no deductible, all distributions below are identical
coverage(dweibull, pweibull, limit = 5)
coverage(dweibull, pweibull, per.loss = TRUE, limit = 5)
coverage(dweibull, pweibull, franchise = TRUE, limit = 5)
coverage(dweibull, pweibull, per.loss = TRUE, franchise = TRUE,
         limit = 5)

## Coinsurance alone; only case that does not require the cdf
coverage(dgamma, coinsurance = 0.8)
```

CTE *Conditional Tail Expectation*

Description

Conditional Tail Expectation, also called Tail Value-at-Risk.

TVaR is an alias for CTE.

Usage

```
CTE(x, ...)

## S3 method for class 'aggregateDist'
```

```
CTE(x, conf.level = c(0.9, 0.95, 0.99),
         names = TRUE, ...)

TVaR(x, ...)
```

Arguments

x	an R object.
conf.level	numeric vector of probabilities with values in $[0, 1)$.
names	logical; if true, the result has a names attribute. Set to FALSE for speedup with many probs.
...	further arguments passed to or from other methods.

Details

The Conditional Tail Expectation (or Tail Value-at-Risk) measures the average of losses above the Value at Risk for some given confidence level, that is $E[X|X > \mathrm{VaR}(X)]$ where X is the loss random variable.

CTE is a generic function with, currently, only a method for objects of class "aggregateDist".

For the recursive, convolution and simulation methods of aggregateDist, the CTE is computed from the definition using the empirical cdf.

For the normal approximation method, an explicit formula exists:

$$\mu + \frac{\sigma}{(1-\alpha)\sqrt{2\pi}} e^{-\mathrm{VaR}(X)^2/2},$$

where μ is the mean, σ the standard deviation and α the confidence level.

For the Normal Power approximation, the explicit formula given in Castañer et al. (2013) is

$$\mu + \frac{\sigma}{(1-\alpha)\sqrt{2\pi}} e^{-\mathrm{VaR}(X)^2/2} \left(1 + \frac{\gamma}{6}\mathrm{VaR}(X)\right),$$

where, as above, μ is the mean, σ the standard deviation, α the confidence level and γ is the skewness.

Value

A numeric vector, named if names is TRUE.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca> and Tommy Ouellet

References

Castañer, A. and Claramunt, M.M. and Mármol, M. (2013), Tail value at risk. An analysis with the Normal-Power approximation. In *Statistical and Soft Computing Approaches in Insurance Problems*, pp. 87-112. Nova Science Publishers, 2013. ISBN 978-1-62618-506-7.

See Also

aggregateDist; VaR

Examples

```
model.freq <- expression(data = rpois(7))
model.sev <- expression(data = rnorm(9, 2))
Fs <- aggregateDist("simulation", model.freq, model.sev, nb.simul = 1000)
CTE(Fs)
```

---

dental *Individual Dental Claims Data Set*

Description

Basic dental claims on a policy with a deductible of 50.

Usage

```
dental
```

Format

A vector containing 10 observations

Source

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (1998), *Loss Models, From Data to Decisions*, Wiley.

---

discretize *Discretization of a Continuous Distribution*

Description

Compute a discrete probability mass function from a continuous cumulative distribution function (cdf) with various methods.

`discretise` is an alias for `discretize`.

Usage

```
discretize(cdf, from, to, step = 1,
           method = c("upper", "lower", "rounding", "unbiased"),
           lev, by = step, xlim = NULL)

discretise(cdf, from, to, step = 1,
           method = c("upper", "lower", "rounding", "unbiased"),
           lev, by = step, xlim = NULL)
```

Arguments

`cdf`	an expression written as a function of `x`, or alternatively the name of a function, giving the cdf to discretize.
`from`, `to`	the range over which the function will be discretized.
`step`	numeric; the discretization step (or span, or lag).
`method`	discretization method to use.
`lev`	an expression written as a function of `x`, or alternatively the name of a function, to compute the limited expected value of the distribution corresponding to `cdf`. Used only with the `"unbiased"` method.
`by`	an alias for `step`.
`xlim`	numeric of length 2; if specified, it serves as default for `c(from, to)`.

Details

Usage is similar to `curve`.

`discretize` returns the probability mass function (pmf) of the random variable obtained by discretization of the cdf specified in `cdf`.

Let $F(x)$ denote the cdf, $E[\min(X, x)]$ the limited expected value at x, h the step, p_x the probability mass at x in the discretized distribution and set $a =$ `from` and $b =$ `to`.

Method `"upper"` is the forward difference of the cdf F:

$$p_x = F(x + h) - F(x)$$

for $x = a, a + h, \ldots, b - step$.

Method `"lower"` is the backward difference of the cdf F:

$$p_x = F(x) - F(x - h)$$

for $x = a + h, \ldots, b$ and $p_a = F(a)$.

Method `"rounding"` has the true cdf pass through the midpoints of the intervals $[x - h/2, x + h/2)$:

$$p_x = F(x + h/2) - F(x - h/2)$$

for $x = a + h, \ldots, b - step$ and $p_a = F(a + h/2)$. The function assumes the cdf is continuous. Any adjusment necessary for discrete distributions can be done via `cdf`.

Method `"unbiased"` matches the first moment of the discretized and the true distributions. The probabilities are as follows:

$$p_a = \frac{E[\min(X, a)] - E[\min(X, a + h)]}{h} + 1 - F(a)$$

$$p_x = \frac{2E[\min(X, x)] - E[\min(X, x - h)] - E[\min(X, x + h)]}{h}, \quad a < x < b$$

$$p_b = \frac{E[\min(X, b)] - E[\min(X, b - h)]}{h} - 1 + F(b),$$

Value

A numeric vector of probabilities suitable for use in aggregateDist.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>

References

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

See Also

aggregateDist

Examples

```
x <- seq(0, 5, 0.5)

op <- par(mfrow = c(1, 1), col = "black")

## Upper and lower discretization
fu <- discretize(pgamma(x, 1), method = "upper",
                 from = 0, to = 5, step = 0.5)
fl <- discretize(pgamma(x, 1), method = "lower",
                 from = 0, to = 5, step = 0.5)
curve(pgamma(x, 1), xlim = c(0, 5))
par(col = "blue")
plot(stepfun(head(x, -1), diffinv(fu)), pch = 19, add = TRUE)
par(col = "green")
plot(stepfun(x, diffinv(fl)), pch = 19, add = TRUE)
par(col = "black")

## Rounding (or midpoint) discretization
fr <- discretize(pgamma(x, 1), method = "rounding",
                 from = 0, to = 5, step = 0.5)
curve(pgamma(x, 1), xlim = c(0, 5))
par(col = "blue")
plot(stepfun(head(x, -1), diffinv(fr)), pch = 19, add = TRUE)
par(col = "black")

## First moment matching
fb <- discretize(pgamma(x, 1), method = "unbiased",
                 lev = levgamma(x, 1), from = 0, to = 5, step = 0.5)
curve(pgamma(x, 1), xlim = c(0, 5))
par(col = "blue")
plot(stepfun(x, diffinv(fb)), pch = 19, add = TRUE)

par(op)
```

elev *Empirical Limited Expected Value*

Description

Compute the empirical limited expected value for individual or grouped data.

Usage

```
elev(x, ...)

## Default S3 method:
elev(x, ...)

## S3 method for class 'grouped.data'
elev(x, ...)

## S3 method for class 'elev'
print(x, digits = getOption("digits") - 2, ...)

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

## S3 method for class 'elev'
knots(Fn, ...)

## S3 method for class 'elev'
plot(x, ..., main = NULL, xlab = "x", ylab = "Empirical LEV")
```

Arguments

x	a vector or an object of class "grouped.data" (in which case only the first column of frequencies is used); for the methods, an object of class "elev", typically.
digits	number of significant digits to use, see print.
Fn, object	an R object inheriting from "ogive".
main	main title.
xlab, ylab	labels of x and y axis.
...	arguments to be passed to subsequent methods.

Details

The limited expected value (LEV) at u of a random variable X is $E[X \wedge u] = E[\min(X, u)]$. For individual data $x_1, \ldots, x_n$, the empirical LEV $E_n[X \wedge u]$ is thus

$$E_n[X \wedge u] = \frac{1}{n} \left(\sum_{x_j < u} x_j + \sum_{x_j \geq u} u \right).$$

Methods of `elev` exist for individual data or for grouped data created with `grouped.data`. The formula in this case is too long to show here. See the reference for details.

Value

For `elev`, a function of class `"elev"`, inheriting from the `"function"` class.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca> and Mathieu Pigeon

References

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (1998), *Loss Models, From Data to Decisions*, Wiley.

See Also

`grouped.data` to create grouped data objects; `stepfun` for related documentation (even though the empirical LEV is not a step function).

Examples

```
data(gdental)
lev <- elev(gdental)
lev
summary(lev)
knots(lev)            # the group boundaries

lev(knots(lev))       # empirical lev at boundaries
lev(c(80, 200, 2000)) # and at other limits

plot(lev, type = "o", pch = 16)
```

---

emm *Empirical Moments*

Description

Raw empirical moments for individual and grouped data.

Usage

```
emm(x, order = 1, ...)

## Default S3 method:
emm(x, order = 1, ...)

## S3 method for class 'grouped.data'
emm(x, order = 1, ...)
```

Arguments

x	a vector or matrix of individual data, or an object of class "grouped data".
order	order of the moment. Must be positive.
...	further arguments passed to or from other methods.

Details

Arguments ... are passed to colMeans; na.rm = TRUE may be useful for individual data with missing values.

For individual data, the kth empirical moment is $\sum_{j=1}^{n} x_j^k$.

For grouped data with group boundaries $c_0, c_1, \ldots, c_r$ and group frequencies $n_1, \ldots, n_r$, the kth empirical moment is

$$\frac{1}{n} \sum_{j=1}^{r} \frac{n_j (c_j^{k+1} - c_{j-1}^{k+1})}{(k+1)(c_j - c_{j-1})},$$

where $n = \sum_{j=1}^{r} n_j$.

Value

A named vector or matrix of moments.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca> and Mathieu Pigeon

References

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (1998), *Loss Models, From Data to Decisions*, Wiley.

See Also

mean and mean.grouped.data for simpler access to the first moment.

Examples

```
## Individual data
data(dental)
emm(dental, order = 1:3)

## Grouped data
data(gdental)
emm(gdental)
x <- grouped.data(cj = gdental[, 1],
                  nj1 = sample(1:100, nrow(gdental)),
                  nj2 = sample(1:100, nrow(gdental)))
emm(x) # same as mean(x)
```

`ExponentialSupp` *Moments and Moment Generating Function of the Exponential Distribution*

Description

Raw moments, limited moments and moment generating function for the exponential distribution with rate `rate` (i.e., mean `1/rate`).

Usage

```
mexp(order, rate = 1)
levexp(limit, rate = 1, order = 1)
mgfexp(t, rate = 1, log = FALSE)
```

Arguments

`order`	order of the moment.
`limit`	limit of the loss variable.
`rate`	vector of rates.
`t`	numeric vector.
`log`	logical; if `TRUE`, the cumulant generating function is returned.

Details

The kth raw moment of the random variable X is $E[X^k]$, the kth limited moment at some limit d is $E[\min(X, d)^k]$ and the moment generating function is $E[e^{tX}]$, $k > -1$.

Value

`mexp` gives the kth raw moment, `levexp` gives the kth moment of the limited loss variable, and `mgfexp` gives the moment generating function in `t`.

Invalid arguments will result in return value `NaN`, with a warning.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>, Christophe Dutang and Mathieu Pigeon.

References

Johnson, N. L. and Kotz, S. (1970), *Continuous Univariate Distributions, Volume 1*, Wiley.

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

See Also

`Exponential`

Examples

```
mexp(2, 3) - mexp(1, 3)^2
levexp(10, 3, order = 2)
mgfexp(1,2)
```

`Extract.grouped.data` *Extract or Replace Parts of a Grouped Data Object*

Description

Extract or replace subsets of grouped data objects.

Usage

```
## S3 method for class 'grouped.data'
x[i, j]
## S3 replacement method for class 'grouped.data'
x[i, j] <- value
```

Arguments

`x`	an object of class `grouped.data`.
`i, j`	elements to extract or replace. `i, j` are `numeric` or `character` or, for `[` only, empty. Numeric values are coerced to integer as if by `as.integer`. For replacement by `[`, a logical matrix is allowed, but not replacement in the group boundaries and group frequencies simultaneously.
`value`	a suitable replacement value.

Details

Objects of class `"grouped.data"` can mostly be indexed like data frames, with the following restrictions:

1. For `[`, the extracted object must keep a group boundaries column and at least one group frequencies column to remain of class `"grouped.data"`;
2. For `[<-`, it is not possible to replace group boundaries and group frequencies simultaneously;
3. When replacing group boundaries, `length(value) == length(i) + 1`.

`x[, 1]` will return the plain vector of group boundaries.

Replacement of non adjacent group boundaries is not possible for obvious reasons.

Otherwise, extraction and replacement should work just like for data frames.

Value

For `[` an object of class `"grouped.data"`, a data frame or a vector.

For `[<-` an object of class `"grouped.data"`.

Note

Currently `[[`, `[[<-`, `$` and `$<-` are not specifically supported, but should work as usual on group frequency columns.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>

See Also

`[.data.frame` for extraction and replacement methods of data frames, `grouped.data` to create grouped data objects.

Examples

```
data(gdental)

(x <- gdental[1])         # select column 1
class(x)                  # no longer a grouped.data object
class(gdental[2])         # same
gdental[, 1]              # group boundaries
gdental[, 2]              # group frequencies

gdental[1:4,]             # a subset
gdental[c(1, 3, 5),]      # avoid this

gdental[1:2, 1] <- c(0, 30, 60) # modified boundaries
gdental[, 2] <- 10              # modified frequencies
## Not run: gdental[1, ] <- 2   # not allowed
```

FellerPareto *The Feller Pareto Distribution*

Description

Density function, distribution function, quantile function, random generation, raw moments and limited moments for the Feller Pareto distribution with parameters `min`, `shape1`, `shape2`, `shape3` and `scale`.

Usage

```
dfpareto(x, min, shape1, shape2, shape3, rate = 1, scale = 1/rate,
        log = FALSE)
pfpareto(q, min, shape1, shape2, shape3, rate = 1, scale = 1/rate,
        lower.tail = TRUE, log.p = FALSE)
qfpareto(p, min, shape1, shape2, shape3, rate = 1, scale = 1/rate,
        lower.tail = TRUE, log.p = FALSE)
rfpareto(n, min, shape1, shape2, shape3, rate = 1, scale = 1/rate)
```

```
mfpareto(order, min, shape1, shape2, shape3, rate = 1, scale = 1/rate)
levfpareto(limit, min, shape1, shape2, shape3, rate = 1, scale = 1/rate,
          order = 1)
```

Arguments

x, q	vector of quantiles.
p	vector of probabilities.
n	number of observations. If length(n) > 1, the length is taken to be the number required.
min	lower bound of the support of the distribution.
shape1, shape2, shape3, scale	parameters. Must be strictly positive.
rate	an alternative way to specify the scale.
log, log.p	logical; if TRUE, probabilities/densities p are returned as $\log(p)$.
lower.tail	logical; if TRUE (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.
order	order of the moment.
limit	limit of the loss variable.

Details

The Feller-Pareto distribution with parameters min $= \mu$, shape1 $= \alpha$, shape2 $= \gamma$, shape3 $= \tau$ and scale $= \theta$, has density:

$$f(x) = \frac{\Gamma(\alpha+\tau)}{\Gamma(\alpha)\Gamma(\tau)} \frac{\gamma((x-\mu)/\theta)^{\gamma\tau-1}}{\theta[1+((x-\mu)/\theta)^{\gamma}]^{\alpha+\tau}}$$

for $x > \mu$, $-\infty < \mu < \infty$, $\alpha > 0$, $\gamma > 0$, $\tau > 0$ and $\theta > 0$. (Here $\Gamma(\alpha)$ is the function implemented by R's gamma() and defined in its help.)

The Feller-Pareto is the distribution of the random variable

$$\mu + \theta \left(\frac{1-X}{X}\right)^{1/\gamma},$$

where X has a beta distribution with parameters α and τ.

The Feller-Pareto defines a large family of distributions encompassing the transformed beta family and many variants of the Pareto distribution. Setting $\mu = 0$ yields the transformed beta distribution.

The Feller-Pareto distribution also has the following direct special cases:

- A Pareto IV distribution when shape3 == 1;
- A Pareto III distribution when shape1 shape3 == 1;
- A Pareto II distribution when shape1 shape2 == 1;
- A Pareto I distribution when shape1 shape2 == 1 and min = scale.

The kth raw moment of the random variable X is $E[X^k]$ for nonnegative integer values of $k < \alpha\gamma$.

The kth limited moment at some limit d is $E[\min(X,d)^k]$ for nonnegative integer values of k and $\alpha - j/\gamma$, $j = 1, \ldots, k$ not a negative integer.

Note that the range of admissible values for k in raw and limited moments is larger when $\mu = 0$.

Value

dfpareto gives the density, pfpareto gives the distribution function, qfpareto gives the quantile function, rfpareto generates random deviates, mfpareto gives the kth raw moment, and levfpareto gives the kth moment of the limited loss variable.

Invalid arguments will result in return value NaN, with a warning.

Note

levfpareto computes the limited expected value using betaint.

For the Feller-Pareto and other Pareto distributions, we use the classification of Arnold (2015) with the parametrization of Klugman et al. (2012).

The "distributions" package vignette provides the interrelations between the continuous size distributions in **actuar** and the complete formulas underlying the above functions.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca> and Nicholas Langevin

References

Dutang, C., Goulet, V., Langevin, N. (2022). Feller-Pareto and Related Distributions: Numerical Implementation and Actuarial Applications. *Journal of Statistical Software*, **103**(6), 1–22. doi:10.18637/jss.v103.i06.

Abramowitz, M. and Stegun, I. A. (1972), *Handbook of Mathematical Functions*, Dover.

Arnold, B. C. (2015), *Pareto Distributions*, Second Edition, CRC Press.

Kleiber, C. and Kotz, S. (2003), *Statistical Size Distributions in Economics and Actuarial Sciences*, Wiley.

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

See Also

dtrbeta for the transformed beta distribution.

Examples

```
exp(dfpareto(2, 1, 2, 3, 4, 5, log = TRUE))
p <- (1:10)/10
pfpareto(qfpareto(p, 1, 2, 3, 4, 5), 1, 2, 3, 4, 5)

## variance
mfpareto(2, 1, 2, 3, 4, 5) - mfpareto(1, 1, 2, 3, 4, 5)^2

## case with shape1 - order/shape2 > 0
levfpareto(10, 1, 2, 3, 4, scale = 1, order = 2)

## case with shape1 - order/shape2 < 0
levfpareto(20, 10, 0.1, 14, 2, scale = 1.5, order = 2)
```

GammaSupp *Moments and Moment Generating Function of the Gamma Distribution*

Description

Raw moments, limited moments and moment generating function for the Gamma distribution with parameters shape and scale.

Usage

```
mgamma(order, shape, rate = 1, scale = 1/rate)
levgamma(limit, shape, rate = 1, scale = 1/rate, order = 1)
mgfgamma(t, shape, rate = 1, scale = 1/rate, log = FALSE)
```

Arguments

order	order of the moment.
limit	limit of the loss variable.
rate	an alternative way to specify the scale.
shape, scale	shape and scale parameters. Must be strictly positive.
t	numeric vector.
log	logical; if TRUE, the cumulant generating function is returned.

Details

The kth raw moment of the random variable X is $E[X^k]$, the kth limited moment at some limit d is $E[\min(X, d)^k]$ and the moment generating function is $E[e^{tX}]$, $k > -\alpha$.

Value

mgamma gives the kth raw moment, levgamma gives the kth moment of the limited loss variable, and mgfgamma gives the moment generating function in t.

Invalid arguments will result in return value NaN, with a warning.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>, Christophe Dutang and Mathieu Pigeon

References

Johnson, N. L. and Kotz, S. (1970), *Continuous Univariate Distributions, Volume 1*, Wiley.

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

See Also

GammaDist

Examples

```
mgamma(2, 3, 4) - mgamma(1, 3, 4)^2
levgamma(10, 3, 4, order = 2)
mgfgamma(1,3,2)
```

---

gdental *Grouped Dental Claims Data Set*

Description

Grouped dental claims, that is presented in a number of claims per claim amount group form.

Usage

```
gdental
```

Format

An object of class "grouped.data" (inheriting from class "data.frame") consisting of 10 rows and 2 columns. The environment of the object contains the plain vector of cj of group boundaries

Source

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (1998), *Loss Models, From Data to Decisions*, Wiley.

See Also

grouped.data for a description of grouped data objects.

GeneralizedBeta *The Generalized Beta Distribution*

Description

Density function, distribution function, quantile function, random generation, raw moments and limited moments for the Generalized Beta distribution with parameters shape1, shape2, shape3 and scale.

Usage

```
dgenbeta(x, shape1, shape2, shape3, rate = 1, scale = 1/rate,
         log = FALSE)
pgenbeta(q, shape1, shape2, shape3, rate = 1, scale = 1/rate,
         lower.tail = TRUE, log.p = FALSE)
qgenbeta(p, shape1, shape2, shape3, rate = 1, scale = 1/rate,
         lower.tail = TRUE, log.p = FALSE)
rgenbeta(n, shape1, shape2, shape3, rate = 1, scale = 1/rate)
mgenbeta(order, shape1, shape2, shape3, rate = 1, scale = 1/rate)
levgenbeta(limit, shape1, shape2, shape3, rate = 1, scale = 1/rate,
           order = 1)
```

Arguments

x, q	vector of quantiles.
p	vector of probabilities.
n	number of observations. If `length(n) > 1`, the length is taken to be the number required.
shape1, shape2, shape3, scale	parameters. Must be strictly positive.
rate	an alternative way to specify the scale.
log, log.p	logical; if TRUE, probabilities/densities p are returned as $\log(p)$.
lower.tail	logical; if TRUE (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.
order	order of the moment.
limit	limit of the loss variable.

Details

The generalized beta distribution with parameters shape1 $= \alpha$, shape2 $= \beta$, shape3 $= \tau$ and scale $= \theta$, has density:

$$f(x) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)}(x/\theta)^{\alpha\tau}(1-(x/\theta)^{\tau})^{\beta-1}\frac{\tau}{x}$$

for $0 < x < \theta$, $\alpha > 0$, $\beta > 0$, $\tau > 0$ and $\theta > 0$. (Here $\Gamma(\alpha)$ is the function implemented by R's `gamma()` and defined in its help.)

The generalized beta is the distribution of the random variable

$$\theta X^{1/\tau},$$

where X has a beta distribution with parameters α and β.

The kth raw moment of the random variable X is $E[X^k]$ and the kth limited moment at some limit d is $E[\min(X,d)]$, $k > -\alpha\tau$.

Value

dgenbeta gives the density, pgenbeta gives the distribution function, qgenbeta gives the quantile function, rgenbeta generates random deviates, mgenbeta gives the kth raw moment, and levgenbeta gives the kth moment of the limited loss variable.

Invalid arguments will result in return value NaN, with a warning.

Note

This is *not* the generalized three-parameter beta distribution defined on page 251 of Johnson et al, 1995.

The "distributions" package vignette provides the interrelations between the continuous size distributions in **actuar** and the complete formulas underlying the above functions.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>

References

Johnson, N. L., Kotz, S. and Balakrishnan, N. (1995) *Continuous Univariate Distributions, Volume 2*, Wiley.

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

Examples

```
exp(dgenbeta(2, 2, 3, 4, 0.2, log = TRUE))
p <- (1:10)/10
pgenbeta(qgenbeta(p, 2, 3, 4, 0.2), 2, 3, 4, 0.2)
mgenbeta(2, 1, 2, 3, 0.25) - mgenbeta(1, 1, 2, 3, 0.25) ^ 2
levgenbeta(10, 1, 2, 3, 0.25, order = 2)
```

GeneralizedPareto *The Generalized Pareto Distribution*

Description

Density function, distribution function, quantile function, random generation, raw moments and limited moments for the Generalized Pareto distribution with parameters shape1, shape2 and scale.

Usage

```
dgenpareto(x, shape1, shape2, rate = 1, scale = 1/rate,
           log = FALSE)
pgenpareto(q, shape1, shape2, rate = 1, scale = 1/rate,
           lower.tail = TRUE, log.p = FALSE)
qgenpareto(p, shape1, shape2, rate = 1, scale = 1/rate,
           lower.tail = TRUE, log.p = FALSE)
rgenpareto(n, shape1, shape2, rate = 1, scale = 1/rate)
mgenpareto(order, shape1, shape2, rate = 1, scale = 1/rate)
levgenpareto(limit, shape1, shape2, rate = 1, scale = 1/rate,
             order = 1)
```

Arguments

x, q	vector of quantiles.
p	vector of probabilities.
n	number of observations. If length(n) > 1, the length is taken to be the number required.
shape1, shape2, scale	parameters. Must be strictly positive.
rate	an alternative way to specify the scale.
log, log.p	logical; if TRUE, probabilities/densities p are returned as $\log(p)$.
lower.tail	logical; if TRUE (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.
order	order of the moment.
limit	limit of the loss variable.

Details

The Generalized Pareto distribution with parameters shape1 $= \alpha$, shape2 $= \tau$ and scale $= \theta$ has density:

$$f(x) = \frac{\Gamma(\alpha+\tau)}{\Gamma(\alpha)\Gamma(\tau)} \frac{\theta^\alpha x^{\tau-1}}{(x+\theta)^{\alpha+\tau}}$$

for $x > 0$, $\alpha > 0$, $\tau > 0$ and $\theta > 0$. (Here $\Gamma(\alpha)$ is the function implemented by R's gamma() and defined in its help.)

The Generalized Pareto is the distribution of the random variable

$$\theta \left(\frac{X}{1-X} \right),$$

where X has a beta distribution with parameters α and τ.

The Generalized Pareto distribution has the following special cases:

- A Pareto distribution when shape2 == 1;
- An Inverse Pareto distribution when shape1 == 1.

The kth raw moment of the random variable X is $E[X^k]$, $-\tau < k < \alpha$.

The kth limited moment at some limit d is $E[\min(X, d)^k]$, $k > -\tau$ and $\alpha - k$ not a negative integer.

Value

dgenpareto gives the density, pgenpareto gives the distribution function, qgenpareto gives the quantile function, rgenpareto generates random deviates, mgenpareto gives the kth raw moment, and levgenpareto gives the kth moment of the limited loss variable.

Invalid arguments will result in return value NaN, with a warning.

Note

levgenpareto computes the limited expected value using betaint.

Distribution also known as the Beta of the Second Kind. See also Kleiber and Kotz (2003) for alternative names and parametrizations.

The Generalized Pareto distribution defined here is different from the one in Embrechts et al. (1997) and in Wikipedia; see also Kleiber and Kotz (2003, section 3.12). One may most likely compute quantities for the latter using functions for the Pareto distribution with the appropriate change of parametrization.

The "distributions" package vignette provides the interrelations between the continuous size distributions in **actuar** and the complete formulas underlying the above functions.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca> and Mathieu Pigeon

References

Embrechts, P., Klüppelberg, C. and Mikisch, T. (1997), *Modelling Extremal Events for Insurance and Finance*, Springer.

Kleiber, C. and Kotz, S. (2003), *Statistical Size Distributions in Economics and Actuarial Sciences*, Wiley.

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

Examples

```
exp(dgenpareto(3, 3, 4, 4, log = TRUE))
p <- (1:10)/10
pgenpareto(qgenpareto(p, 3, 3, 1), 3, 3, 1)
qgenpareto(.3, 3, 4, 4, lower.tail = FALSE)

## variance
mgenpareto(2, 3, 2, 1) - mgenpareto(1, 3, 2, 1)^2

## case with shape1 - order > 0
levgenpareto(10, 3, 3, scale = 1, order = 2)

## case with shape1 - order < 0
levgenpareto(10, 1.5, 3, scale = 1, order = 2)
```

`grouped.data` *Grouped data*

Description

Creation of grouped data objects, from either a provided set of group boundaries and group frequencies, or from individual data using automatic or specified breakpoints.

Usage

```
grouped.data(..., breaks = "Sturges", include.lowest = TRUE,
             right = TRUE, nclass = NULL, group = FALSE,
             row.names = NULL, check.rows = FALSE,
             check.names = TRUE)
```

Arguments

`...`	arguments of the form `value` or `tag = value`; see Details.
`breaks`	same as for `hist`, namely one of: • a vector giving the breakpoints between groups; • a function to compute the vector of breakpoints; • a single number giving the number of groups; • a character string naming an algorithm to compute the number of groups (see `hist`); • a function to compute the number of groups. In the last three cases the number is a suggestion only; the breakpoints will be set to `pretty` values. If `breaks` is a function, the first element in `...` is supplied to it as the only argument.
`include.lowest`	logical; if `TRUE`, a data point equal to the `breaks` value will be included in the first (or last, for `right = FALSE`) group. Used only for individual data; see Details.
`right`	logical; indicating if the intervals should be closed on the right (and open on the left) or vice versa.
`nclass`	numeric (integer); equivalent to `breaks` for a scalar or character argument.
`group`	logical; an alternative way to force grouping of individual data.
`row.names, check.rows, check.names`	arguments identical to those of `data.frame`.

Details

A grouped data object is a special form of data frame consisting of one column of contiguous group boundaries and one or more columns of frequencies within each group.

The function can create a grouped data object from two types of arguments.

1. Group boundaries and frequencies. This is the default mode of operation if the call has at least two elements in `...`.

   The first argument will then be taken as the vector of group boundaries. This vector must be exactly one element longer than the other arguments, which will be taken as vectors of group frequencies. All arguments are coerced to data frames.

2. Individual data. This mode of operation is active if there is a single argument in `...`, or if either `breaks` or `nclass` is specified or `group` is `TRUE`.

   Arguments of `...` are first grouped using `hist`. If needed, breakpoints are set using the first argument.

Missing (`NA`) frequencies are replaced by zeros, with a warning.

Extraction and replacement methods exist for `grouped.data` objects, but working on non adjacent groups will most likely yield useless results.

Value

An object of `class` `c("grouped.data", "data.frame")` with an environment containing the vector `cj` of group boundaries.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>, Mathieu Pigeon and Louis-Philippe Pouliot

References

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (1998), *Loss Models, From Data to Decisions*, Wiley.

See Also

`[.grouped.data` for extraction and replacement methods.

`data.frame` for usual data frame creation and manipulation.

`hist` for details on the calculation of breakpoints.

Examples

```
## Most common usage using a predetermined set of group
## boundaries and group frequencies.
cj <- c(0, 25, 50, 100, 250, 500, 1000)
nj <- c(30, 31, 57, 42, 45, 10)
(x <- grouped.data(Group = cj, Frequency = nj))
class(x)

x[, 1] # group boundaries
x[, 2] # group frequencies

## Multiple frequency columns are supported
x <- sample(1:100, 9)
y <- sample(1:100, 9)
```

```
grouped.data(cj = 1:10, nj.1 = x, nj.2 = y)

## Alternative usage with grouping of individual data.
grouped.data(x)                          # automatic breakpoints
grouped.data(x, breaks = 7)              # forced number of groups
grouped.data(x, breaks = c(0,25,75,100))    # specified groups
grouped.data(x, y, breaks = c(0,25,75,100)) # multiple data sets

## Not run: ## Providing two or more data sets and automatic breakpoints is
## very error-prone since the range of the first data set has to
## include the ranges of all the other data sets.
range(x)
range(y)
grouped.data(x, y, group = TRUE)
## End(Not run)
```

Gumbel *The Gumbel Distribution*

Description

Density function, distribution function, quantile function, random generation and raw moments for the Gumbel extreme value distribution with parameters `alpha` and `scale`.

Usage

```
dgumbel(x, alpha, scale, log = FALSE)
pgumbel(q, alpha, scale, lower.tail = TRUE, log.p = FALSE)
qgumbel(p, alpha, scale, lower.tail = TRUE, log.p = FALSE)
rgumbel(n, alpha, scale)
mgumbel(order, alpha, scale)
mgfgumbel(t, alpha, scale, log = FALSE)
```

Arguments

`x`, `q`	vector of quantiles.
`p`	vector of probabilities.
`n`	number of observations. If `length(n) > 1`, the length is taken to be the number required.
`alpha`	location parameter.
`scale`	parameter. Must be strictly positive.
`log`, `log.p`	logical; if `TRUE`, probabilities/densities p are returned as $\log(p)$.
`lower.tail`	logical; if `TRUE` (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.
`order`	order of the moment. Only values 1 and 2 are supported.
`t`	numeric vector.

Details

The Gumbel distribution with parameters `alpha` $= \alpha$ and `scale` $= \theta$ has distribution function:

$$F(x) = \exp[-\exp(-(x-\alpha)/\theta)]$$

for $-\infty < x < \infty$, $-\infty < a < \infty$ and $\theta > 0$.

The mode of the distribution is in α, the mean is $\alpha + \gamma\theta$, where $\gamma = 0.57721566$ is the Euler-Mascheroni constant, and the variance is $\pi^2\theta^2/6$.

Value

`dgumbel` gives the density, `pgumbel` gives the distribution function, `qgumbel` gives the quantile function, `rgumbel` generates random deviates, `mgumbel` gives the kth raw moment, $k = 1, 2$, and `mgfgamma` gives the moment generating function in `t`.

Invalid arguments will result in return value `NaN`, with a warning.

Note

Distribution also knonw as the generalized extreme value distribution Type-I.

The `"distributions"` package vignette provides the interrelations between the continuous size distributions in **actuar** and the complete formulas underlying the above functions.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>

References

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

Examples

```
dgumbel(c(-5, 0, 10, 20), 0.5, 2)

p <- (1:10)/10
pgumbel(qgumbel(p, 2, 3), 2, 3)

curve(pgumbel(x, 0.5, 2), from = -5, to = 20, col = "red")
curve(pgumbel(x, 1.0, 2), add = TRUE, col = "green")
curve(pgumbel(x, 1.5, 3), add = TRUE, col = "blue")
curve(pgumbel(x, 3.0, 4), add = TRUE, col = "cyan")

a <- 3; s <- 4
mgumbel(1, a, s)                        # mean
a - s * digamma(1)                      # same

mgumbel(2, a, s) - mgumbel(1, a, s)^2   # variance
(pi * s)^2/6                            # same
```

hachemeister *Hachemeister Data Set*

Description

Hachemeister (1975) data set giving average claim amounts in private passenger bodily injury insurance in five U.S. states over 12 quarters between July 1970 and June 1973 and the corresponding number of claims.

Usage

```
hachemeister
```

Format

A matrix with 5 rows and the following 25 columns:

`state` the state number;

`ratio.1`, ..., `ratio.12` the average claim amounts;

`weight.1`, ..., `weight.12` the corresponding number of claims.

Source

Hachemeister, C. A. (1975), *Credibility for regression models with application to trend*, Proceedings of the Berkeley Actuarial Research Conference on Credibility, Academic Press.

hist.grouped.data *Histogram for Grouped Data*

Description

This method for the generic function `hist` is mainly useful to plot the histogram of grouped data. If `plot = FALSE`, the resulting object of class `"histogram"` is returned for compatibility with `hist.default`, but does not contain much information not already in `x`.

Usage

```
## S3 method for class 'grouped.data'
hist(x, freq = NULL, probability = !freq,
     density = NULL, angle = 45, col = NULL, border = NULL,
     main = paste("Histogram of" , xname),
     xlim = range(x), ylim = NULL, xlab = xname, ylab,
     axes = TRUE, plot = TRUE, labels = FALSE, ...)
```

Arguments

x	an object of class "grouped.data"; only the first column of frequencies is used.
freq	logical; if TRUE, the histogram graphic is a representation of frequencies, the counts component of the result; if FALSE, probability densities, component density, are plotted (so that the histogram has a total area of one). Defaults to TRUE *iff* group boundaries are equidistant (and probability is not specified).
probability	an *alias* for !freq, for S compatibility.
density	the density of shading lines, in lines per inch. The default value of NULL means that no shading lines are drawn. Non-positive values of density also inhibit the drawing of shading lines.
angle	the slope of shading lines, given as an angle in degrees (counter-clockwise).
col	a colour to be used to fill the bars. The default of NULL yields unfilled bars.
border	the color of the border around the bars. The default is to use the standard foreground color.
main, xlab, ylab	these arguments to title have useful defaults here.
xlim, ylim	the range of x and y values with sensible defaults. Note that xlim is *not* used to define the histogram (breaks), but only for plotting (when plot = TRUE).
axes	logical. If TRUE (default), axes are draw if the plot is drawn.
plot	logical. If TRUE (default), a histogram is plotted, otherwise a list of breaks and counts is returned.
labels	logical or character. Additionally draw labels on top of bars, if not FALSE; see plot.histogram.
...	further graphical parameters passed to plot.histogram and their to title and axis (if plot=TRUE).

Value

An object of class "histogram" which is a list with components:

breaks	the $r + 1$ group boundaries.
counts	r integers; the frequency within each group.
density	the relative frequencies within each group n_j/n, where n_j = counts[j].
intensities	same as density. Deprecated, but retained for compatibility.
mids	the r group midpoints.
xname	a character string with the actual x argument name.
equidist	logical, indicating if the distances between breaks are all the same.

Note

The resulting value does *not* depend on the values of the arguments freq (or probability) or plot. This is intentionally different from S.

References

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (1998), *Loss Models, From Data to Decisions*, Wiley.

See Also

`hist` and `hist.default` for histograms of individual data and fancy examples.

Examples

```
data(gdental)
hist(gdental)
```

`InverseBurr` *The Inverse Burr Distribution*

Description

Density function, distribution function, quantile function, random generation, raw moments and limited moments for the Inverse Burr distribution with parameters `shape1`, `shape2` and `scale`.

Usage

```
dinvburr(x, shape1, shape2, rate = 1, scale = 1/rate,
         log = FALSE)
pinvburr(q, shape1, shape2, rate = 1, scale = 1/rate,
         lower.tail = TRUE, log.p = FALSE)
qinvburr(p, shape1, shape2, rate = 1, scale = 1/rate,
         lower.tail = TRUE, log.p = FALSE)
rinvburr(n, shape1, shape2, rate = 1, scale = 1/rate)
minvburr(order, shape1, shape2, rate = 1, scale = 1/rate)
levinvburr(limit, shape1, shape2, rate = 1, scale = 1/rate,
           order = 1)
```

Arguments

`x`, `q`	vector of quantiles.
`p`	vector of probabilities.
`n`	number of observations. If `length(n) > 1`, the length is taken to be the number required.
`shape1`, `shape2`, `scale`	parameters. Must be strictly positive.
`rate`	an alternative way to specify the scale.
`log`, `log.p`	logical; if `TRUE`, probabilities/densities p are returned as $\log(p)$.
`lower.tail`	logical; if `TRUE` (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.
`order`	order of the moment.
`limit`	limit of the loss variable.

Details

The inverse Burr distribution with parameters `shape1` $= \tau$, `shape2` $= \gamma$ and `scale` $= \theta$, has density:

$$f(x) = \frac{\tau\gamma(x/\theta)^{\gamma\tau}}{x[1+(x/\theta)^{\gamma}]^{\tau+1}}$$

for $x > 0$, $\tau > 0$, $\gamma > 0$ and $\theta > 0$.

The inverse Burr is the distribution of the random variable

$$\theta\left(\frac{X}{1-X}\right)^{1/\gamma},$$

where X has a beta distribution with parameters τ and 1.

The inverse Burr distribution has the following special cases:

- A Loglogistic distribution when `shape1 == 1`;
- An Inverse Pareto distribution when `shape2 == 1`;
- An Inverse Paralogistic distribution when `shape1 == shape2`.

The kth raw moment of the random variable X is $E[X^k]$, $-\tau\gamma < k < \gamma$.

The kth limited moment at some limit d is $E[\min(X, d)^k]$, $k > -\tau\gamma$ and $1 - k/\gamma$ not a negative integer.

Value

`dinvburr` gives the density, `invburr` gives the distribution function, `qinvburr` gives the quantile function, `rinvburr` generates random deviates, `minvburr` gives the kth raw moment, and `levinvburr` gives the kth moment of the limited loss variable.

Invalid arguments will result in return value `NaN`, with a warning.

Note

`levinvburr` computes the limited expected value using `betaint`.

Also known as the Dagum distribution. See also Kleiber and Kotz (2003) for alternative names and parametrizations.

The `"distributions"` package vignette provides the interrelations between the continuous size distributions in **actuar** and the complete formulas underlying the above functions.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca> and Mathieu Pigeon

References

Kleiber, C. and Kotz, S. (2003), *Statistical Size Distributions in Economics and Actuarial Sciences*, Wiley.

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

Examples

```
exp(dinvburr(2, 2, 3, 1, log = TRUE))
p <- (1:10)/10
pinvburr(qinvburr(p, 2, 3, 1), 2, 3, 1)

## variance
minvburr(2, 2, 3, 1) - minvburr(1, 2, 3, 1) ^ 2

## case with 1 - order/shape2 > 0
levinvburr(10, 2, 3, 1, order = 2)

## case with 1 - order/shape2 < 0
levinvburr(10, 2, 1.5, 1, order = 2)
```

InverseExponential *The Inverse Exponential Distribution*

Description

Density function, distribution function, quantile function, random generation raw moments and limited moments for the Inverse Exponential distribution with parameter `scale`.

Usage

```
dinvexp(x, rate = 1, scale = 1/rate, log = FALSE)
pinvexp(q, rate = 1, scale = 1/rate, lower.tail = TRUE, log.p = FALSE)
qinvexp(p, rate = 1, scale = 1/rate, lower.tail = TRUE, log.p = FALSE)
rinvexp(n, rate = 1, scale = 1/rate)
minvexp(order, rate = 1, scale = 1/rate)
levinvexp(limit, rate = 1, scale = 1/rate, order)
```

Arguments

`x`, `q`	vector of quantiles.
`p`	vector of probabilities.
`n`	number of observations. If `length(n) > 1`, the length is taken to be the number required.
`scale`	parameter. Must be strictly positive.
`rate`	an alternative way to specify the scale.
`log`, `log.p`	logical; if `TRUE`, probabilities/densities p are returned as $\log(p)$.
`lower.tail`	logical; if `TRUE` (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.
`order`	order of the moment.
`limit`	limit of the loss variable.

Details

The inverse exponential distribution with parameter `scale` $= \theta$ has density:

$$f(x) = \frac{\theta e^{-\theta/x}}{x^2}$$

for $x > 0$ and $\theta > 0$.

The kth raw moment of the random variable X is $E[X^k]$, $k < 1$, and the kth limited moment at some limit d is $E[\min(X, d)^k]$, all k.

Value

`dinvexp` gives the density, `pinvexp` gives the distribution function, `qinvexp` gives the quantile function, `rinvexp` generates random deviates, `minvexp` gives the kth raw moment, and `levinvexp` calculates the kth limited moment.

Invalid arguments will result in return value `NaN`, with a warning.

Note

`levinvexp` computes the limited expected value using `gammainc` from package **expint**.

The `"distributions"` package vignette provides the interrelations between the continuous size distributions in **actuar** and the complete formulas underlying the above functions.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca> and Mathieu Pigeon

References

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

Examples

```
exp(dinvexp(2, 2, log = TRUE))
p <- (1:10)/10
pinvexp(qinvexp(p, 2), 2)
minvexp(0.5, 2)
```

`InverseGamma` *The Inverse Gamma Distribution*

Description

Density function, distribution function, quantile function, random generation, raw moments, and limited moments for the Inverse Gamma distribution with parameters `shape` and `scale`.

Usage

```
dinvgamma(x, shape, rate = 1, scale = 1/rate, log = FALSE)
pinvgamma(q, shape, rate = 1, scale = 1/rate,
          lower.tail = TRUE, log.p = FALSE)
qinvgamma(p, shape, rate = 1, scale = 1/rate,
          lower.tail = TRUE, log.p = FALSE)
rinvgamma(n, shape, rate = 1, scale = 1/rate)
minvgamma(order, shape, rate = 1, scale = 1/rate)
levinvgamma(limit, shape, rate = 1, scale = 1/rate,
            order = 1)
mgfinvgamma(t, shape, rate =1, scale = 1/rate, log =FALSE)
```

Arguments

x, q	vector of quantiles.
p	vector of probabilities.
n	number of observations. If length(n) > 1, the length is taken to be the number required.
shape, scale	parameters. Must be strictly positive.
rate	an alternative way to specify the scale.
log, log.p	logical; if TRUE, probabilities/densities p are returned as $\log(p)$.
lower.tail	logical; if TRUE (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.
order	order of the moment.
limit	limit of the loss variable.
t	numeric vector.

Details

The inverse gamma distribution with parameters shape $= \alpha$ and scale $= \theta$ has density:

$$f(x) = \frac{u^\alpha e^{-u}}{x\Gamma(\alpha)}, \quad u = \theta/x$$

for $x > 0$, $\alpha > 0$ and $\theta > 0$. (Here $\Gamma(\alpha)$ is the function implemented by R's gamma() and defined in its help.)

The special case shape == 1 is an Inverse Exponential distribution.

The kth raw moment of the random variable X is $E[X^k]$, $k < \alpha$, and the kth limited moment at some limit d is $E[\min(X, d)^k]$, all k.

The moment generating function is given by $E[e^{tX}]$.

Value

dinvgamma gives the density, pinvgamma gives the distribution function, qinvgamma gives the quantile function, rinvgamma generates random deviates, minvgamma gives the kth raw moment, levinvgamma gives the kth moment of the limited loss variable, and mgfinvgamma gives the moment generating function in t.

Invalid arguments will result in return value NaN, with a warning.

Note

`levinvgamma` computes the limited expected value using `gammainc` from package **expint**.

Also known as the Vinci distribution. See also Kleiber and Kotz (2003) for alternative names and parametrizations.

The `"distributions"` package vignette provides the interrelations between the continuous size distributions in **actuar** and the complete formulas underlying the above functions.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca> and Mathieu Pigeon

References

Kleiber, C. and Kotz, S. (2003), *Statistical Size Distributions in Economics and Actuarial Sciences*, Wiley.

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

Examples

```
exp(dinvgamma(2, 3, 4, log = TRUE))
p <- (1:10)/10
pinvgamma(qinvgamma(p, 2, 3), 2, 3)
minvgamma(-1, 2, 2) ^ 2
levinvgamma(10, 2, 2, order = 1)
mgfinvgamma(-1, 3, 2)
```

InverseGaussian *The Inverse Gaussian Distribution*

Description

Density function, distribution function, quantile function, random generation, raw moments, limited moments and moment generating function for the Inverse Gaussian distribution with parameters `mean` and `shape`.

Usage

```
dinvgauss(x, mean, shape = 1, dispersion = 1/shape,
          log = FALSE)
pinvgauss(q, mean, shape = 1, dispersion = 1/shape,
          lower.tail = TRUE, log.p = FALSE)
qinvgauss(p, mean, shape = 1, dispersion = 1/shape,
          lower.tail = TRUE, log.p = FALSE,
          tol = 1e-14, maxit = 100, echo = FALSE, trace = echo)
rinvgauss(n, mean, shape = 1, dispersion = 1/shape)
minvgauss(order, mean, shape = 1, dispersion = 1/shape)
```

```
levinvgauss(limit, mean, shape = 1, dispersion = 1/shape, order = 1)
mgfinvgauss(t, mean, shape = 1, dispersion = 1/shape, log = FALSE)
```

Arguments

x, q	vector of quantiles.
p	vector of probabilities.
n	number of observations. If length(n) > 1, the length is taken to be the number required.
mean, shape	parameters. Must be strictly positive. Infinite values are supported.
dispersion	an alternative way to specify the shape.
log, log.p	logical; if TRUE, probabilities/densities p are returned as $\log(p)$.
lower.tail	logical; if TRUE (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.
order	order of the moment. Only order = 1 is supported by levinvgauss.
limit	limit of the loss variable.
tol	small positive value. Tolerance to assess convergence in the Newton computation of quantiles.
maxit	positive integer; maximum number of recursions in the Newton computation of quantiles.
echo, trace	logical; echo the recursions to screen in the Newton computation of quantiles.
t	numeric vector.

Details

The inverse Gaussian distribution with parameters mean $= \mu$ and dispersion $= \phi$ has density:

$$f(x) = \left(\frac{1}{2\pi\phi x^3}\right)^{1/2} \exp\left(-\frac{(x-\mu)^2}{2\mu^2\phi x}\right),$$

for $x \geq 0$, $\mu > 0$ and $\phi > 0$.

The limiting case $\mu = \infty$ is an inverse chi-squared distribution (or inverse gamma with shape $= 1/2$ and rate $= 2$phi). This distribution has no finite strictly positive, integer moments.

The limiting case $\phi = 0$ is an infinite spike in $x = 0$.

If the random variable X is IG(μ, ϕ), then X/μ is IG$(1, \phi\mu)$.

The kth raw moment of the random variable X is $E[X^k]$, $k = 1, 2, \ldots$, the limited expected value at some limit d is $E[\min(X, d)]$ and the moment generating function is $E[e^{tX}]$.

The moment generating function of the inverse guassian is defined for t <= 1/(2 * mean^2 * phi).

Value

dinvgauss gives the density, pinvgauss gives the distribution function, qinvgauss gives the quantile function, rinvgauss generates random deviates, minvgauss gives the kth raw moment, levinvgauss gives the limited expected value, and mgfinvgauss gives the moment generating function in t.

Invalid arguments will result in return value NaN, with a warning.

Note

Functions `dinvgauss`, `pinvgauss` and `qinvgauss` are C implementations of functions of the same name in package **statmod**; see Giner and Smyth (2016).

Devroye (1986, chapter 4) provides a nice presentation of the algorithm to generate random variates from an inverse Gaussian distribution.

The `"distributions"` package vignette provides the interrelations between the continuous size distributions in **actuar** and the complete formulas underlying the above functions.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>

References

Giner, G. and Smyth, G. K. (2016), "**statmod**: Probability Calculations for the Inverse Gaussian Distribution", *The R Journal*, vol. 8, no 1, p. 339-351. doi:10.32614/RJ2016024

Chhikara, R. S. and Folk, T. L. (1989), *The Inverse Gaussian Distribution: Theory, Methodology and Applications*, Decker.

Devroye, L. (1986), *Non-Uniform Random Variate Generation*, Springer-Verlag. https://luc.devroye.org/rnbookindex.html

See Also

`dinvgamma` for the inverse gamma distribution.

Examples

```
dinvgauss(c(-1, 0, 1, 2, Inf), mean = 1.5, dis = 0.7)
dinvgauss(c(-1, 0, 1, 2, Inf), mean = Inf, dis = 0.7)
dinvgauss(c(-1, 0, 1, 2, Inf), mean = 1.5, dis = Inf) # spike at zero

## Typical graphical representations of the inverse Gaussian
## distribution. First fixed mean and varying shape; second
## varying mean and fixed shape.
col = c("red", "blue", "green", "cyan", "yellow", "black")
par = c(0.125, 0.5, 1, 2, 8, 32)
curve(dinvgauss(x, 1, par[1]), from = 0, to = 2, col = col[1])
for (i in 2:6)
    curve(dinvgauss(x, 1, par[i]), add = TRUE, col = col[i])

curve(dinvgauss(x, par[1], 1), from = 0, to = 2, col = col[1])
for (i in 2:6)
    curve(dinvgauss(x, par[i], 1), add = TRUE, col = col[i])

pinvgauss(qinvgauss((1:10)/10, 1.5, shape = 2), 1.5, 2)

minvgauss(1:4, 1.5, 2)

levinvgauss(c(0, 0.5, 1, 1.2, 10, Inf), 1.5, 2)
```

`InverseParalogistic` *The Inverse Paralogistic Distribution*

Description

Density function, distribution function, quantile function, random generation, raw moments and limited moments for the Inverse Paralogistic distribution with parameters `shape` and `scale`.

Usage

```
dinvparalogis(x, shape, rate = 1, scale = 1/rate, log = FALSE)
pinvparalogis(q, shape, rate = 1, scale = 1/rate,
              lower.tail = TRUE, log.p = FALSE)
qinvparalogis(p, shape, rate = 1, scale = 1/rate,
              lower.tail = TRUE, log.p = FALSE)
rinvparalogis(n, shape, rate = 1, scale = 1/rate)
minvparalogis(order, shape, rate = 1, scale = 1/rate)
levinvparalogis(limit, shape, rate = 1, scale = 1/rate,
                order = 1)
```

Arguments

`x`, `q`	vector of quantiles.
`p`	vector of probabilities.
`n`	number of observations. If `length(n) > 1`, the length is taken to be the number required.
`shape`, `scale`	parameters. Must be strictly positive.
`rate`	an alternative way to specify the scale.
`log`, `log.p`	logical; if `TRUE`, probabilities/densities p are returned as $\log(p)$.
`lower.tail`	logical; if `TRUE` (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.
`order`	order of the moment.
`limit`	limit of the loss variable.

Details

The inverse paralogistic distribution with parameters `shape` $= \tau$ and `scale` $= \theta$ has density:

$$f(x) = \frac{\tau^2 (x/\theta)^{\tau^2}}{x[1 + (x/\theta)^{\tau}]^{\tau+1}}$$

for $x > 0$, $\tau > 0$ and $\theta > 0$.

The kth raw moment of the random variable X is $E[X^k]$, $-\tau^2 < k < \tau$.

The kth limited moment at some limit d is $E[\min(X, d)^k]$, $k > -\tau^2$ and $1 - k/\tau$ not a negative integer.

Value

dinvparalogis gives the density, pinvparalogis gives the distribution function, qinvparalogis gives the quantile function, rinvparalogis generates random deviates, minvparalogis gives the kth raw moment, and levinvparalogis gives the kth moment of the limited loss variable.

Invalid arguments will result in return value NaN, with a warning.

Note

levinvparalogis computes computes the limited expected value using betaint.

See Kleiber and Kotz (2003) for alternative names and parametrizations.

The "distributions" package vignette provides the interrelations between the continuous size distributions in **actuar** and the complete formulas underlying the above functions.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca> and Mathieu Pigeon

References

Kleiber, C. and Kotz, S. (2003), *Statistical Size Distributions in Economics and Actuarial Sciences*, Wiley.

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

Examples

```
exp(dinvparalogis(2, 3, 4, log = TRUE))
p <- (1:10)/10
pinvparalogis(qinvparalogis(p, 2, 3), 2, 3)

## first negative moment
minvparalogis(-1, 2, 2)

## case with 1 - order/shape > 0
levinvparalogis(10, 2, 2, order = 1)

## case with 1 - order/shape < 0
levinvparalogis(10, 2/3, 2, order = 1)
```

InversePareto *The Inverse Pareto Distribution*

Description

Density function, distribution function, quantile function, random generation raw moments and limited moments for the Inverse Pareto distribution with parameters shape and scale.

Usage

```
dinvpareto(x, shape, scale, log = FALSE)
pinvpareto(q, shape, scale, lower.tail = TRUE, log.p = FALSE)
qinvpareto(p, shape, scale, lower.tail = TRUE, log.p = FALSE)
rinvpareto(n, shape, scale)
minvpareto(order, shape, scale)
levinvpareto(limit, shape, scale, order = 1)
```

Arguments

x, q	vector of quantiles.
p	vector of probabilities.
n	number of observations. If length(n) > 1, the length is taken to be the number required.
shape, scale	parameters. Must be strictly positive.
log, log.p	logical; if TRUE, probabilities/densities p are returned as $\log(p)$.
lower.tail	logical; if TRUE (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.
order	order of the moment.
limit	limit of the loss variable.

Details

The inverse Pareto distribution with parameters shape $= \tau$ and scale $= \theta$ has density:

$$f(x) = \frac{\tau\theta x^{\tau-1}}{(x+\theta)^{\tau+1}}$$

for $x > 0$, $\tau > 0$ and $\theta > 0$.

The kth raw moment of the random variable X is $E[X^k]$, $-\tau < k < 1$.

The kth limited moment at some limit d is $E[\min(X, d)^k]$, $k > -\tau$.

Value

dinvpareto gives the density, pinvpareto gives the distribution function, qinvpareto gives the quantile function, rinvpareto generates random deviates, minvpareto gives the kth raw moment, and levinvpareto calculates the kth limited moment.

Invalid arguments will result in return value NaN, with a warning.

Note

Evaluation of levinvpareto is done using numerical integration.

The "distributions" package vignette provides the interrelations between the continuous size distributions in **actuar** and the complete formulas underlying the above functions.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca> and Mathieu Pigeon

References

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

Examples

```
exp(dinvpareto(2, 3, 4, log = TRUE))
p <- (1:10)/10
pinvpareto(qinvpareto(p, 2, 3), 2, 3)
minvpareto(0.5, 1, 2)
```

InverseTransformedGamma

The Inverse Transformed Gamma Distribution

Description

Density function, distribution function, quantile function, random generation, raw moments, and limited moments for the Inverse Transformed Gamma distribution with parameters shape1, shape2 and scale.

Usage

```
dinvtrgamma(x, shape1, shape2, rate = 1, scale = 1/rate,
            log = FALSE)
pinvtrgamma(q, shape1, shape2, rate = 1, scale = 1/rate,
            lower.tail = TRUE, log.p = FALSE)
qinvtrgamma(p, shape1, shape2, rate = 1, scale = 1/rate,
            lower.tail = TRUE, log.p = FALSE)
rinvtrgamma(n, shape1, shape2, rate = 1, scale = 1/rate)
minvtrgamma(order, shape1, shape2, rate = 1, scale = 1/rate)
levinvtrgamma(limit, shape1, shape2, rate = 1, scale = 1/rate,
              order = 1)
```

Arguments

x, q	vector of quantiles.
p	vector of probabilities.
n	number of observations. If length(n) > 1, the length is taken to be the number required.
shape1, shape2, scale	parameters. Must be strictly positive.
rate	an alternative way to specify the scale.
log, log.p	logical; if TRUE, probabilities/densities p are returned as $\log(p)$.
lower.tail	logical; if TRUE (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.
order	order of the moment.
limit	limit of the loss variable.

Details

The inverse transformed gamma distribution with parameters `shape1` $= \alpha$, `shape2` $= \tau$ and `scale` $= \theta$, has density:

$$f(x) = \frac{\tau u^{\alpha} e^{-u}}{x\Gamma(\alpha)}, \quad u = (\theta/x)^{\tau}$$

for $x > 0$, $\alpha > 0$, $\tau > 0$ and $\theta > 0$. (Here $\Gamma(\alpha)$ is the function implemented by R's `gamma()` and defined in its help.)

The inverse transformed gamma is the distribution of the random variable $\theta X^{-1/\tau}$, where X has a gamma distribution with shape parameter α and scale parameter 1 or, equivalently, of the random variable $Y^{-1/\tau}$ with Y a gamma distribution with shape parameter α and scale parameter $\theta^{-\tau}$.

The inverse transformed gamma distribution defines a family of distributions with the following special cases:

- An Inverse Gamma distribution when `shape2 == 1`;
- An Inverse Weibull distribution when `shape1 == 1`;
- An Inverse Exponential distribution when `shape1 == shape2 == 1`;

The kth raw moment of the random variable X is $E[X^k]$, $k < \alpha\tau$, and the kth limited moment at some limit d is $E[\min(X, d)^k]$ for all k.

Value

`dinvtrgamma` gives the density, `pinvtrgamma` gives the distribution function, `qinvtrgamma` gives the quantile function, `rinvtrgamma` generates random deviates, `minvtrgamma` gives the kth raw moment, and `levinvtrgamma` gives the kth moment of the limited loss variable.

Invalid arguments will result in return value `NaN`, with a warning.

Note

`levinvtrgamma` computes the limited expected value using `gammainc` from package **expint**.

Distribution also known as the Inverse Generalized Gamma. See also Kleiber and Kotz (2003) for alternative names and parametrizations.

The `"distributions"` package vignette provides the interrelations between the continuous size distributions in **actuar** and the complete formulas underlying the above functions.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca> and Mathieu Pigeon

References

Kleiber, C. and Kotz, S. (2003), *Statistical Size Distributions in Economics and Actuarial Sciences*, Wiley.

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

Examples

```
exp(dinvtrgamma(2, 3, 4, 5, log = TRUE))
p <- (1:10)/10
pinvtrgamma(qinvtrgamma(p, 2, 3, 4), 2, 3, 4)
minvtrgamma(2, 3, 4, 5)
levinvtrgamma(200, 3, 4, 5, order = 2)
```

InverseWeibull *The Inverse Weibull Distribution*

Description

Density function, distribution function, quantile function, random generation, raw moments and limited moments for the Inverse Weibull distribution with parameters shape and scale.

Usage

```
dinvweibull(x, shape, rate = 1, scale = 1/rate, log = FALSE)
pinvweibull(q, shape, rate = 1, scale = 1/rate,
            lower.tail = TRUE, log.p = FALSE)
qinvweibull(p, shape, rate = 1, scale = 1/rate,
            lower.tail = TRUE, log.p = FALSE)
rinvweibull(n, shape, rate = 1, scale = 1/rate)
minvweibull(order, shape, rate = 1, scale = 1/rate)
levinvweibull(limit, shape, rate = 1, scale = 1/rate,
              order = 1)
```

Arguments

x, q	vector of quantiles.
p	vector of probabilities.
n	number of observations. If length(n) > 1, the length is taken to be the number required.
shape, scale	parameters. Must be strictly positive.
rate	an alternative way to specify the scale.
log, log.p	logical; if TRUE, probabilities/densities p are returned as $\log(p)$.
lower.tail	logical; if TRUE (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.
order	order of the moment.
limit	limit of the loss variable.

Details

The inverse Weibull distribution with parameters `shape` $= \tau$ and `scale` $= \theta$ has density:

$$f(x) = \frac{\tau(\theta/x)^\tau e^{-(\theta/x)^\tau}}{x}$$

for $x > 0$, $\tau > 0$ and $\theta > 0$.

The special case `shape == 1` is an Inverse Exponential distribution.

The kth raw moment of the random variable X is $E[X^k]$, $k < \tau$, and the kth limited moment at some limit d is $E[\min(X, d)^k]$, all k.

Value

`dinvweibull` gives the density, `pinvweibull` gives the distribution function, `qinvweibull` gives the quantile function, `rinvweibull` generates random deviates, `minvweibull` gives the kth raw moment, and `levinvweibull` gives the kth moment of the limited loss variable.

Invalid arguments will result in return value `NaN`, with a warning.

Note

`levinvweibull` computes the limited expected value using `gammainc` from package **expint**.

Distribution also knonw as the log-Gompertz. See also Kleiber and Kotz (2003) for alternative names and parametrizations.

The `"distributions"` package vignette provides the interrelations between the continuous size distributions in **actuar** and the complete formulas underlying the above functions.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca> and Mathieu Pigeon

References

Kleiber, C. and Kotz, S. (2003), *Statistical Size Distributions in Economics and Actuarial Sciences*, Wiley.

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

Examples

```
exp(dinvweibull(2, 3, 4, log = TRUE))
p <- (1:10)/10
pinvweibull(qinvweibull(p, 2, 3), 2, 3)
mlgompertz(-1, 3, 3)
levinvweibull(10, 2, 3, order = 1)
```

Logarithmic *The Logarithmic Distribution*

Description

Density function, distribution function, quantile function and random generation for the Logarithmic (or log-series) distribution with parameter prob.

Usage

```
dlogarithmic(x, prob, log = FALSE)
plogarithmic(q, prob, lower.tail = TRUE, log.p = FALSE)
qlogarithmic(p, prob, lower.tail = TRUE, log.p = FALSE)
rlogarithmic(n, prob)
```

Arguments

x	vector of (strictly positive integer) quantiles.
q	vector of quantiles.
p	vector of probabilities.
n	number of observations. If length(n) > 1, the length is taken to be the number required.
prob	parameter. 0 <= prob < 1.
log, log.p	logical; if TRUE, probabilities p are returned as $\log(p)$.
lower.tail	logical; if TRUE (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.

Details

The logarithmic (or log-series) distribution with parameter prob $= \theta$ has probability mass function

$$p(x) = \frac{a\theta^x}{x},$$

with $a = -1/\log(1-\theta)$ and for $x = 1, 2, \ldots$, $0 \leq \theta < 1$.

The logarithmic distribution is the limiting case of the zero-truncated negative binomial distribution with size parameter equal to 0. Note that in this context, parameter prob generally corresponds to the probability of *failure* of the zero-truncated negative binomial.

If an element of x is not integer, the result of dlogarithmic is zero, with a warning.

The quantile is defined as the smallest value x such that $F(x) \geq p$, where F is the distribution function.

Value

`dlogarithmic` gives the probability mass function, `plogarithmic` gives the distribution function, `qlogarithmic` gives the quantile function, and `rlogarithmic` generates random deviates.

Invalid `prob` will result in return value `NaN`, with a warning.

The length of the result is determined by `n` for `rlogarithmic`, and is the maximum of the lengths of the numerical arguments for the other functions.

Note

`qlogarithmic` is based on `qbinom` et al.; it uses the Cornish–Fisher Expansion to include a skewness correction to a normal approximation, followed by a search.

`rlogarithmic` is an implementation of the LS and LK algorithms of Kemp (1981) with automatic selection. As suggested by Devroye (1986), the LS algorithm is used when `prob` < `0.95`, and the LK algorithm otherwise.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>

References

Johnson, N. L., Kemp, A. W. and Kotz, S. (2005), *Univariate Discrete Distributions, Third Edition*, Wiley.

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

Kemp, A. W. (1981), "Efficient Generation of Logarithmically Distributed Pseudo-Random Variables", *Journal of the Royal Statistical Society, Series C*, vol. 30, p. 249-253.

Devroye, L. (1986), *Non-Uniform Random Variate Generation*, Springer-Verlag. https://luc.devroye.org/rnbookindex.html

See Also

`dztnbinom` for the zero-truncated negative binomial distribution.

Examples

```
## Table 1 of Kemp (1981) [also found in Johnson et al. (2005), chapter 7]
p <- c(0.1, 0.3, 0.5, 0.7, 0.8, 0.85, 0.9, 0.95, 0.99, 0.995, 0.999, 0.9999)
round(rbind(dlogarithmic(1, p),
            dlogarithmic(2, p),
            plogarithmic(9, p, lower.tail = FALSE),
            -p/((1 - p) * log(1 - p))), 2)

qlogarithmic(plogarithmic(1:10, 0.9), 0.9)

x <- rlogarithmic(1000, 0.8)
y <- sort(unique(x))
plot(y, table(x)/length(x), type = "h", lwd = 2,
```

```
     pch = 19, col = "black", xlab = "x", ylab = "p(x)",
     main = "Empirical vs theoretical probabilities")
points(y, dlogarithmic(y, prob = 0.8),
       pch = 19, col = "red")
legend("topright", c("empirical", "theoretical"),
       lty = c(1, NA), pch = c(NA, 19), col = c("black", "red"))
```

Loggamma *The Loggamma Distribution*

Description

Density function, distribution function, quantile function, random generation, raw moments and limited moments for the Loggamma distribution with parameters `shapelog` and `ratelog`.

Usage

```
dlgamma(x, shapelog, ratelog, log = FALSE)
plgamma(q, shapelog, ratelog, lower.tail = TRUE, log.p = FALSE)
qlgamma(p, shapelog, ratelog, lower.tail = TRUE, log.p = FALSE)
rlgamma(n, shapelog, ratelog)
mlgamma(order, shapelog, ratelog)
levlgamma(limit, shapelog, ratelog, order = 1)
```

Arguments

`x`, `q`	vector of quantiles.
`p`	vector of probabilities.
`n`	number of observations. If `length(n) > 1`, the length is taken to be the number required.
`shapelog`, `ratelog`	parameters. Must be strictly positive.
`log`, `log.p`	logical; if `TRUE`, probabilities/densities p are returned as $\log(p)$.
`lower.tail`	logical; if `TRUE` (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.
`order`	order of the moment.
`limit`	limit of the loss variable.

Details

The loggamma distribution with parameters `shapelog` $= \alpha$ and `ratelog` $= \lambda$ has density:

$$f(x) = \frac{\lambda^\alpha}{\Gamma(\alpha)} \frac{(\log x)^{\alpha-1}}{x^{\lambda+1}}$$

for $x > 1$, $\alpha > 0$ and $\lambda > 0$. (Here $\Gamma(\alpha)$ is the function implemented by R's `gamma()` and defined in its help.)

The loggamma is the distribution of the random variable e^X, where X has a gamma distribution with shape parameter $alpha$ and scale parameter $1/\lambda$.

The kth raw moment of the random variable X is $E[X^k]$ and the kth limited moment at some limit d is $E[\min(X, d)^k]$, $k < \lambda$.

Value

`dlgamma` gives the density, `plgamma` gives the distribution function, `qlgamma` gives the quantile function, `rlgamma` generates random deviates, `mlgamma` gives the kth raw moment, and `levlgamma` gives the kth moment of the limited loss variable.

Invalid arguments will result in return value `NaN`, with a warning.

Note

The `"distributions"` package vignette provides the interrelations between the continuous size distributions in **actuar** and the complete formulas underlying the above functions.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca> and Mathieu Pigeon

References

Hogg, R. V. and Klugman, S. A. (1984), *Loss Distributions*, Wiley.

Examples

```
exp(dlgamma(2, 3, 4, log = TRUE))
p <- (1:10)/10
plgamma(qlgamma(p, 2, 3), 2, 3)
mlgamma(2, 3, 4) - mlgamma(1, 3, 4)^2
levlgamma(10, 3, 4, order = 2)
```

Loglogistic *The Loglogistic Distribution*

Description

Density function, distribution function, quantile function, random generation, raw moments and limited moments for the Loglogistic distribution with parameters `shape` and `scale`.

Usage

```
dllogis(x, shape, rate = 1, scale = 1/rate, log = FALSE)
pllogis(q, shape, rate = 1, scale = 1/rate,
        lower.tail = TRUE, log.p = FALSE)
qllogis(p, shape, rate = 1, scale = 1/rate,
        lower.tail = TRUE, log.p = FALSE)
rllogis(n, shape, rate = 1, scale = 1/rate)
mllogis(order, shape, rate = 1, scale = 1/rate)
levllogis(limit, shape, rate = 1, scale = 1/rate,
          order = 1)
```

Arguments

x, q	vector of quantiles.
p	vector of probabilities.
n	number of observations. If length(n) > 1, the length is taken to be the number required.
shape, scale	parameters. Must be strictly positive.
rate	an alternative way to specify the scale.
log, log.p	logical; if TRUE, probabilities/densities p are returned as $\log(p)$.
lower.tail	logical; if TRUE (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.
order	order of the moment.
limit	limit of the loss variable.

Details

The loglogistic distribution with parameters shape $= \gamma$ and scale $= \theta$ has density:

$$f(x) = \frac{\gamma(x/\theta)^\gamma}{x[1 + (x/\theta)^\gamma]^2}$$

for $x > 0$, $\gamma > 0$ and $\theta > 0$.

The kth raw moment of the random variable X is $E[X^k]$, $-\gamma < k < \gamma$.

The kth limited moment at some limit d is $E[\min(X, d)^k]$, $k > -\gamma$ and $1 - k/\gamma$ not a negative integer.

Value

dllogis gives the density, pllogis gives the distribution function, qllogis gives the quantile function, rllogis generates random deviates, mllogis gives the kth raw moment, and levllogis gives the kth moment of the limited loss variable.

Invalid arguments will result in return value NaN, with a warning.

Note

`levllogis` computes the limited expected value using `betaint`.

Also known as the Fisk distribution. See also Kleiber and Kotz (2003) for alternative names and parametrizations.

The `"distributions"` package vignette provides the interrelations between the continuous size distributions in **actuar** and the complete formulas underlying the above functions.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca> and Mathieu Pigeon

References

Kleiber, C. and Kotz, S. (2003), *Statistical Size Distributions in Economics and Actuarial Sciences*, Wiley.

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

See Also

`dpareto3` for an equivalent distribution with a location parameter.

Examples

```
exp(dllogis(2, 3, 4, log = TRUE))
p <- (1:10)/10
pllogis(qllogis(p, 2, 3), 2, 3)

## mean
mllogis(1, 2, 3)

## case with 1 - order/shape > 0
levllogis(10, 2, 3, order = 1)

## case with 1 - order/shape < 0
levllogis(10, 2/3, 3, order = 1)
```

`LognormalMoments` *Raw and Limited Moments of the Lognormal Distribution*

Description

Raw moments and limited moments for the Lognormal distribution whose logarithm has mean equal to `meanlog` and standard deviation equal to `sdlog`.

Usage

```
mlnorm(order, meanlog = 0, sdlog = 1)
levlnorm(limit, meanlog = 0, sdlog = 1, order = 1)
```

Arguments

order	order of the moment.
limit	limit of the loss variable.
meanlog, sdlog	mean and standard deviation of the distribution on the log scale with default values of 0 and 1 respectively.

Value

mlnorm gives the kth raw moment and levlnorm gives the kth moment of the limited loss variable.

Invalid arguments will result in return value NaN, with a warning.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca> and Mathieu Pigeon

References

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

See Also

Lognormal for details on the lognormal distribution and functions [dpqr]lnorm.

Examples

```
mlnorm(2, 3, 4) - mlnorm(1, 3, 4)^2
levlnorm(10, 3, 4, order = 2)
```

---

mde *Minimum Distance Estimation*

Description

Minimum distance fitting of univariate distributions, allowing parameters to be held fixed if desired.

Usage

```
mde(x, fun, start, measure = c("CvM", "chi-square", "LAS"),
    weights = NULL, ...)
```

Arguments

x	a vector or an object of class "grouped data" (in which case only the first column of frequencies is used).
fun	function returning a cumulative distribution (for measure = "CvM" and measure = "chi-square") or a limited expected value (for measure = "LAS") evaluated at its first argument.
start	a named list giving the parameters to be optimized with initial values
measure	either "CvM" for the Cramer-von Mises method, "chi-square" for the modified chi-square method, or "LAS" for the layer average severity method.
weights	weights; see Details.
...	Additional parameters, either for fun or for optim. In particular, it can be used to specify bounds via lower or upper or both. If arguments of fun are included they will be held fixed.

Details

The Cramer-von Mises method ("CvM") minimizes the squared difference between the theoretical cdf and the empirical cdf at the data points (for individual data) or the ogive at the knots (for grouped data).

The modified chi-square method ("chi-square") minimizes the modified chi-square statistic for grouped data, that is the squared difference between the expected and observed frequency within each group.

The layer average severity method ("LAS") minimizes the squared difference between the theoretical and empirical limited expected value within each group for grouped data.

All sum of squares can be weighted. If arguments weights is missing, weights default to 1 for measure = "CvM" and measure = "LAS"; for measure = "chi-square", weights default to $1/n_j$, where n_j is the frequency in group $j = 1, \ldots, r$.

Optimization is performed using optim. For one-dimensional problems the Nelder-Mead method is used and for multi-dimensional problems the BFGS method, unless arguments named lower or upper are supplied when L-BFGS-B is used or method is supplied explicitly.

Value

An object of class "mde", a list with two components:

estimate	the parameter estimates, and
distance	the distance.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca> and Mathieu Pigeon

References

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (1998), *Loss Models, From Data to Decisions*, Wiley.

Examples

```
## Individual data example
data(dental)
mde(dental, pexp, start = list(rate = 1/200), measure = "CvM")

## Example 2.21 of Klugman et al. (1998)
data(gdental)
mde(gdental, pexp, start = list(rate = 1/200), measure = "CvM")
mde(gdental, pexp, start = list(rate = 1/200), measure = "chi-square")
mde(gdental, levexp, start = list(rate = 1/200), measure = "LAS")

## Two-parameter distribution example
try(mde(gdental, ppareto, start = list(shape = 3, scale = 600),
        measure = "CvM")) # no convergence

## Working in log scale often solves the problem
pparetolog <- function(x, shape, scale)
    ppareto(x, exp(shape), exp(scale))

( p <- mde(gdental, pparetolog, start = list(shape = log(3),
           scale = log(600)), measure = "CvM") )
exp(p$estimate)
```

---

mean.grouped.data *Arithmetic Mean*

Description

Mean of grouped data objects.

Usage

```
## S3 method for class 'grouped.data'
mean(x, ...)
```

Arguments

x	an object of class "grouped.data".
...	further arguments passed to or from other methods.

Details

The mean of grouped data with group boundaries $c_0, c_1, \ldots, c_r$ and group frequencies $n_1, \ldots, n_r$ is

$$\frac{1}{n}\sum_{j=1}^{r} a_j n_j,$$

where $a_j = (c_{j-1} + c_j)/2$ is the midpoint of the jth interval, and $n = \sum_{j=1}^{r} n_j$.

Value

A named vector of means.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>

References

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (1998), *Loss Models, From Data to Decisions*, Wiley.

See Also

`grouped.data` to create grouped data objects; `emm` to compute higher moments.

Examples

```
data(gdental)
mean(gdental)
```

NormalSupp *Moments and Moment generating function of the Normal Distribution*

Description

Raw moments and moment generating function for the normal distribution with mean equal to `mean` and standard deviation equal to `sd`.

Usage

```
mnorm(order, mean = 0, sd = 1)
mgfnorm(t, mean = 0, sd = 1, log = FALSE)
```

Arguments

`order`	vector of integers; order of the moment.
`mean`	vector of means.
`sd`	vector of standard deviations.
`t`	numeric vector.
`log`	logical; if `TRUE`, the cumulant generating function is returned.

Details

The kth raw moment of the random variable X is $E[X^k]$ and the moment generating function is $E[e^{tX}]$.

Only integer moments are supported.

Value

mnorm gives the kth raw moment and mgfnorm gives the moment generating function in t. Invalid arguments will result in return value NaN, with a warning.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>, Christophe Dutang

References

Johnson, N. L. and Kotz, S. (1970), *Continuous Univariate Distributions, Volume 1*, Wiley.

See Also

Normal

Examples

```
mgfnorm(0:4,1,2)
mnorm(3)
```

---

ogive *Ogive for Grouped Data*

Description

Compute a smoothed empirical distribution function for grouped data.

Usage

```
ogive(x, ...)

## Default S3 method:
ogive(x, y = NULL, breaks = "Sturges", nclass = NULL, ...)

## S3 method for class 'grouped.data'
ogive(x, ...)

## S3 method for class 'ogive'
print(x, digits = getOption("digits") - 2, ...)

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

## S3 method for class 'ogive'
knots(Fn, ...)

## S3 method for class 'ogive'
plot(x, main = NULL, xlab = "x", ylab = "F(x)", ...)
```

Arguments

x	for the generic and all but the default method, an object of class "grouped.data"; for the default method, a vector of individual data if y is NULL, a vector of group boundaries otherwise.
y	a vector of group frequencies.
breaks, nclass	arguments passed to grouped.data; used only for individual data (when y is NULL).
digits	number of significant digits to use, see print.
Fn, object	an R object inheriting from "ogive".
main	main title.
xlab, ylab	labels of x and y axis.
...	arguments to be passed to subsequent methods.

Details

The ogive is a linear interpolation of the empirical cumulative distribution function.

The equation of the ogive is

$$G_n(x) = \frac{(c_j - x)F_n(c_{j-1}) + (x - c_{j-1})F_n(c_j)}{c_j - c_{j-1}}$$

for $c_{j-1} < x \leq c_j$ and where $c_0, \ldots, c_r$ are the $r + 1$ group boundaries and F_n is the empirical distribution function of the sample.

Value

For ogive, a function of class "ogive", inheriting from the "function" class.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca> and Mathieu Pigeon

References

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (1998), *Loss Models, From Data to Decisions*, Wiley.

See Also

grouped.data to create grouped data objects; quantile.grouped.data for the inverse function; approxfun, which is used to compute the ogive; stepfun for related documentation (even though the ogive is not a step function).

Examples

```
## Most common usage: create ogive from grouped data object.
Fn <- ogive(gdental)
Fn
summary(Fn)
knots(Fn)                     # the group boundaries

Fn(knots(Fn))                 # true values of the empirical cdf
Fn(c(80, 200, 2000))          # linear interpolations

plot(Fn)                      # graphical representation

## Alternative 1: create ogive directly from individual data
## without first creating a grouped data object.
ogive(dental)                 # automatic class boundaries
ogive(dental, breaks = c(0, 50, 200, 500, 1500, 2000))

## Alternative 2: create ogive from set of group boundaries and
## group frequencies.
cj <- c(0, 25, 50, 100, 250, 500, 1000)
nj <- c(30, 31, 57, 42, 45, 10)
ogive(cj, nj)
```

Paralogistic *The Paralogistic Distribution*

Description

Density function, distribution function, quantile function, random generation, raw moments and limited moments for the Paralogistic distribution with parameters `shape` and `scale`.

Usage

```
dparalogis(x, shape, rate = 1, scale = 1/rate, log = FALSE)
pparalogis(q, shape, rate = 1, scale = 1/rate,
           lower.tail = TRUE, log.p = FALSE)
qparalogis(p, shape, rate = 1, scale = 1/rate,
           lower.tail = TRUE, log.p = FALSE)
rparalogis(n, shape, rate = 1, scale = 1/rate)
mparalogis(order, shape, rate = 1, scale = 1/rate)
levparalogis(limit, shape, rate = 1, scale = 1/rate,
             order = 1)
```

Arguments

`x, q`	vector of quantiles.
`p`	vector of probabilities.

n	number of observations. If length(n) > 1, the length is taken to be the number required.
shape, scale	parameters. Must be strictly positive.
rate	an alternative way to specify the scale.
log, log.p	logical; if TRUE, probabilities/densities p are returned as $\log(p)$.
lower.tail	logical; if TRUE (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.
order	order of the moment.
limit	limit of the loss variable.

Details

The paralogistic distribution with parameters shape $= \alpha$ and scale $= \theta$ has density:

$$f(x) = \frac{\alpha^2 (x/\theta)^\alpha}{x[1 + (x/\theta)^\alpha)^{\alpha+1}}$$

for $x > 0$, $\alpha > 0$ and $\theta > 0$.

The kth raw moment of the random variable X is $E[X^k]$, $-\alpha < k < \alpha^2$.

The kth limited moment at some limit d is $E[\min(X, d)^k]$, $k > -\alpha$ and $\alpha - k/\alpha$ not a negative integer.

Value

dparalogis gives the density, pparalogis gives the distribution function, qparalogis gives the quantile function, rparalogis generates random deviates, mparalogis gives the kth raw moment, and levparalogis gives the kth moment of the limited loss variable.

Invalid arguments will result in return value NaN, with a warning.

Note

levparalogis computes the limited expected value using betaint.

See Kleiber and Kotz (2003) for alternative names and parametrizations.

The "distributions" package vignette provides the interrelations between the continuous size distributions in **actuar** and the complete formulas underlying the above functions.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca> and Mathieu Pigeon

References

Kleiber, C. and Kotz, S. (2003), *Statistical Size Distributions in Economics and Actuarial Sciences*, Wiley.

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

Examples

```
exp(dparalogis(2, 3, 4, log = TRUE))
p <- (1:10)/10
pparalogis(qparalogis(p, 2, 3), 2, 3)

## variance
mparalogis(2, 2, 3) - mparalogis(1, 2, 3)^2

## case with shape - order/shape > 0
levparalogis(10, 2, 3, order = 2)

## case with shape - order/shape < 0
levparalogis(10, 1.25, 3, order = 2)
```

Pareto *The Pareto Distribution*

Description

Density function, distribution function, quantile function, random generation, raw moments and limited moments for the Pareto distribution with parameters shape and scale.

Usage

```
dpareto(x, shape, scale, log = FALSE)
ppareto(q, shape, scale, lower.tail = TRUE, log.p = FALSE)
qpareto(p, shape, scale, lower.tail = TRUE, log.p = FALSE)
rpareto(n, shape, scale)
mpareto(order, shape, scale)
levpareto(limit, shape, scale, order = 1)
```

Arguments

x, q	vector of quantiles.
p	vector of probabilities.
n	number of observations. If length(n) > 1, the length is taken to be the number required.
shape, scale	parameters. Must be strictly positive.
log, log.p	logical; if TRUE, probabilities/densities p are returned as $\log(p)$.
lower.tail	logical; if TRUE (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.
order	order of the moment.
limit	limit of the loss variable.

Details

The Pareto distribution with parameters `shape` $= \alpha$ and `scale` $= \theta$ has density:

$$f(x) = \frac{\alpha\theta^\alpha}{(x+\theta)^{\alpha+1}}$$

for $x > 0$, $\alpha > 0$ and θ.

There are many different definitions of the Pareto distribution in the literature; see Arnold (2015) or Kleiber and Kotz (2003). In the nomenclature of **actuar**, The "Pareto distribution" does not have a location parameter. The version with a location parameter is the Pareto II.

The kth raw moment of the random variable X is $E[X^k]$, $-1 < k < \alpha$.

The kth limited moment at some limit d is $E[\min(X, d)^k]$, $k > -1$ and $\alpha - k$ not a negative integer.

Value

`dpareto` gives the density, `ppareto` gives the distribution function, `qpareto` gives the quantile function, `rpareto` generates random deviates, `mpareto` gives the kth raw moment, and `levpareto` gives the kth moment of the limited loss variable.

Invalid arguments will result in return value `NaN`, with a warning.

Note

`levpareto` computes the limited expected value using `betaint`.

The version of the Pareto defined for $x > \theta$ is named Single Parameter Pareto, or Pareto I, in **actuar**.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca> and Mathieu Pigeon

References

Kleiber, C. and Kotz, S. (2003), *Statistical Size Distributions in Economics and Actuarial Sciences*, Wiley.

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

See Also

`dpareto2` for an equivalent distribution with location parameter.

`dpareto1` for the Single Parameter Pareto distribution.

`"distributions"` package vignette for details on the interrelations between the continuous size distributions in **actuar** and complete formulas underlying the above functions.

Examples

```
exp(dpareto(2, 3, 4, log = TRUE))
p <- (1:10)/10
ppareto(qpareto(p, 2, 3), 2, 3)

## variance
mpareto(2, 4, 1) - mpareto(1, 4, 1)^2

## case with shape - order > 0
levpareto(10, 3, scale = 1, order = 2)

## case with shape - order < 0
levpareto(10, 1.5, scale = 1, order = 2)
```

Pareto2 *The Pareto II Distribution*

Description

Density function, distribution function, quantile function, random generation, raw moments and limited moments for the Pareto II distribution with parameters `min`, `shape` and `scale`.

Usage

```
dpareto2(x, min, shape, rate = 1, scale = 1/rate,
         log = FALSE)
ppareto2(q, min, shape, rate = 1, scale = 1/rate,
         lower.tail = TRUE, log.p = FALSE)
qpareto2(p, min, shape, rate = 1, scale = 1/rate,
         lower.tail = TRUE, log.p = FALSE)
rpareto2(n, min, shape, rate = 1, scale = 1/rate)
mpareto2(order, min, shape, rate = 1, scale = 1/rate)
levpareto2(limit, min, shape, rate = 1, scale = 1/rate,
           order = 1)
```

Arguments

`x`, `q`	vector of quantiles.
`p`	vector of probabilities.
`n`	number of observations. If `length(n) > 1`, the length is taken to be the number required.
`min`	lower bound of the support of the distribution.
`shape`, `scale`	parameters. Must be strictly positive.
`rate`	an alternative way to specify the scale.
`log`, `log.p`	logical; if `TRUE`, probabilities/densities p are returned as $\log(p)$.
`lower.tail`	logical; if `TRUE` (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.
`order`	order of the moment.
`limit`	limit of the loss variable.

Details

The Pareto II (or "type II") distribution with parameters `min` $= \mu$, `shape` $= \alpha$ and `scale` $= \theta$ has density:

$$f(x) = \frac{\alpha}{\theta[1 + (x - \mu)/\theta]^{\alpha+1}}$$

for $x > \mu$, $-\infty < \mu < \infty$, $\alpha > 0$ and $\theta > 0$.

The Pareto II is the distribution of the random variable

$$\mu + \theta \left(\frac{X}{1 - X} \right),$$

where X has a beta distribution with parameters 1 and α. It derives from the Feller-Pareto distribution with $\tau = \gamma = 1$. Setting $\mu = 0$ yields the familiar Pareto distribution.

The Pareto I (or Single parameter Pareto) distribution is a special case of the Pareto II with `min == scale`.

The kth raw moment of the random variable X is $E[X^k]$ for nonnegative integer values of $k < \alpha$.

The kth limited moment at some limit d is $E[\min(X, d)^k]$ for nonnegative integer values of k and $\alpha - j$, $j = 1, \ldots, k$ not a negative integer.

Value

`dpareto2` gives the density, `ppareto2` gives the distribution function, `qpareto2` gives the quantile function, `rpareto2` generates random deviates, `mpareto2` gives the kth raw moment, and `levpareto2` gives the kth moment of the limited loss variable.

Invalid arguments will result in return value `NaN`, with a warning.

Note

`levpareto2` computes the limited expected value using `betaint`.

For Pareto distributions, we use the classification of Arnold (2015) with the parametrization of Klugman et al. (2012).

The `"distributions"` package vignette provides the interrelations between the continuous size distributions in **actuar** and the complete formulas underlying the above functions.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>

References

Arnold, B.C. (2015), *Pareto Distributions*, Second Edition, CRC Press.

Kleiber, C. and Kotz, S. (2003), *Statistical Size Distributions in Economics and Actuarial Sciences*, Wiley.

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

See Also

dpareto for the Pareto distribution without a location parameter.

Examples

```
exp(dpareto2(1, min = 10, 3, 4, log = TRUE))
p <- (1:10)/10
ppareto2(qpareto2(p, min = 10, 2, 3), min = 10, 2, 3)

## variance
mpareto2(2, min = 10, 4, 1) - mpareto2(1, min = 10, 4, 1)^2

## case with shape - order > 0
levpareto2(10, min = 10, 3, scale = 1, order = 2)

## case with shape - order < 0
levpareto2(10, min = 10, 1.5, scale = 1, order = 2)
```

Pareto3 *The Pareto III Distribution*

Description

Density function, distribution function, quantile function, random generation, raw moments and limited moments for the Pareto III distribution with parameters min, shape and scale.

Usage

```
dpareto3(x, min, shape, rate = 1, scale = 1/rate,
         log = FALSE)
ppareto3(q, min, shape, rate = 1, scale = 1/rate,
         lower.tail = TRUE, log.p = FALSE)
qpareto3(p, min, shape, rate = 1, scale = 1/rate,
         lower.tail = TRUE, log.p = FALSE)
rpareto3(n, min, shape, rate = 1, scale = 1/rate)
mpareto3(order, min, shape, rate = 1, scale = 1/rate)
levpareto3(limit, min, shape, rate = 1, scale = 1/rate,
           order = 1)
```

Arguments

x, q	vector of quantiles.
p	vector of probabilities.
n	number of observations. If length(n) > 1, the length is taken to be the number required.
min	lower bound of the support of the distribution.
shape, scale	parameters. Must be strictly positive.

`rate`	an alternative way to specify the scale.
`log`, `log.p`	logical; if `TRUE`, probabilities/densities p are returned as $\log(p)$.
`lower.tail`	logical; if `TRUE` (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.
`order`	order of the moment.
`limit`	limit of the loss variable.

Details

The Pareto III (or "type III") distribution with parameters `min` $= \mu$, `shape` $= \gamma$ and `scale` $= \theta$ has density:

$$f(x) = \frac{\gamma((x-\mu)/\theta)^{\gamma-1}}{\theta[1+((x-\mu)/\theta)^{\gamma}]^2}$$

for $x > \mu$, $-\infty < \mu < \infty$, $\gamma > 0$ and $\theta > 0$.

The Pareto III is the distribution of the random variable

$$\mu + \theta\left(\frac{X}{1-X}\right)^{1/\gamma},$$

where X has a uniform distribution on $(0, 1)$. It derives from the Feller-Pareto distribution with $\alpha = \tau = 1$. Setting $\mu = 0$ yields the loglogistic distribution.

The kth raw moment of the random variable X is $E[X^k]$ for nonnegative integer values of $k < \gamma$.

The kth limited moment at some limit d is $E[\min(X, d)^k]$ for nonnegative integer values of k and $1 - j/\gamma$, $j = 1, \ldots, k$ not a negative integer.

Value

`dpareto3` gives the density, `ppareto3` gives the distribution function, `qpareto3` gives the quantile function, `rpareto3` generates random deviates, `mpareto3` gives the kth raw moment, and `levpareto3` gives the kth moment of the limited loss variable.

Invalid arguments will result in return value `NaN`, with a warning.

Note

`levpareto3` computes the limited expected value using `betaint`.

For Pareto distributions, we use the classification of Arnold (2015) with the parametrization of Klugman et al. (2012).

The `"distributions"` package vignette provides the interrelations between the continuous size distributions in **actuar** and the complete formulas underlying the above functions.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>

References

Arnold, B.C. (2015), *Pareto Distributions*, Second Edition, CRC Press.

Kleiber, C. and Kotz, S. (2003), *Statistical Size Distributions in Economics and Actuarial Sciences*, Wiley.

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

See Also

dllogis for the loglogistic distribution.

Examples

```
exp(dpareto3(1, min = 10, 3, 4, log = TRUE))
p <- (1:10)/10
ppareto3(qpareto3(p, min = 10, 2, 3), min = 10, 2, 3)

## mean
mpareto3(1, min = 10, 2, 3)

## case with 1 - order/shape > 0
levpareto3(20, min = 10, 2, 3, order = 1)

## case with 1 - order/shape < 0
levpareto3(20, min = 10, 2/3, 3, order = 1)
```

Pareto4 *The Pareto IV Distribution*

Description

Density function, distribution function, quantile function, random generation, raw moments and limited moments for the Pareto IV distribution with parameters min, shape1, shape2 and scale.

Usage

```
dpareto4(x, min, shape1, shape2, rate = 1, scale = 1/rate,
         log = FALSE)
ppareto4(q, min, shape1, shape2, rate = 1, scale = 1/rate,
         lower.tail = TRUE, log.p = FALSE)
qpareto4(p, min, shape1, shape2, rate = 1, scale = 1/rate,
         lower.tail = TRUE, log.p = FALSE)
rpareto4(n, min, shape1, shape2, rate = 1, scale = 1/rate)
mpareto4(order, min, shape1, shape2, rate = 1, scale = 1/rate)
levpareto4(limit, min, shape1, shape2, rate = 1, scale = 1/rate,
           order = 1)
```

Arguments

x, q	vector of quantiles.
p	vector of probabilities.
n	number of observations. If length(n) > 1, the length is taken to be the number required.
min	lower bound of the support of the distribution.
shape1, shape2, scale	parameters. Must be strictly positive.
rate	an alternative way to specify the scale.
log, log.p	logical; if TRUE, probabilities/densities p are returned as $\log(p)$.
lower.tail	logical; if TRUE (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.
order	order of the moment.
limit	limit of the loss variable.

Details

The Pareto IV (or "type IV") distribution with parameters min $= \mu$, shape1 $= \alpha$, shape2 $= \gamma$ and scale $= \theta$ has density:

$$f(x) = \frac{\alpha\gamma((x-\mu)/\theta)^{\gamma-1}}{\theta[1+((x-\mu)/\theta)^{\gamma}]^{\alpha+1}}$$

for $x > \mu$, $-\infty < \mu < \infty$, $\alpha > 0$, $\gamma > 0$ and $\theta > 0$.

The Pareto IV is the distribution of the random variable

$$\mu + \theta\left(\frac{X}{1-X}\right)^{1/\gamma},$$

where X has a beta distribution with parameters 1 and α. It derives from the Feller-Pareto distribution with $\tau = 1$. Setting $\mu = 0$ yields the Burr distribution.

The Pareto IV distribution also has the following direct special cases:

- A Pareto III distribution when shape1 == 1;
- A Pareto II distribution when shape1 == 1.

The kth raw moment of the random variable X is $E[X^k]$ for nonnegative integer values of $k < \alpha\gamma$.

The kth limited moment at some limit d is $E[\min(X,d)^k]$ for nonnegative integer values of k and $\alpha - j/\gamma$, $j = 1, \ldots, k$ not a negative integer.

Value

dpareto4 gives the density, ppareto4 gives the distribution function, qpareto4 gives the quantile function, rpareto4 generates random deviates, mpareto4 gives the kth raw moment, and levpareto4 gives the kth moment of the limited loss variable.

Invalid arguments will result in return value NaN, with a warning.

Note

levpareto4 computes the limited expected value using betaint.

For Pareto distributions, we use the classification of Arnold (2015) with the parametrization of Klugman et al. (2012).

The "distributions" package vignette provides the interrelations between the continuous size distributions in **actuar** and the complete formulas underlying the above functions.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>

References

Arnold, B.C. (2015), *Pareto Distributions*, Second Edition, CRC Press.

Kleiber, C. and Kotz, S. (2003), *Statistical Size Distributions in Economics and Actuarial Sciences*, Wiley.

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

See Also

dburr for the Burr distribution.

Examples

```
exp(dpareto4(1, min = 10, 2, 3, log = TRUE))
p <- (1:10)/10
ppareto4(qpareto4(p, min = 10, 2, 3, 2), min = 10, 2, 3, 2)

## variance
mpareto4(2, min = 10, 2, 3, 1) - mpareto4(1, min = 10, 2, 3, 1) ^ 2

## case with shape1 - order/shape2 > 0
levpareto4(10, min = 10, 2, 3, 1, order = 2)

## case with shape1 - order/shape2 < 0
levpareto4(10, min = 10, 1.5, 0.5, 1, order = 2)
```

PhaseType *The Phase-type Distribution*

Description

Density, distribution function, random generation, raw moments and moment generating function for the (continuous) Phase-type distribution with parameters prob and rates.

Usage

```
dphtype(x, prob, rates, log = FALSE)
pphtype(q, prob, rates, lower.tail = TRUE, log.p = FALSE)
rphtype(n, prob, rates)
mphtype(order, prob, rates)
mgfphtype(t, prob, rates, log = FALSE)
```

Arguments

x, q	vector of quantiles.
n	number of observations. If length(n) > 1, the length is taken to be the number required.
prob	vector of initial probabilities for each of the transient states of the underlying Markov chain. The initial probability of the absorbing state is 1 - sum(prob).
rates	square matrix of the rates of transition among the states of the underlying Markov chain.
log, log.p	logical; if TRUE, probabilities/densities p are returned as $\log(p)$.
lower.tail	logical; if TRUE (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.
order	order of the moment.
t	numeric vector.

Details

The phase-type distribution with parameters prob $= \pi$ and rates $= \boldsymbol{T}$ has density:

$$f(x) = \pi e^{\boldsymbol{T}x}\boldsymbol{t}$$

for $x \geq 0$ and $f(0) = 1 - \pi\boldsymbol{e}$, where $\boldsymbol{e}$ is a column vector with all components equal to one, $\boldsymbol{t} = -\boldsymbol{T}\boldsymbol{e}$ is the exit rates vector and $e^{\boldsymbol{T}x}$ denotes the matrix exponential of $\boldsymbol{T}x$. The matrix exponential of a matrix $\boldsymbol{M}$ is defined as the Taylor series

$$e^{\boldsymbol{M}} = \sum_{n=0}^{\infty} \frac{\boldsymbol{M}^n}{n!}.$$

The parameters of the distribution must satisfy $\pi\boldsymbol{e} \leq 1$, $\boldsymbol{T}_{ii} < 0$, $\boldsymbol{T}_{ij} \geq 0$ and $\boldsymbol{T}\boldsymbol{e} \leq 0$.

The kth raw moment of the random variable X is $E[X^k]$ and the moment generating function is $E[e^{tX}]$.

Value

dphasetype gives the density, pphasetype gives the distribution function, rphasetype generates random deviates, mphasetype gives the kth raw moment, and mgfphasetype gives the moment generating function in x.

Invalid arguments will result in return value NaN, with a warning.

Note

The "distributions" package vignette provides the interrelations between the continuous size distributions in **actuar** and the complete formulas underlying the above functions.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca> and Christophe Dutang

References

https://en.wikipedia.org/wiki/Phase-type_distribution

Neuts, M. F. (1981), *Generating random variates from a distribution of phase type*, WSC '81: Proceedings of the 13th conference on Winter simulation, IEEE Press.

Examples

```
## Erlang(3, 2) distribution
T <- cbind(c(-2, 0, 0), c(2, -2, 0), c(0, 2, -2))
pi <- c(1,0,0)
x <- 0:10

dphtype(x, pi, T)  # density
dgamma(x, 3, 2)   # same
pphtype(x, pi, T)  # cdf
pgamma(x, 3, 2)   # same

rphtype(10, pi, T)  # random values

mphtype(1, pi, T)  # expected value

curve(mgfphtype(x, pi, T), from = -10, to = 1)
```

PoissonInverseGaussian

The Poisson-Inverse Gaussian Distribution

Description

Density function, distribution function, quantile function and random generation for the Poisson-inverse Gaussian discrete distribution with parameters mean and shape.

Usage

```
dpoisinvgauss(x, mean, shape = 1, dispersion = 1/shape,
              log = FALSE)
ppoisinvgauss(q, mean, shape = 1, dispersion = 1/shape,
              lower.tail = TRUE, log.p = FALSE)
qpoisinvgauss(p, mean, shape = 1, dispersion = 1/shape,
              lower.tail = TRUE, log.p = FALSE)
rpoisinvgauss(n, mean, shape = 1, dispersion = 1/shape)
```

Arguments

x	vector of (positive integer) quantiles.
q	vector of quantiles.
p	vector of probabilities.
n	number of observations. If length(n) > 1, the length is taken to be the number required.
mean, shape	parameters. Must be strictly positive. Infinite values are supported.
dispersion	an alternative way to specify the shape.
log, log.p	logical; if TRUE, probabilities p are returned as $\log(p)$.
lower.tail	logical; if TRUE (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.

Details

The Poisson-inverse Gaussian distribution is the result of the continuous mixture between a Poisson distribution and an inverse Gaussian, that is, the distribution with probability mass function

$$p(x) = \int_0^\infty \frac{\lambda^x e^{-\lambda}}{x!}\, g(\lambda; \mu, \phi)\, d\lambda,$$

where $g(\lambda; \mu, \phi)$ is the density function of the inverse Gaussian distribution with parameters mean $= \mu$ and dispersion $= \phi$ (see dinvgauss).

The resulting probability mass function is

$$p(x) = \sqrt{\frac{2}{\pi\phi}} \frac{e^{(\phi\mu)^{-1}}}{x!} \left(\sqrt{2\phi\left(1 + \frac{1}{2\phi\mu^2}\right)}\right)^{-(x-\frac{1}{2})} K_{x-\frac{1}{2}}\left(\sqrt{\frac{2}{\phi}\left(1 + \frac{1}{2\phi\mu^2}\right)}\right),$$

for $x = 0, 1, \ldots$, $\mu > 0$, $\phi > 0$ and where $K_\nu(x)$ is the modified Bessel function of the third kind implemented by R's besselK() and defined in its help.

The limiting case $\mu = \infty$ has well defined probability mass and distribution functions, but has no finite strictly positive, integer moments. The pmf in this case reduces to

$$p(x) = \sqrt{\frac{2}{\pi\phi}} \frac{1}{x!} (\sqrt{2\phi})^{-(x-\frac{1}{2})} K_{x-\frac{1}{2}}(\sqrt{2/\phi}).$$

The limiting case $\phi = 0$ is a degenerate distribution in $x = 0$.

If an element of x is not integer, the result of dpoisinvgauss is zero, with a warning.

The quantile is defined as the smallest value x such that $F(x) \geq p$, where F is the distribution function.

Value

dpoisinvgauss gives the probability mass function, ppoisinvgauss gives the distribution function, qpoisinvgauss gives the quantile function, and rpoisinvgauss generates random deviates.

Invalid arguments will result in return value NaN, with a warning.

The length of the result is determined by n for rpoisinvgauss, and is the maximum of the lengths of the numerical arguments for the other functions.

Note

`[dpqr]pig` are aliases for `[dpqr]poisinvgauss`.

`qpoisinvgauss` is based on `qbinom` et al.; it uses the Cornish–Fisher Expansion to include a skewness correction to a normal approximation, followed by a search.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>

References

Holla, M. S. (1966), "On a Poisson-Inverse Gaussian Distribution", *Metrika*, vol. 15, p. 377-384.

Johnson, N. L., Kemp, A. W. and Kotz, S. (2005), *Univariate Discrete Distributions, Third Edition*, Wiley.

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

Shaban, S. A., (1981) "Computation of the poisson-inverse gaussian distribution", *Communications in Statistics - Theory and Methods*, vol. 10, no. 14, p. 1389-1399.

See Also

`dpois` for the Poisson distribution, `dinvgauss` for the inverse Gaussian distribution.

Examples

```
## Tables I and II of Shaban (1981)
x <- 0:2
sapply(c(0.4, 0.8, 1), dpoisinvgauss, x = x, mean = 0.1)
sapply(c(40, 80, 100, 130), dpoisinvgauss, x = x, mean = 1)

qpoisinvgauss(ppoisinvgauss(0:10, 1, dis = 2.5), 1, dis = 2.5)

x <- rpoisinvgauss(1000, 1, dis = 2.5)
y <- sort(unique(x))
plot(y, table(x)/length(x), type = "h", lwd = 2,
     pch = 19, col = "black", xlab = "x", ylab = "p(x)",
     main = "Empirical vs theoretical probabilities")
points(y, dpoisinvgauss(y, 1, dis = 2.5),
       pch = 19, col = "red")
legend("topright", c("empirical", "theoretical"),
       lty = c(1, NA), pch = c(NA, 19), col = c("black", "red"))
```

quantile.aggregateDist

Quantiles of Aggregate Claim Amount Distribution

Description

Quantile and Value-at-Risk methods for objects of class "aggregateDist".

Usage

```
## S3 method for class 'aggregateDist'
quantile(x,
         probs = c(0.25, 0.5, 0.75, 0.9, 0.95, 0.975, 0.99, 0.995),
         smooth = FALSE, names = TRUE, ...)

## S3 method for class 'aggregateDist'
VaR(x, conf.level = c(0.9, 0.95, 0.99),
         smooth = FALSE, names = TRUE, ...)
```

Arguments

x	an object of class "aggregateDist".
probs, conf.level	numeric vector of probabilities with values in $[0, 1)$.
smooth	logical; when TRUE and x is a step function, quantiles are linearly interpolated between knots.
names	logical; if true, the result has a names attribute. Set to FALSE for speedup with many probs.
...	further arguments passed to or from other methods.

Details

The quantiles are taken directly from the cumulative distribution function defined in x. Linear interpolation is available for step functions.

Value

A numeric vector, named if names is TRUE.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca> and Louis-Philippe Pouliot

See Also

aggregateDist

Examples

```
model.freq <- expression(data = rpois(3))
model.sev <- expression(data = rlnorm(10, 1.5))
Fs <- aggregateDist("simulation", model.freq, model.sev, nb.simul = 1000)
quantile(Fs, probs = c(0.25, 0.5, 0.75))
VaR(Fs)
```

---

quantile.grouped.data *Quantiles of Grouped Data*

Description

Sample quantiles corresponding to the given probabilities for objects of class "grouped.data".

Usage

```
## S3 method for class 'grouped.data'
quantile(x, probs = seq(0, 1, 0.25),
         names = TRUE, ...)

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

Arguments

x, object	an object of class "grouped.data".
probs	numeric vector of probabilities with values in $[0, 1]$.
names	logical; if true, the result has a names attribute. Set to FALSE for speedup with many probs.
...	further arguments passed to or from other methods.

Details

The quantile function is the inverse of the ogive, that is a linear interpolation of the empirical quantile function.

The equation of the quantile function is

$$x = \frac{c_j(F_n(c_{j-1}) - q) + c_{j-1}(q - F_n(c_j)}{F_n(c_j) - F_n(c_{j-1})}$$

for $0 \leq q \leq c_j$ and where $c_0, \ldots, c_r$ are the $r + 1$ group boundaries and F_n is the empirical distribution function of the sample.

Value

For quantile, a numeric vector, named if names is TRUE.

For the summary method, an object of class c("summaryDefault", "table") which has specialized format and print methods.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>

See Also

ogive for the smoothed empirical distribution of which quantile.grouped.data is an inverse; mean.grouped.data and var.grouped.data to compute the mean and variance of grouped data.

grouped.data to create grouped data objects.

Examples

```
data(gdental)
quantile(gdental)
summary(gdental)
Fn <- ogive(gdental)
Fn(quantile(gdental))  # inverse function
```

---

rcomphierarc *Simulation from Compound Hierarchical Models*

Description

Simulate data for insurance applications allowing hierarchical structures and separate models for the frequency and severity of claims distributions.

rcomphierarc is an alias for simul.

Usage

```
rcomphierarc(nodes, model.freq = NULL, model.sev = NULL, weights = NULL)

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

Arguments

nodes	a vector or a named list giving the number of "nodes" at each level in the hierarchy of the portfolio. The nodes are listed from top (portfolio) to bottom (usually the years of experience).
model.freq	a named vector of expressions specifying the frequency of claims model (see Details); if NULL, only claim amounts are simulated.
model.sev	a named vector of expressions specifying the severity of claims model (see Details); if NULL, only claim numbers are simulated.
weights	a vector of weights.
x	a portfolio object.
...	potential further arguments required by generic.

Details

The order and the names of the elements in `nodes`, `model.freq` and `model.sev` must match. At least one of `model.freq` and `model.sev` must be non `NULL`.

`nodes` may be a basic vector, named or not, for non hierarchical models. The rule above still applies, so `model.freq` and `model.sev` should not be named if `nodes` is not. However, for non hierarchical models, `rcompound` is faster and has a simpler interface.

`nodes` specifies the hierarchical layout of the portfolio. Each element of the list is a vector of the number of nodes at a given level. Vectors are recycled as necessary.

`model.freq` and `model.sev` specify the simulation models for claim numbers and claim amounts, respectively. A model is expressed in a semi-symbolic fashion using an object of mode `expression`. Each element of the object must be named and should be a complete call to a random number generation function, with the number of variates omitted. Hierarchical (or mixtures of) models are achieved by replacing one or more parameters of a distribution at a given level by any combination of the names of the levels above. If no mixing is to take place at a level, the model for this level can be `NULL`.

The argument of the random number generation functions for the number of variates to simulate **must** be named `n`.

Weights will be used wherever the name `"weights"` appears in a model. It is the user's responsibility to ensure that the length of `weights` will match the number of nodes when weights are to be used. Normally, there should be one weight per node at the lowest level of the model.

Data is generated in lexicographic order, that is by row in the output matrix.

Value

An object of `class` `"portfolio"`. A `print` method for this class displays the models used in the simulation as well as the frequency of claims for each year and entity in the portfolio.

An object of class `"portfolio"` is a list containing the following components:

`data`	a two dimension list where each element is a vector of claim amounts;
`weights`	the vector of weights given in argument reshaped as a matrix matching element `data`, or `NULL`;
`classification`	a matrix of integers where each row is a unique set of subscripts identifying an entity in the portfolio (e.g. integers i, j and k for data X_{ijkt});
`nodes`	the `nodes` argument, appropriately recycled;
`model.freq`	the frequency model as given in argument;
`model.sev`	the severity model as given in argument.

It is recommended to manipulate objects of class `"portfolio"` by means of the corresponding methods of functions `aggregate`, `frequency` and `severity`.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>, Sébastien Auclair and Louis-Philippe Pouliot

References

Goulet, V. and Pouliot, L.-P. (2008), Simulation of compound hierarchical models in R, *North American Actuarial Journal* **12**, 401–412.

See Also

rcomphierarc.summaries for the functions to create the matrices of aggregate claim amounts, frequencies and individual claim amounts.

rcompound for a simpler and much faster way to generate variates from standard, non hierarchical, compound models.

Examples

```
## Two level (contracts and years) portfolio with frequency model
## Nit|Theta_i ~ Poisson(Theta_i), Theta_i ~ Gamma(2, 3) and severity
## model X ~ Lognormal(5, 1)
rcomphierarc(nodes = list(contract = 10, year = 5),
             model.freq = expression(contract = rgamma(2, 3),
                                     year = rpois(contract)),
             model.sev = expression(contract = NULL,
                                    year = rlnorm(5, 1)))

## Model with weights and mixtures for both frequency and severity
## models
nodes <- list(entity = 8, year = c(5, 4, 4, 5, 3, 5, 4, 5))
mf <- expression(entity = rgamma(2, 3),
                 year = rpois(weights * entity))
ms <- expression(entity = rnorm(5, 1),
                 year = rlnorm(entity, 1))
wit <- sample(2:10, 35, replace = TRUE)
pf <- rcomphierarc(nodes, mf, ms, wit)
pf     # print method
weights(pf)   # extraction of weights
aggregate(pf)[, -1]/weights(pf)[, -1] # ratios

## Four level hierarchical model for frequency only
nodes <- list(sector = 3, unit = c(3, 4),
              employer = c(3, 4, 3, 4, 2, 3, 4), year = 5)
mf <- expression(sector = rexp(1),
                 unit = rexp(sector),
                 employer = rgamma(unit, 1),
                 year = rpois(employer))
pf <- rcomphierarc(nodes, mf, NULL)
pf     # print method
aggregate(pf)    # aggregate claim amounts
frequency(pf)     # frequencies
severity(pf)   # individual claim amounts

## Standard, non hierarchical, compound model with simplified
## syntax (function rcompound() is much faster for such cases)
rcomphierarc(10,
```

```
                model.freq = expression(rpois(2)),
                model.sev = expression(rgamma(2, 3)))
```

`rcomphierarc.summaries` *Summary Statistics of a Portfolio*

Description

Methods for class `"portfolio"` objects.

`aggregate` splits portfolio data into subsets and computes summary statistics for each.

`frequency` computes the frequency of claims for subsets of portfolio data.

`severity` extracts the individual claim amounts.

`weights` extracts the matrix of weights.

Usage

```
## S3 method for class 'portfolio'
aggregate(x, by = names(x$nodes), FUN = sum,
        classification = TRUE, prefix = NULL, ...)

## S3 method for class 'portfolio'
frequency(x, by = names(x$nodes),
        classification = TRUE, prefix = NULL, ...)

## S3 method for class 'portfolio'
severity(x, by = head(names(x$node), -1), splitcol = NULL,
        classification = TRUE, prefix = NULL, ...)

## S3 method for class 'portfolio'
weights(object, classification = TRUE, prefix = NULL, ...)
```

Arguments

`x, object`	an object of class `"portfolio"`, typically created with `simul`.
`by`	character vector of grouping elements using the level names of the portfolio in `x`. The names can be abbreviated.
`FUN`	the function to be applied to data subsets.
`classification`	boolean; if `TRUE`, the node identifier columns are included in the output.
`prefix`	characters to prefix column names with; if `NULL`, sensible defaults are used when appropriate.
`splitcol`	columns of the data matrix to extract separately; usual matrix indexing methods are supported.
`...`	optional arguments to `FUN`, or passed to or from other methods.

Details

By default, aggregate.portfolio computes the aggregate claim amounts for the grouping specified in by. Any other statistic based on the individual claim amounts can be used through argument FUN.

frequency.portfolio is equivalent to using aggregate.portfolio with argument FUN equal to if (identical(x, NA)) NA else length(x).

severity.portfolio extracts individual claim amounts of a portfolio by groupings using the default method of severity. Argument splitcol allows to get the individual claim amounts of specific columns separately.

weights.portfolio extracts the weight matrix of a portfolio.

Value

A matrix or vector depending on the groupings specified in by.

For the aggregate and frequency methods: if at least one level other than the last one is used for grouping, the result is a matrix obtained by binding the appropriate node identifiers extracted from x$classification if classification = TRUE, and the summaries per grouping. If the last level is used for grouping, the column names of x$data are retained; if the last level is not used for grouping, the column name is replaced by the deparsed name of FUN. If only the last level is used (column summaries), a named vector is returned.

For the severity method: a list of two elements:

main	NULL or a matrix of claim amounts for the columns not specified in splitcol, with the appropriate node identifiers extracted from x$classification if classification = TRUE;
split	same as above, but for the columns specified in splitcol.

For the weights method: the weight matrix of the portfolio with node identifiers if classification = TRUE.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>, Louis-Philippe Pouliot.

See Also

rcomphierarc

Examples

```
nodes <- list(sector = 3, unit = c(3, 4),
              employer = c(3, 4, 3, 4, 2, 3, 4), year = 5)
model.freq <- expression(sector = rexp(1),
                         unit = rexp(sector),
                         employer = rgamma(unit, 1),
                         year = rpois(employer))
model.sev <- expression(sector = rnorm(6, 0.1),
                        unit = rnorm(sector, 1),
```

```
                        employer = rnorm(unit, 1),
                        year = rlnorm(employer, 1))
pf <- rcomphierarc(nodes, model.freq, model.sev)

aggregate(pf)            # aggregate claim amount by employer and year
aggregate(pf, classification = FALSE) # same, without node identifiers
aggregate(pf, by = "sector")       # by sector
aggregate(pf, by = "y")        # by year
aggregate(pf, by = c("s", "u"), mean) # average claim amount

frequency(pf)         # number of claims
frequency(pf, prefix = "freq.")       # more explicit column names

severity(pf)         # claim amounts by row
severity(pf, by = "year")       # by column
severity(pf, by = c("s", "u"))        # by unit
severity(pf, splitcol = "year.5")     # last year separate
severity(pf, splitcol = 5)            # same
severity(pf, splitcol = c(FALSE, FALSE, FALSE, FALSE, TRUE)) # same

weights(pf)

## For portfolios with weights, the following computes loss ratios.
## Not run: aggregate(pf, classif = FALSE) / weights(pf, classif = FALSE)
```

`rcompound` *Simulation from Compound Models*

Description

`rcompound` generates random variates from a compound model.

`rcomppois` is a simplified version for a common case.

Usage

```
rcompound(n, model.freq, model.sev, SIMPLIFY = TRUE)

rcomppois(n, lambda, model.sev, SIMPLIFY = TRUE)
```

Arguments

`n`	number of observations. If `length(n) > 1`, the length is taken to be the number required.
`model.freq`, `model.sev`	expressions specifying the frequency and severity simulation models with the number of variates omitted; see Details.
`lambda`	Poisson parameter.
`SIMPLIFY`	boolean; if `FALSE` the frequency and severity variates are returned along with the aggregate variates.

Details

rcompound generates variates from a random variable of the form

$$S = X_1 + ... + X_N,$$

where N is the frequency random variable and $X_1, X_2, \ldots$ are the severity random variables. The latter are mutually independent, identically distributed and independent from N.

model.freq and model.sev specify the simulation models for the frequency and the severity random variables, respectively. A model is a complete call to a random number generation function, with the number of variates omitted. This is similar to rcomphierarc, but the calls need not be wrapped into expression. Either argument may also be the name of an object containing an expression, in which case the object will be evaluated in the parent frame to retrieve the expression.

The argument of the random number generation functions for the number of variates to simulate **must** be named n.

rcomppois generates variates from the common Compound Poisson model, that is when random variable N is Poisson distributed with mean lambda.

Value

When SIMPLIFY = TRUE, a vector of aggregate amounts $S_1, \ldots, S_n$.

When SIMPLIFY = FALSE, a list of three elements:

aggregate	vector of aggregate amounts $S_1, \ldots, S_n$;
frequency	vector of frequencies $N_1, \ldots, N_n$;
severity	vector of severities $X_1, X_2, \ldots$.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>

See Also

rcomphierarc to simulate from compound hierarchical models.

Examples

```
## Compound Poisson model with gamma severity.
rcompound(10, rpois(2), rgamma(2, 3))
rcomppois(10, 2, rgamma(2, 3))          # same

## Frequencies and individual claim amounts along with aggregate
## values.
rcomppois(10, 2, rgamma(2, 3), SIMPLIFY = FALSE)

## Wrapping the simulation models into expression() is allowed, but
## not needed.
rcompound(10, expression(rpois(2)), expression(rgamma(2, 3)))

## Not run: ## Speed comparison between rcompound() and rcomphierarc().
```

```
## [Also note the simpler syntax for rcompound().]
system.time(rcompound(1e6, rpois(2), rgamma(2, 3)))
system.time(rcomphierarc(1e6, expression(rpois(2)), expression(rgamma(2, 3))))
## End(Not run)
## The severity can itself be a compound model. It makes sense
## in such a case to use a zero-truncated frequency distribution
## for the second level model.
rcomppois(10, 2,
          rcompound(rztnbinom(1.5, 0.7), rlnorm(1.2, 1)))
```

`rmixture` *Simulation from Discrete Mixtures*

Description

Generate random variates from a discrete mixture of distributions.

Usage

```
rmixture(n, probs, models, shuffle = TRUE)
```

Arguments

`n`	number of random variates to generate. If `length(n) > 1`, the length is taken to be the number required.
`probs`	numeric non-negative vector specifying the probability for each model; is internally normalized to sum 1. Infinite and missing values are not allowed. Values are recycled as necessary to match the length of `models`.
`models`	vector of expressions specifying the simulation models with the number of variates omitted; see Details. Models are recycled as necessary to match the length of `probs`.
`shuffle`	logical; should the random variates from the distributions be shuffled?

Details

`rmixture` generates variates from a discrete mixture, that is the random variable with a probability density function of the form

$$f(x) = p_1 f_1(x) + ... + p_n f_n(x),$$

where $f_1, \ldots, f_n$ are densities and $\sum_{i=1}^{n} p_i = 1$.

The values in `probs` will be internally normalized to be used as probabilities $p_1 + \cdots + p_n$.

The specification of simulation models uses the syntax of `rcomphierarc`. Models $f_1, \ldots, f_n$ are expressed in a semi-symbolic fashion using an object of mode `expression` where each element is a complete call to a random number generation function, with the number of variates omitted.

The argument of the random number generation functions for the number of variates to simulate **must** be named `n`.

If shuffle is FALSE, the output vector contains all the random variates from the first model, then all the random variates from the second model, and so on. If the order of the variates is irrelevant, this cuts the time to generate the variates roughly in half.

Value

A vector of random variates from the mixture with density $f(x)$.

Note

Building the expressions in models from the arguments of another function is delicate. The expressions must be such that evaluation is possible in the frame of rmixture or its parent. See the examples.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>

See Also

rcompound to simulate from compound models.

rcomphierarc to simulate from compound hierarchical models.

Examples

```
## Mixture of two exponentials (with means 1/3 and 1/7) with equal
## probabilities.
rmixture(10, 0.5, expression(rexp(3), rexp(7)))
rmixture(10, 42, expression(rexp(3), rexp(7))) # same

## Mixture of two lognormals with different probabilities.
rmixture(10, probs = c(0.55, 0.45),
         models = expression(rlnorm(3.6, 0.6),
                             rlnorm(4.6, 0.3)))

## Building the model expressions in the following example
## works as 'rate' is defined in the parent frame of
## 'rmixture'.
probs <- c(2, 5)
g <- function(n, p, rate)
    rmixture(n, p, expression(rexp(rate[1]), rexp(rate[2])))
g(10, probs, c(3, 7))

## The following example does not work: 'rate' does not exist
## in the evaluation frame of 'rmixture'.
f <- function(n, p, model) rmixture(n, p, model)
h <- function(n, p, rate)
    f(n, p, expression(rexp(rate[1]), rexp(rate[2])))
## Not run: h(10, probs, c(3, 7))

## Fix: substitute the values in the model expressions.
```

```
h <- function(n, p, rate)
{
    models <- eval(substitute(expression(rexp(a[1]), rexp(a[2])),
                              list(a = rate)))
    f(n, p, models)
}
h(10, probs, c(3, 7))
```

---

ruin *Probability of Ruin*

Description

Calulation of infinite time probability of ruin in the models of Cramér-Lundberg and Sparre Andersen, that is with exponential or phase-type (including mixtures of exponentials, Erlang and mixture of Erlang) claims interarrival time.

Usage

```
ruin(claims = c("exponential", "Erlang", "phase-type"), par.claims,
     wait = c("exponential", "Erlang", "phase-type"), par.wait,
     premium.rate = 1, tol = sqrt(.Machine$double.eps),
     maxit = 200L, echo = FALSE)

## S3 method for class 'ruin'
plot(x, from = NULL, to = NULL, add = FALSE,
     xlab = "u", ylab = expression(psi(u)),
     main = "Probability of Ruin", xlim = NULL, ...)
```

Arguments

claims	character; the type of claim severity distribution.
wait	character; the type of claim interarrival (wait) time distribution.
par.claims, par.wait	named list containing the parameters of the distribution; see Details.
premium.rate	numeric vector of length 1; the premium rate.
tol, maxit, echo	respectively the tolerance level of the stopping criteria, the maximum number of iterations and whether or not to echo the procedure when the transition rates matrix is determined iteratively. Ignored if wait = "exponential".
x	an object of class "ruin".
from, to	the range over which the function will be plotted.
add	logical; if TRUE add to already existing plot.
xlim	numeric of length 2; if specified, it serves as default for c(from, to).
xlab, ylab	label of the x and y axes, respectively.
main	main title.
...	further graphical parameters accepted by curve.

Details

The names of the parameters in `par.claims` and `par.wait` must be the same as in `dexp`, `dgamma` or `dphtype`, as appropriate. A model will be a mixture of exponential or Erlang distributions (but not phase-type) when the parameters are vectors of length > 1 and the parameter list contains a vector `weights` of the coefficients of the mixture.

Parameters are recycled when needed. Their names can be abbreviated.

Combinations of exponentials as defined in Dufresne and Gerber (1988) are *not* supported.

Ruin probabilities are evaluated using `pphtype` except when both distributions are exponential, in which case an explicit formula is used.

When `wait != "exponential"` (Sparre Andersen model), the transition rate matrix $\boldsymbol{Q}$ of the distribution of the probability of ruin is determined iteratively using a fixed point-like algorithm. The stopping criteria used is

$$\max\left\{\sum_{j=1}^{n}|\boldsymbol{Q}_{ij}-\boldsymbol{Q}'_{ij}|\right\} < \texttt{tol},$$

where $\boldsymbol{Q}$ and $\boldsymbol{Q}'$ are two successive values of the matrix.

Value

A function of class `"ruin"` inheriting from the `"function"` class to compute the probability of ruin given initial surplus levels. The function has arguments:

`u`	numeric vector of initial surplus levels;
`survival`	logical; if `FALSE` (default), probabilities are $\psi(u)$, otherwise, $\phi(u) = 1 - \psi(u)$;
`lower.tail`	an alias for `!survival`.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>, and Christophe Dutang

References

Asmussen, S. and Rolski, T. (1991), Computational methods in risk theory: A matrix algorithmic approach, *Insurance: Mathematics and Economics* **10**, 259–274.

Dufresne, F. and Gerber, H. U. (1988), Three methods to calculate the probability of ruin, *Astin Bulletin* **19**, 71–90.

Gerber, H. U. (1979), *An Introduction to Mathematical Risk Theory*, Huebner Foundation.

Examples

```
## Case with an explicit formula: exponential claims and exponential
## interarrival times.
psi <- ruin(claims = "exponential", par.claims = list(rate = 5),
            wait   = "exponential", par.wait   = list(rate = 3))
psi
psi(0:10)
plot(psi, from = 0, to = 10)
```

```
## Mixture of two exponentials for claims, exponential interarrival
## times (Gerber 1979)
psi <- ruin(claims = "exponential",
            par.claims = list(rate = c(3, 7), w = 0.5),
            wait   = "exponential",
            par.wait   = list(rate = 3), pre = 1)
u <- 0:10
psi(u)
(24 * exp(-u) + exp(-6 * u))/35 # same

## Mixtures of Erlang distributions for claims and interarrival times.
psi <- ruin(claims = 'Erlang',
            par.claims = list(shape = c(1, 2, 3),
                              scale = c(3, 2, 1),
                              weights = c(3, 4, 1)/8),
            wait = 'Erlang',
            par.wait = list(shape = c(6, 4, 4),
                            scale= c(3, 2, 2),
                            weights = c(3, 4, 1)/8),
            premium.rate = 0.6)
psi(0:10)

## Phase-type claims, exponential interarrival times (Asmussen and
## Rolski 1991)
p <- c(0.5614, 0.4386)
r <- matrix(c(-8.64, 0.101, 1.997, -1.095), 2, 2)
lambda <- 1/(1.1 * mphtype(1, p, r))
psi <- ruin(claims = "p", par.claims = list(prob = p, rates = r),
            wait   = "e", par.wait   = list(rate = lambda))
psi
plot(psi, xlim = c(0, 50))

## Phase-type claims, mixture of two exponentials for interarrival times
## (Asmussen and Rolski 1991)
a <- (0.4/5 + 0.6) * lambda
ruin(claims = "p", par.claims = list(prob = p, rates = r),
     wait   = "e", par.wait   = list(rate = c(5 * a, a), weights =
                                       c(0.4, 0.6)),
     maxit = 225L)
```

`severity` *Manipulation of Individual Claim Amounts*

Description

`severity` is a generic function created to manipulate individual claim amounts. The function invokes particular *methods* which depend on the `class` of the first argument.

Usage

```
severity(x, ...)

## Default S3 method:
severity(x, bycol = FALSE, drop = TRUE, ...)
```

Arguments

x	an R object.
bycol	logical; whether to "unroll" horizontally (FALSE) or vertically (TRUE)
...	further arguments to be passed to or from other methods.
drop	logical; if TRUE, the result is coerced to the lowest possible dimension.

Details

Currently, the default method is equivalent to unroll. This is liable to change since the link between the name and the use of the function is rather weak.

Value

A vector or matrix.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca> and Louis-Philippe Pouliot

See Also

severity.portfolio for the original motivation of these functions.

Examples

```
x <- list(c(1:3), c(1:8), c(1:4), c(1:3))
(mat <- matrix(x, 2, 2))
severity(mat)
severity(mat, bycol = TRUE)
```

SingleParameterPareto *The Single-parameter Pareto Distribution*

Description

Density function, distribution function, quantile function, random generation, raw moments, and limited moments for the Single-parameter Pareto distribution with parameter shape.

Usage

```
dpareto1(x, shape, min, log = FALSE)
ppareto1(q, shape, min, lower.tail = TRUE, log.p = FALSE)
qpareto1(p, shape, min, lower.tail = TRUE, log.p = FALSE)
rpareto1(n, shape, min)
mpareto1(order, shape, min)
levpareto1(limit, shape, min, order = 1)
```

Arguments

x, q	vector of quantiles.
p	vector of probabilities.
n	number of observations. If length(n) > 1, the length is taken to be the number required.
shape	parameter. Must be strictly positive.
min	lower bound of the support of the distribution.
log, log.p	logical; if TRUE, probabilities/densities p are returned as $\log(p)$.
lower.tail	logical; if TRUE (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.
order	order of the moment.
limit	limit of the loss variable.

Details

The single-parameter Pareto, or Pareto I, distribution with parameter shape $= \alpha$ has density:

$$f(x) = \frac{\alpha \theta^\alpha}{x^{\alpha+1}}$$

for $x > \theta$, $\alpha > 0$ and $\theta > 0$.

Although there appears to be two parameters, only shape is a true parameter. The value of min $= \theta$ must be set in advance.

The kth raw moment of the random variable X is $E[X^k]$, $k < \alpha$ and the kth limited moment at some limit d is $E[\min(X, d)^k]$, $x \geq \theta$.

Value

dpareto1 gives the density, ppareto1 gives the distribution function, qpareto1 gives the quantile function, rpareto1 generates random deviates, mpareto1 gives the kth raw moment, and levpareto1 gives the kth moment of the limited loss variable.

Invalid arguments will result in return value NaN, with a warning.

Note

For Pareto distributions, we use the classification of Arnold (2015) with the parametrization of Klugman et al. (2012).

The "distributions" package vignette provides the interrelations between the continuous size distributions in **actuar** and the complete formulas underlying the above functions.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca> and Mathieu Pigeon

References

Arnold, B.C. (2015), *Pareto Distributions*, Second Edition, CRC Press.

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

See Also

dpareto for the two-parameter Pareto distribution.

Examples

```
exp(dpareto1(5, 3, 4, log = TRUE))
p <- (1:10)/10
ppareto1(qpareto1(p, 2, 3), 2, 3)
mpareto1(2, 3, 4) - mpareto(1, 3, 4) ^ 2
levpareto(10, 3, 4, order = 2)
```

TransformedBeta *The Transformed Beta Distribution*

Description

Density function, distribution function, quantile function, random generation, raw moments and limited moments for the Transformed Beta distribution with parameters shape1, shape2, shape3 and scale.

Usage

```
dtrbeta(x, shape1, shape2, shape3, rate = 1, scale = 1/rate,
        log = FALSE)
ptrbeta(q, shape1, shape2, shape3, rate = 1, scale = 1/rate,
        lower.tail = TRUE, log.p = FALSE)
qtrbeta(p, shape1, shape2, shape3, rate = 1, scale = 1/rate,
        lower.tail = TRUE, log.p = FALSE)
rtrbeta(n, shape1, shape2, shape3, rate = 1, scale = 1/rate)
mtrbeta(order, shape1, shape2, shape3, rate = 1, scale = 1/rate)
levtrbeta(limit, shape1, shape2, shape3, rate = 1, scale = 1/rate,
          order = 1)
```

Arguments

x, q	vector of quantiles.
p	vector of probabilities.
n	number of observations. If length(n) > 1, the length is taken to be the number required.
shape1, shape2, shape3, scale	parameters. Must be strictly positive.
rate	an alternative way to specify the scale.
log, log.p	logical; if TRUE, probabilities/densities p are returned as $\log(p)$.
lower.tail	logical; if TRUE (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.
order	order of the moment.
limit	limit of the loss variable.

Details

The transformed beta distribution with parameters shape1 $= \alpha$, shape2 $= \gamma$, shape3 $= \tau$ and scale $= \theta$, has density:

$$f(x) = \frac{\Gamma(\alpha+\tau)}{\Gamma(\alpha)\Gamma(\tau)} \frac{\gamma(x/\theta)^{\gamma\tau}}{x[1+(x/\theta)^{\gamma}]^{\alpha+\tau}}$$

for $x > 0$, $\alpha > 0$, $\gamma > 0$, $\tau > 0$ and $\theta > 0$. (Here $\Gamma(\alpha)$ is the function implemented by R's gamma() and defined in its help.)

The transformed beta is the distribution of the random variable

$$\theta \left(\frac{X}{1-X}\right)^{1/\gamma},$$

where X has a beta distribution with parameters τ and α.

The transformed beta distribution defines a family of distributions with the following special cases:

- A Burr distribution when shape3 == 1;
- A loglogistic distribution when shape1 == shape3 == 1;
- A paralogistic distribution when shape3 == 1 and shape2 == shape1;
- A generalized Pareto distribution when shape2 == 1;
- A Pareto distribution when shape2 == shape3 == 1;
- An inverse Burr distribution when shape1 == 1;
- An inverse Pareto distribution when shape2 == shape1 == 1;
- An inverse paralogistic distribution when shape1 == 1 and shape3 == shape2.

The kth raw moment of the random variable X is $E[X^k]$, $-\tau\gamma < k < \alpha\gamma$.

The kth limited moment at some limit d is $E[\min(X,d)^k]$, $k > -\tau\gamma$ and $\alpha - k/\gamma$ not a negative integer.

Value

`dtrbeta` gives the density, `ptrbeta` gives the distribution function, `qtrbeta` gives the quantile function, `rtrbeta` generates random deviates, `mtrbeta` gives the kth raw moment, and `levtrbeta` gives the kth moment of the limited loss variable.

Invalid arguments will result in return value `NaN`, with a warning.

Note

`levtrbeta` computes the limited expected value using `betaint`.

Distribution also known as the Generalized Beta of the Second Kind and Pearson Type VI. See also Kleiber and Kotz (2003) for alternative names and parametrizations.

The `"distributions"` package vignette provides the interrelations between the continuous size distributions in **actuar** and the complete formulas underlying the above functions.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca> and Mathieu Pigeon

References

Kleiber, C. and Kotz, S. (2003), *Statistical Size Distributions in Economics and Actuarial Sciences*, Wiley.

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

See Also

`dfpareto` for an equivalent distribution with a location parameter.

Examples

```
exp(dtrbeta(2, 2, 3, 4, 5, log = TRUE))
p <- (1:10)/10
ptrbeta(qtrbeta(p, 2, 3, 4, 5), 2, 3, 4, 5)
qpearson6(0.3, 2, 3, 4, 5, lower.tail = FALSE)

## variance
mtrbeta(2, 2, 3, 4, 5) - mtrbeta(1, 2, 3, 4, 5)^2

## case with shape1 - order/shape2 > 0
levtrbeta(10, 2, 3, 4, scale = 1, order = 2)

## case with shape1 - order/shape2 < 0
levtrbeta(10, 1/3, 0.75, 4, scale = 0.5, order = 2)
```

`TransformedGamma` *The Transformed Gamma Distribution*

Description

Density function, distribution function, quantile function, random generation, raw moments and limited moments for the Transformed Gamma distribution with parameters `shape1`, `shape2` and `scale`.

Usage

```
dtrgamma(x, shape1, shape2, rate = 1, scale = 1/rate,
         log = FALSE)
ptrgamma(q, shape1, shape2, rate = 1, scale = 1/rate,
         lower.tail = TRUE, log.p = FALSE)
qtrgamma(p, shape1, shape2, rate = 1, scale = 1/rate,
         lower.tail = TRUE, log.p = FALSE)
rtrgamma(n, shape1, shape2, rate = 1, scale = 1/rate)
mtrgamma(order, shape1, shape2, rate = 1, scale = 1/rate)
levtrgamma(limit, shape1, shape2, rate = 1, scale = 1/rate,
           order = 1)
```

Arguments

`x`, `q`	vector of quantiles.
`p`	vector of probabilities.
`n`	number of observations. If `length(n) > 1`, the length is taken to be the number required.
`shape1`, `shape2`, `scale`	parameters. Must be strictly positive.
`rate`	an alternative way to specify the scale.
`log`, `log.p`	logical; if `TRUE`, probabilities/densities p are returned as $\log(p)$.
`lower.tail`	logical; if `TRUE` (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.
`order`	order of the moment.
`limit`	limit of the loss variable.

Details

The transformed gamma distribution with parameters `shape1` $= \alpha$, `shape2` $= \tau$ and `scale` $= \theta$ has density:

$$f(x) = \frac{\tau u^{\alpha} e^{-u}}{x\Gamma(\alpha)}, \quad u = (x/\theta)^{\tau}$$

for $x > 0$, $\alpha > 0$, $\tau > 0$ and $\theta > 0$. (Here $\Gamma(\alpha)$ is the function implemented by R's `gamma()` and defined in its help.)

The transformed gamma is the distribution of the random variable $\theta X^{1/\tau}$, where X has a gamma distribution with shape parameter α and scale parameter 1 or, equivalently, of the random variable $Y^{1/\tau}$ with Y a gamma distribution with shape parameter α and scale parameter θ^{τ}.

The transformed gamma probability distribution defines a family of distributions with the following special cases:

- A Gamma distribution when `shape2 == 1`;
- A Weibull distribution when `shape1 == 1`;
- An Exponential distribution when `shape2 == shape1 == 1`.

The kth raw moment of the random variable X is $E[X^k]$ and the kth limited moment at some limit d is $E[\min(X, d)^k]$, $k > -\alpha\tau$.

Value

`dtrgamma` gives the density, `ptrgamma` gives the distribution function, `qtrgamma` gives the quantile function, `rtrgamma` generates random deviates, `mtrgamma` gives the kth raw moment, and `levtrgamma` gives the kth moment of the limited loss variable.

Invalid arguments will result in return value `NaN`, with a warning.

Note

Distribution also known as the Generalized Gamma. See also Kleiber and Kotz (2003) for alternative names and parametrizations.

The `"distributions"` package vignette provides the interrelations between the continuous size distributions in **actuar** and the complete formulas underlying the above functions.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca> and Mathieu Pigeon

References

Kleiber, C. and Kotz, S. (2003), *Statistical Size Distributions in Economics and Actuarial Sciences*, Wiley.

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

Examples

```
exp(dtrgamma(2, 3, 4, 5, log = TRUE))
p <- (1:10)/10
ptrgamma(qtrgamma(p, 2, 3, 4), 2, 3, 4)
mtrgamma(2, 3, 4, 5) - mtrgamma(1, 3, 4, 5) ^ 2
levtrgamma(10, 3, 4, 5, order = 2)
```

UniformSupp *Moments and Moment Generating Function of the Uniform Distribution*

Description

Raw moments, limited moments and moment generating function for the Uniform distribution from `min` to `max`.

Usage

```
munif(order, min = 0, max = 1)
levunif(limit, min = 0, max =1, order = 1)
mgfunif(t, min = 0, max = 1, log = FALSE)
```

Arguments

`order`	order of the moment.
`min`, `max`	lower and upper limits of the distribution. Must be finite.
`limit`	limit of the random variable.
`t`	numeric vector.
`log`	logical; if `TRUE`, the cumulant generating function is returned.

Details

The kth raw moment of the random variable X is $E[X^k]$, the kth limited moment at some limit d is $E[\min(X, d)^k]$ and the moment generating function is $E[e^{tX}]$.

Value

`munif` gives the kth raw moment, `levunif` gives the kth moment of the limited random variable, and `mgfunif` gives the moment generating function in `t`.

Invalid arguments will result in return value `NaN`, with a warning.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>, Christophe Dutang

References

https://en.wikipedia.org/wiki/Uniform_distribution_%28continuous%29

See Also

`Uniform`.

Examples

```
munif(-1)
munif(1:5)
levunif(3, order=1:5)
levunif(3, 2, 4)
mgfunif(1, 1, 2)
```

`unroll` *Display a Two-Dimension Version of a Matrix of Vectors*

Description

Displays all values of a matrix of vectors by "unrolling" the object vertically or horizontally.

Usage

```
unroll(x, bycol = FALSE, drop = TRUE)
```

Arguments

`x`	a list of vectors with a `dim` attribute of length 0, 1 or 2.
`bycol`	logical; whether to unroll horizontally (`FALSE`) or vertically (`TRUE`).
`drop`	logical; if `TRUE`, the result is coerced to the lowest possible dimension.

Details

`unroll` returns a matrix where elements of `x` are concatenated ("unrolled") by row (`bycol = FALSE`) or by column (`bycol = TRUE`). `NA` is used to make rows/columns of equal length.

Vectors and one dimensional arrays are coerced to **row** matrices.

Value

A vector or matrix.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca> and Louis-Philippe Pouliot

See Also

This function was originally written for use in `severity.portfolio`.

Examples

```
x <- list(c(1:3), c(1:8), c(1:4), c(1:3))
(mat <- matrix(x, 2, 2))

unroll(mat)
unroll(mat, bycol = TRUE)

unroll(mat[1, ])
unroll(mat[1, ], drop = FALSE)
```

---

var *Variance and Standard Deviation*

Description

Generic functions for the variance and standard deviation, and methods for individual and grouped data.

The default methods for individual data are the functions from the **stats** package.

Usage

```
var(x, ...)

## Default S3 method:
var(x, y = NULL, na.rm = FALSE, use, ...)

## S3 method for class 'grouped.data'
var(x, ...)

sd(x, ...)

## Default S3 method:
sd(x, na.rm = FALSE, ...)

## S3 method for class 'grouped.data'
sd(x, ...)
```

Arguments

`x`	a vector or matrix of individual data, or an object of class `"grouped data"`.
`y`	see `stats::var`.
`na.rm`	see `stats::var`.
`use`	see `stats::var`.
`...`	further arguments passed to or from other methods.

Details

This page documents variance and standard deviation computations for grouped data. For individual data, see `var` and `sd` from the **stats** package.

For grouped data with group boundaries $c_0, c_1, \ldots, c_r$ and group frequencies $n_1, \ldots, n_r$, `var` computes the sample variance

$$\frac{1}{n-1}\sum_{j=1}^{r} n_j(a_j - m_1)^2,$$

where $a_j = (c_{j-1} + c_j)/2$ is the midpoint of the jth interval, m_1 is the sample mean (or sample first moment) of the data, and $n = \sum_{j=1}^{r} n_j$. The sample sample standard deviation is the square root of the sample variance.

The sample variance for grouped data differs from the variance computed from the empirical raw moments with `emm` in two aspects. First, it takes into account the degrees of freedom. Second, it applies Sheppard's correction factor to compensate for the overestimation of the true variation in the data. For groups of equal width k, Sheppard's correction factor is equal to $-k^2/12$.

Value

A named vector of variances or standard deviations.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>. Variance and standard deviation methods for grouped data contributed by Walter Garcia-Fontes <walter.garcia@upf.edu>.

References

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (1998), *Loss Models, From Data to Decisions*, Wiley.

Heumann, C., Schomaker, M., Shalabh (2016), *Introduction to Statistics and Data Analysis*, Springer.

See Also

`grouped.data` to create grouped data objects; `mean.grouped.data` for the mean and `emm` for higher moments.

Examples

```
data(gdental)
var(gdental)
sd(gdental)

## Illustration of Sheppard's correction factor
cj <- c(0, 2, 4, 6, 8)
nj <- c(1, 5,  3,  2)
gd <- grouped.data(Group = cj, Frequency = nj)
(sum(nj) - 1)/sum(nj) * var(gd)
(emm(gd, 2) - emm(gd)^2) - 4/12
```

VaR *Value at Risk*

Description

Value at Risk.

Usage

```
VaR(x, ...)
```

Arguments

x	an R object.
...	further arguments passed to or from other methods.

Details

This is a generic function with, currently, only a method for objects of class "aggregateDist".

Value

An object of class numeric.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca> and Tommy Ouellet

See Also

VaR.aggregateDist, aggregateDist

WeibullMoments *Raw and Limited Moments of the Weibull Distribution*

Description

Raw moments and limited moments for the Weibull distribution with parameters shape and scale.

Usage

```
mweibull(order, shape, scale = 1)
levweibull(limit, shape, scale = 1, order = 1)
```

Arguments

order	order of the moment.
limit	limit of the loss variable.
shape, scale	shape and scale parameters, the latter defaulting to 1.

Details

The kth raw moment of the random variable X is $E[X^k]$ and the kth limited moment at some limit d is $E[\min(X, d)^k]$, $k > -\tau$.

Value

mweibull gives the kth raw moment and levweibull gives the kth moment of the limited loss variable.

Invalid arguments will result in return value NaN, with a warning.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca> and Mathieu Pigeon

References

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

See Also

Weibull for details on the Weibull distribution and functions [dpqr]weibull.

Examples

```
mweibull(2, 3, 4) - mweibull(1, 3, 4)^2
levweibull(10, 3, 4, order = 2)
```

ZeroModifiedBinomial *The Zero-Modified Binomial Distribution*

Description

Density function, distribution function, quantile function and random generation for the Zero-Modified Binomial distribution with parameters size and prob, and probability at zero p0.

Usage

```
dzmbinom(x, size, prob, p0, log = FALSE)
pzmbinom(q, size, prob, p0, lower.tail = TRUE, log.p = FALSE)
qzmbinom(p, size, prob, p0, lower.tail = TRUE, log.p = FALSE)
rzmbinom(n, size, prob, p0)
```

Arguments

x	vector of (strictly positive integer) quantiles.
q	vector of quantiles.
p	vector of probabilities.
n	number of observations. If length(n) > 1, the length is taken to be the number required.
size	number of trials (strictly positive integer).
prob	probability of success on each trial. 0 <= prob <= 1.
p0	probability mass at zero. 0 <= p0 <= 1.
log, log.p	logical; if TRUE, probabilities p are returned as $\log(p)$.
lower.tail	logical; if TRUE (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.

Details

The zero-modified binomial distribution with size $= n$, prob $= p$ and p0 $= p_0$ is a discrete mixture between a degenerate distribution at zero and a (standard) binomial. The probability mass function is $p(0) = p_0$ and

$$p(x) = \frac{(1 - p_0)}{(1 - (1 - p)^n)} f(x)$$

for $x = 1, \ldots, n$, $0 < p \leq 1$ and $0 \leq p_0 \leq 1$, where $f(x)$ is the probability mass function of the binomial. The cumulative distribution function is

$$P(x) = p_0 + (1 - p_0) \left(\frac{F(x) - F(0)}{1 - F(0)} \right)$$

The mean is $(1 - p_0)\mu$ and the variance is $(1 - p_0)\sigma^2 + p_0(1 - p_0)\mu^2$, where μ and σ^2 are the mean and variance of the zero-truncated binomial.

In the terminology of Klugman et al. (2012), the zero-modified binomial is a member of the $(a, b, 1)$ class of distributions with $a = -p/(1 - p)$ and $b = (n + 1)p/(1 - p)$.

The special case p0 == 0 is the zero-truncated binomial.

If an element of x is not integer, the result of dzmbinom is zero, with a warning.

The quantile is defined as the smallest value x such that $P(x) \geq p$, where P is the distribution function.

Value

dzmbinom gives the probability mass function, pzmbinom gives the distribution function, qzmbinom gives the quantile function, and rzmbinom generates random deviates.

Invalid size, prob or p0 will result in return value NaN, with a warning.

The length of the result is determined by n for rzmbinom, and is the maximum of the lengths of the numerical arguments for the other functions.

Note

Functions {d,p,q}zmbinom use {d,p,q}binom for all but the trivial input values and $p(0)$.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>

References

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

See Also

dbinom for the binomial distribution.

dztbinom for the zero-truncated binomial distribution.

Examples

```
dzmbinom(1:5, size = 5, prob = 0.4, p0 = 0.2)
(1-0.2) * dbinom(1:5, 5, 0.4)/pbinom(0, 5, 0.4, lower = FALSE) # same

## simple relation between survival functions
pzmbinom(0:5, 5, 0.4, p0 = 0.2, lower = FALSE)
(1-0.2) * pbinom(0:5, 5, 0.4, lower = FALSE) /
    pbinom(0, 5, 0.4, lower = FALSE) # same

qzmbinom(pzmbinom(1:10, 10, 0.6, p0 = 0.1), 10, 0.6, p0 = 0.1)

n <- 8; p <- 0.3; p0 <- 0.025
x <- 0:n
title <- paste("ZM Binomial(", n, ", ", p, ", p0 = ", p0,
               ") and Binomial(", n, ", ", p,") PDF",
               sep = "")
plot(x, dzmbinom(x, n, p, p0), type = "h", lwd = 2, ylab = "p(x)",
     main = title)
points(x, dbinom(x, n, p), pch = 19, col = "red")
legend("topright", c("ZT binomial probabilities", "Binomial probabilities"),
       col = c("black", "red"), lty = c(1, 0), lwd = 2, pch = c(NA, 19))
```

ZeroModifiedGeometric *The Zero-Modified Geometric Distribution*

Description

Density function, distribution function, quantile function and random generation for the Zero-Modified Geometric distribution with parameter prob and arbitrary probability at zero p0.

Usage

```
dzmgeom(x, prob, p0, log = FALSE)
pzmgeom(q, prob, p0, lower.tail = TRUE, log.p = FALSE)
qzmgeom(p, prob, p0, lower.tail = TRUE, log.p = FALSE)
rzmgeom(n, prob, p0)
```

Arguments

x	vector of (strictly positive integer) quantiles.
q	vector of quantiles.
p	vector of probabilities.
n	number of observations. If length(n) > 1, the length is taken to be the number required.
prob	parameter. 0 < prob <= 1.
p0	probability mass at zero. 0 <= p0 <= 1.
log, log.p	logical; if TRUE, probabilities p are returned as $\log(p)$.
lower.tail	logical; if TRUE (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.

Details

The zero-modified geometric distribution with prob $= p$ and p0 $= p_0$ is a discrete mixture between a degenerate distribution at zero and a (standard) geometric. The probability mass function is $p(0) = p_0$ and

$$p(x) = \frac{(1 - p_0)}{(1 - p)} f(x)$$

for $x = 1, 2, \ldots$, $0 < p < 1$ and $0 \leq p_0 \leq 1$, where $f(x)$ is the probability mass function of the geometric. The cumulative distribution function is

$$P(x) = p_0 + (1 - p_0) \left(\frac{F(x) - F(0)}{1 - F(0)} \right)$$

The mean is $(1 - p_0)\mu$ and the variance is $(1 - p_0)\sigma^2 + p_0(1 - p_0)\mu^2$, where μ and σ^2 are the mean and variance of the zero-truncated geometric.

In the terminology of Klugman et al. (2012), the zero-modified geometric is a member of the $(a, b, 1)$ class of distributions with $a = 1 - p$ and $b = 0$.

The special case p0 == 0 is the zero-truncated geometric.

If an element of x is not integer, the result of dzmgeom is zero, with a warning.

The quantile is defined as the smallest value x such that $P(x) \geq p$, where P is the distribution function.

Value

dzmgeom gives the (log) probability mass function, pzmgeom gives the (log) distribution function, qzmgeom gives the quantile function, and rzmgeom generates random deviates.

Invalid prob or p0 will result in return value NaN, with a warning.

The length of the result is determined by n for rzmgeom, and is the maximum of the lengths of the numerical arguments for the other functions.

Note

Functions {d,p,q}zmgeom use {d,p,q}geom for all but the trivial input values and $p(0)$.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>

References

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

See Also

dgeom for the geometric distribution.

dztgeom for the zero-truncated geometric distribution.

dzmnbinom for the zero-modified negative binomial, of which the zero-modified geometric is a special case.

Examples

```
p <- 1/(1 + 0.5)
dzmgeom(1:5, prob = p, p0 = 0.6)
(1-0.6) * dgeom(1:5, p)/pgeom(0, p, lower = FALSE) # same

## simple relation between survival functions
pzmgeom(0:5, p, p0 = 0.2, lower = FALSE)
(1-0.2) * pgeom(0:5, p, lower = FALSE)/pgeom(0, p, lower = FALSE) # same

qzmgeom(pzmgeom(0:10, 0.3, p0 = 0.6), 0.3, p0 = 0.6)
```

ZeroModifiedLogarithmic

The Zero-Modified Logarithmic Distribution

Description

Density function, distribution function, quantile function and random generation for the Zero-Modified Logarithmic (or log-series) distribution with parameter prob and arbitrary probability at zero p0.

Usage

```
dzmlogarithmic(x, prob, p0, log = FALSE)
pzmlogarithmic(q, prob, p0, lower.tail = TRUE, log.p = FALSE)
qzmlogarithmic(p, prob, p0, lower.tail = TRUE, log.p = FALSE)
rzmlogarithmic(n, prob, p0)
```

Arguments

x	vector of (strictly positive integer) quantiles.
q	vector of quantiles.
p	vector of probabilities.
n	number of observations. If length(n) > 1, the length is taken to be the number required.
prob	parameter. 0 <= prob < 1.
p0	probability mass at zero. 0 <= p0 <= 1.
log, log.p	logical; if TRUE, probabilities p are returned as $\log(p)$.
lower.tail	logical; if TRUE (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.

Details

The zero-modified logarithmic distribution with prob $= p$ and p0 $= p_0$ is a discrete mixture between a degenerate distribution at zero and a (standard) logarithmic. The probability mass function is $p(0) = p_0$ and

$$p(x) = (1 - p_0)f(x)$$

for $x = 1, 2, \ldots$, $0 < p < 1$ and $0 \leq p_0 \leq 1$, where $f(x)$ is the probability mass function of the logarithmic. The cumulative distribution function is

$$P(x) = p_0 + (1 - p_0)F(x)$$

The special case p0 == 0 is the standard logarithmic.

The zero-modified logarithmic distribution is the limiting case of the zero-modified negative binomial distribution with size parameter equal to 0. Note that in this context, parameter prob generally corresponds to the probability of *failure* of the zero-truncated negative binomial.

If an element of x is not integer, the result of dzmlogarithmic is zero, with a warning.

The quantile is defined as the smallest value x such that $F(x) \geq p$, where F is the distribution function.

Value

dzmlogarithmic gives the probability mass function, pzmlogarithmic gives the distribution function, qzmlogarithmic gives the quantile function, and rzmlogarithmic generates random deviates.

Invalid prob or p0 will result in return value NaN, with a warning.

The length of the result is determined by n for rzmlogarithmic, and is the maximum of the lengths of the numerical arguments for the other functions.

Note

Functions {d,p,q}zmlogarithmic use {d,p,q}logarithmic for all but the trivial input values and $p(0)$.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>

References

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

See Also

`dlogarithmic` for the logarithmic distribution.

`dztnbinom` for the zero modified negative binomial distribution.

Examples

```
p <- 1/(1 + 0.5)
dzmlogarithmic(1:5, prob = p, p0 = 0.6)
(1-0.6) * dlogarithmic(1:5, p)/plogarithmic(0, p, lower = FALSE) # same

## simple relation between survival functions
pzmlogarithmic(0:5, p, p0 = 0.2, lower = FALSE)
(1-0.2) * plogarithmic(0:5, p, lower = FALSE)/plogarithmic(0, p, lower = FALSE) # same

qzmlogarithmic(pzmlogarithmic(0:10, 0.3, p0 = 0.6), 0.3, p0 = 0.6)
```

ZeroModifiedNegativeBinomial

The Zero-Modified Negative Binomial Distribution

Description

Density function, distribution function, quantile function and random generation for the Zero-Modified Negative Binomial distribution with parameters `size` and `prob`, and arbitrary probability at zero `p0`.

Usage

```
dzmnbinom(x, size, prob, p0, log = FALSE)
pzmnbinom(q, size, prob, p0, lower.tail = TRUE, log.p = FALSE)
qzmnbinom(p, size, prob, p0, lower.tail = TRUE, log.p = FALSE)
rzmnbinom(n, size, prob, p0)
```

Arguments

x	vector of (strictly positive integer) quantiles.
q	vector of quantiles.
p	vector of probabilities.
n	number of observations. If length(n) > 1, the length is taken to be the number required.
size	target for number of successful trials, or dispersion parameter. Must be positive, need not be integer.
prob	parameter. 0 < prob <= 1.
p0	probability mass at zero. 0 <= p0 <= 1.
log, log.p	logical; if TRUE, probabilities p are returned as $\log(p)$.
lower.tail	logical; if TRUE (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.

Details

The zero-modified negative binomial distribution with size $= r$, prob $= p$ and p0 $= p_0$ is a discrete mixture between a degenerate distribution at zero and a (standard) negative binomial. The probability mass function is $p(0) = p_0$ and

$$p(x) = \frac{(1 - p_0)}{(1 - p^r)} f(x)$$

for $x = 1, 2, \ldots$, $r \geq 0$, $0 < p < 1$ and $0 \leq p_0 \leq 1$, where $f(x)$ is the probability mass function of the negative binomial. The cumulative distribution function is

$$P(x) = p_0 + (1 - p_0) \left(\frac{F(x) - F(0)}{1 - F(0)} \right)$$

The mean is $(1 - p_0)\mu$ and the variance is $(1 - p_0)\sigma^2 + p_0(1 - p_0)\mu^2$, where μ and σ^2 are the mean and variance of the zero-truncated negative binomial.

In the terminology of Klugman et al. (2012), the zero-modified negative binomial is a member of the $(a, b, 1)$ class of distributions with $a = 1 - p$ and $b = (r - 1)(1 - p)$.

The special case p0 == 0 is the zero-truncated negative binomial.

The limiting case size == 0 is the zero-modified logarithmic distribution with parameters 1 - prob and p0.

Unlike the standard negative binomial functions, parametrization through the mean mu is not supported to avoid ambiguity as to whether mu is the mean of the underlying negative binomial or the mean of the zero-modified distribution.

If an element of x is not integer, the result of dzmnbinom is zero, with a warning.

The quantile is defined as the smallest value x such that $P(x) \geq p$, where P is the distribution function.

Value

`dzmnbinom` gives the (log) probability mass function, `pzmnbinom` gives the (log) distribution function, `qzmnbinom` gives the quantile function, and `rzmnbinom` generates random deviates.

Invalid `size`, `prob` or `p0` will result in return value `NaN`, with a warning.

The length of the result is determined by `n` for `rzmnbinom`, and is the maximum of the lengths of the numerical arguments for the other functions.

Note

Functions `{d,p,q}zmnbinom` use `{d,p,q}nbinom` for all but the trivial input values and $p(0)$.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>

References

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

See Also

`dnbinom` for the negative binomial distribution.

`dztnbinom` for the zero-truncated negative binomial distribution.

`dzmgeom` for the zero-modified geometric and `dzmlogarithmic` for the zero-modified logarithmic, which are special cases of the zero-modified negative binomial.

Examples

```
## Example 6.3 of Klugman et al. (2012)
p <- 1/(1 + 0.5)
dzmnbinom(1:5, size = 2.5, prob = p, p0 = 0.6)
(1-0.6) * dnbinom(1:5, 2.5, p)/pnbinom(0, 2.5, p, lower = FALSE) # same

## simple relation between survival functions
pzmnbinom(0:5, 2.5, p, p0 = 0.2, lower = FALSE)
(1-0.2) * pnbinom(0:5, 2.5, p, lower = FALSE) /
    pnbinom(0, 2.5, p, lower = FALSE) # same

qzmnbinom(pzmnbinom(0:10, 2.5, 0.3, p0 = 0.1), 2.5, 0.3, p0 = 0.1)
```

`ZeroModifiedPoisson` *The Zero-Modified Poisson Distribution*

Description

Density function, distribution function, quantile function, random generation for the Zero-Modified Poisson distribution with parameter `lambda` and arbitrary probability at zero `p0`.

Usage

```
dzmpois(x, lambda, p0, log = FALSE)
pzmpois(q, lambda, p0, lower.tail = TRUE, log.p = FALSE)
qzmpois(p, lambda, p0, lower.tail = TRUE, log.p = FALSE)
rzmpois(n, lambda, p0)
```

Arguments

`x`	vector of (strictly positive integer) quantiles.
`q`	vector of quantiles.
`p`	vector of probabilities.
`n`	number of values to return.
`lambda`	vector of (non negative) means.
`p0`	probability mass at zero. `0 <= p0 <= 1`.
`log, log.p`	logical; if `TRUE`, probabilities p are returned as $\log(p)$.
`lower.tail`	logical; if `TRUE` (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.

Details

The zero-modified Poisson distribution is a discrete mixture between a degenerate distribution at zero and a (standard) Poisson. The probability mass function is $p(0) = p_0$ and

$$p(x) = \frac{(1 - p_0)}{(1 - e^{-\lambda})} f(x)$$

for $x = 1, 2, ...$, $\lambda > 0$ and $0 \leq p_0 \leq 1$, where $f(x)$ is the probability mass function of the Poisson. The cumulative distribution function is

$$P(x) = p_0 + (1 - p_0) \left(\frac{F(x) - F(0)}{1 - F(0)} \right).$$

The mean is $(1 - p_0)\mu$ and the variance is $(1 - p_0)\sigma^2 + p_0(1 - p_0)\mu^2$, where μ and σ^2 are the mean and variance of the zero-truncated Poisson.

In the terminology of Klugman et al. (2012), the zero-modified Poisson is a member of the $(a, b, 1)$ class of distributions with $a = 0$ and $b = \lambda$.

The special case `p0 == 0` is the zero-truncated Poisson.

If an element of `x` is not integer, the result of `dzmpois` is zero, with a warning.

The quantile is defined as the smallest value x such that $P(x) \geq p$, where P is the distribution function.

Value

dzmpois gives the (log) probability mass function, pzmpois gives the (log) distribution function, qzmpois gives the quantile function, and rzmpois generates random deviates.

Invalid lambda or p0 will result in return value NaN, with a warning.

The length of the result is determined by n for rzmpois, and is the maximum of the lengths of the numerical arguments for the other functions.

Note

Functions {d,p,q}zmpois use {d,p,q}pois for all but the trivial input values and $p(0)$.

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>

References

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

See Also

dpois for the standard Poisson distribution.

dztpois for the zero-truncated Poisson distribution.

Examples

```
dzmpois(0:5, lambda = 1, p0 = 0.2)
(1-0.2) * dpois(0:5, lambda = 1)/ppois(0, 1, lower = FALSE) # same

## simple relation between survival functions
pzmpois(0:5, 1, p0 = 0.2, lower = FALSE)
(1-0.2) * ppois(0:5, 1, lower = FALSE) /
    ppois(0, 1, lower = FALSE) # same

qzmpois(pzmpois(0:10, 1, p0 = 0.7), 1, p0 = 0.7)
```

ZeroTruncatedBinomial *The Zero-Truncated Binomial Distribution*

Description

Density function, distribution function, quantile function and random generation for the Zero-Truncated Binomial distribution with parameters size and prob.

Usage

```
dztbinom(x, size, prob, log = FALSE)
pztbinom(q, size, prob, lower.tail = TRUE, log.p = FALSE)
qztbinom(p, size, prob, lower.tail = TRUE, log.p = FALSE)
rztbinom(n, size, prob)
```

Arguments

x	vector of (strictly positive integer) quantiles.
q	vector of quantiles.
p	vector of probabilities.
n	number of observations. If length(n) > 1, the length is taken to be the number required.
size	number of trials (strictly positive integer).
prob	probability of success on each trial. 0 <= prob <= 1.
log, log.p	logical; if TRUE, probabilities p are returned as $\log(p)$.
lower.tail	logical; if TRUE (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.

Details

The zero-truncated binomial distribution with size $= n$ and prob $= p$ has probability mass function

$$p(x) = \binom{n}{x} \frac{p^x (1-p)^{n-x}}{1-(1-p)^n}$$

for $x = 1, \ldots, n$ and $0 < p \leq 1$, and $p(1) = 1$ when $p = 0$. The cumulative distribution function is

$$P(x) = \frac{F(x) - F(0)}{1 - F(0)},$$

where $F(x)$ is the distribution function of the standard binomial.

The mean is $np/(1-(1-p)^n)$ and the variance is $np[(1-p)-(1-p+np)(1-p)^n]/[1-(1-p)^n]^2$.

In the terminology of Klugman et al. (2012), the zero-truncated binomial is a member of the $(a, b, 1)$ class of distributions with $a = -p/(1-p)$ and $b = (n+1)p/(1-p)$.

If an element of x is not integer, the result of dztbinom is zero, with a warning.

The quantile is defined as the smallest value x such that $P(x) \geq p$, where P is the distribution function.

Value

dztbinom gives the probability mass function, pztbinom gives the distribution function, qztbinom gives the quantile function, and rztbinom generates random deviates.

Invalid size or prob will result in return value NaN, with a warning.

The length of the result is determined by n for rztbinom, and is the maximum of the lengths of the numerical arguments for the other functions.

Note

Functions {d,p,q}ztbinom use {d,p,q}binom for all but the trivial input values and $p(0)$.

rztbinom uses the simple inversion algorithm suggested by Peter Dalgaard on the r-help mailing list on 1 May 2005 (https://stat.ethz.ch/pipermail/r-help/2005-May/070680.html).

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>

References

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

See Also

dbinom for the binomial distribution.

Examples

```
dztbinom(1:5, size = 5, prob = 0.4)
dbinom(1:5, 5, 0.4)/pbinom(0, 5, 0.4, lower = FALSE) # same

pztbinom(1, 2, prob = 0)        # point mass at 1

qztbinom(pztbinom(1:10, 10, 0.6), 10, 0.6)

n <- 8; p <- 0.3
x <- 0:n
title <- paste("ZT Binomial(", n, ", ", p,
               ") and Binomial(", n, ", ", p,") PDF",
               sep = "")
plot(x, dztbinom(x, n, p), type = "h", lwd = 2, ylab = "p(x)",
     main = title)
points(x, dbinom(x, n, p), pch = 19, col = "red")
legend("topright", c("ZT binomial probabilities", "Binomial probabilities"),
       col = c("black", "red"), lty = c(1, 0), lwd = 2, pch = c(NA, 19))
```

ZeroTruncatedGeometric

The Zero-Truncated Geometric Distribution

Description

Density function, distribution function, quantile function and random generation for the Zero-Truncated Geometric distribution with parameter prob.

Usage

```
dztgeom(x, prob, log = FALSE)
pztgeom(q, prob, lower.tail = TRUE, log.p = FALSE)
qztgeom(p, prob, lower.tail = TRUE, log.p = FALSE)
rztgeom(n, prob)
```

Arguments

x	vector of (strictly positive integer) quantiles.
q	vector of quantiles.
p	vector of probabilities.
n	number of observations. If length(n) > 1, the length is taken to be the number required.
prob	parameter. 0 < prob <= 1.
log, log.p	logical; if TRUE, probabilities p are returned as $\log(p)$.
lower.tail	logical; if TRUE (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.

Details

The zero-truncated geometric distribution with prob $= p$ has probability mass function

$$p(x) = p(1-p)^{x-1}$$

for $x = 1, 2, \ldots$ and $0 < p < 1$, and $p(1) = 1$ when $p = 1$. The cumulative distribution function is

$$P(x) = \frac{F(x) - F(0)}{1 - F(0)},$$

where $F(x)$ is the distribution function of the standard geometric.

The mean is $1/p$ and the variance is $(1-p)/p^2$.

In the terminology of Klugman et al. (2012), the zero-truncated geometric is a member of the $(a, b, 1)$ class of distributions with $a = 1 - p$ and $b = 0$.

If an element of x is not integer, the result of dztgeom is zero, with a warning.

The quantile is defined as the smallest value x such that $P(x) \geq p$, where P is the distribution function.

Value

dztgeom gives the (log) probability mass function, pztgeom gives the (log) distribution function, qztgeom gives the quantile function, and rztgeom generates random deviates.

Invalid prob will result in return value NaN, with a warning.

The length of the result is determined by n for rztgeom, and is the maximum of the lengths of the numerical arguments for the other functions.

Note

Functions {d,p,q}ztgeom use {d,p,q}geom for all but the trivial input values and $p(0)$.

rztgeom uses the simple inversion algorithm suggested by Peter Dalgaard on the r-help mailing list on 1 May 2005 (https://stat.ethz.ch/pipermail/r-help/2005-May/070680.html).

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>

References

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

See Also

dgeom for the geometric distribution.

dztnbinom for the zero-truncated negative binomial, of which the zero-truncated geometric is a special case.

Examples

```
p <- 1/(1 + 0.5)
dztgeom(c(1, 2, 3), prob = p)
dgeom(c(1, 2, 3), p)/pgeom(0, p, lower = FALSE) # same
dgeom(c(1, 2, 3) - 1, p)                        # same

pztgeom(1, prob = 1)        # point mass at 1

qztgeom(pztgeom(1:10, 0.3), 0.3)
```

ZeroTruncatedNegativeBinomial

The Zero-Truncated Negative Binomial Distribution

Description

Density function, distribution function, quantile function and random generation for the Zero-Truncated Negative Binomial distribution with parameters size and prob.

Usage

```
dztnbinom(x, size, prob, log = FALSE)
pztnbinom(q, size, prob, lower.tail = TRUE, log.p = FALSE)
qztnbinom(p, size, prob, lower.tail = TRUE, log.p = FALSE)
rztnbinom(n, size, prob)
```

Arguments

x	vector of (strictly positive integer) quantiles.
q	vector of quantiles.
p	vector of probabilities.
n	number of observations. If length(n) > 1, the length is taken to be the number required.
size	target for number of successful trials, or dispersion parameter. Must be positive, need not be integer.
prob	parameter. 0 < prob <= 1.
log, log.p	logical; if TRUE, probabilities p are returned as $\log(p)$.
lower.tail	logical; if TRUE (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.

Details

The zero-truncated negative binomial distribution with size $= r$ and prob $= p$ has probability mass function

$$p(x) = \frac{\Gamma(x+r)p^r(1-p)^x}{\Gamma(r)x!(1-p^r)}$$

for $x = 1, 2, \ldots$, $r \geq 0$ and $0 < p < 1$, and $p(1) = 1$ when $p = 1$. The cumulative distribution function is

$$P(x) = \frac{F(x) - F(0)}{1 - F(0)},$$

where $F(x)$ is the distribution function of the standard negative binomial.

The mean is $r(1-p)/(p(1-p^r))$ and the variance is $[r(1-p)(1-(1+r(1-p))p^r)]/[p(1-p^r)]^2$.

In the terminology of Klugman et al. (2012), the zero-truncated negative binomial is a member of the $(a, b, 1)$ class of distributions with $a = 1 - p$ and $b = (r-1)(1-p)$.

The limiting case size == 0 is the logarithmic distribution with parameter 1 - prob.

Unlike the standard negative binomial functions, parametrization through the mean mu is not supported to avoid ambiguity as to whether mu is the mean of the underlying negative binomial or the mean of the zero-truncated distribution.

If an element of x is not integer, the result of dztnbinom is zero, with a warning.

The quantile is defined as the smallest value x such that $P(x) \geq p$, where P is the distribution function.

Value

dztnbinom gives the (log) probability mass function, pztnbinom gives the (log) distribution function, qztnbinom gives the quantile function, and rztnbinom generates random deviates.

Invalid size or prob will result in return value NaN, with a warning.

The length of the result is determined by n for rztnbinom, and is the maximum of the lengths of the numerical arguments for the other functions.

Note

Functions `{d,p,q}ztnbinom` use `{d,p,q}nbinom` for all but the trivial input values and $p(0)$.

`rztnbinom` uses the simple inversion algorithm suggested by Peter Dalgaard on the r-help mailing list on 1 May 2005 (https://stat.ethz.ch/pipermail/r-help/2005-May/070680.html).

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>

References

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

See Also

`dnbinom` for the negative binomial distribution.

`dztgeom` for the zero-truncated geometric and `dlogarithmic` for the logarithmic, which are special cases of the zero-truncated negative binomial.

Examples

```
## Example 6.3 of Klugman et al. (2012)
p <- 1/(1 + 0.5)
dztnbinom(c(1, 2, 3), size = 2.5, prob = p)
dnbinom(c(1, 2, 3), 2.5, p)/pnbinom(0, 2.5, p, lower = FALSE) # same

pztnbinom(1, 2, prob = 1)        # point mass at 1
dztnbinom(2, size = 1, 0.25)     # == dztgeom(2, 0.25)
dztnbinom(2, size = 0, 0.25)     # == dlogarithmic(2, 0.75)

qztnbinom(pztnbinom(1:10, 2.5, 0.3), 2.5, 0.3)

x <- rztnbinom(1000, size = 2.5, prob = 0.4)
y <- sort(unique(x))
plot(y, table(x)/length(x), type = "h", lwd = 2,
     pch = 19, col = "black", xlab = "x", ylab = "p(x)",
     main = "Empirical vs theoretical probabilities")
points(y, dztnbinom(y, size = 2.5, prob = 0.4),
       pch = 19, col = "red")
legend("topright", c("empirical", "theoretical"),
       lty = c(1, NA), lwd = 2, pch = c(NA, 19), col = c("black", "red"))
```

`ZeroTruncatedPoisson` *The Zero-Truncated Poisson Distribution*

Description

Density function, distribution function, quantile function, random generation for the Zero-Truncated Poisson distribution with parameter `lambda`.

Usage

```
dztpois(x, lambda, log = FALSE)
pztpois(q, lambda, lower.tail = TRUE, log.p = FALSE)
qztpois(p, lambda, lower.tail = TRUE, log.p = FALSE)
rztpois(n, lambda)
```

Arguments

`x`	vector of (strictly positive integer) quantiles.
`q`	vector of quantiles.
`p`	vector of probabilities.
`n`	number of values to return.
`lambda`	vector of (non negative) means.
`log`, `log.p`	logical; if `TRUE`, probabilities p are returned as $\log(p)$.
`lower.tail`	logical; if `TRUE` (default), probabilities are $P[X \leq x]$, otherwise, $P[X > x]$.

Details

The zero-truncated Poisson distribution has probability mass function

$$p(x) = \frac{e^{-/lambda}\lambda^x}{x!(1-e^{-\lambda})} = \frac{\lambda^x}{x!(e^{\lambda}-1)}$$

for $x = 1, 2, ...$, and $p(1) = 1$ when $\lambda = 0$. The cumulative distribution function is

$$P(x) = \frac{F(x) - F(0)}{1 - F(0)},$$

where $F(x)$ is the distribution function of the standard Poisson.

The mean is $\lambda/(1-e^{-\lambda})$ and the variance is $\lambda[1-(\lambda+1)e^{-\lambda}]/(1-e^{-\lambda})^2$.

In the terminology of Klugman et al. (2012), the zero-truncated Poisson is a member of the $(a, b, 1)$ class of distributions with $a = 0$ and $b = \lambda$.

If an element of `x` is not integer, the result of `dztpois` is zero, with a warning.

The quantile is defined as the smallest value x such that $P(x) \geq p$, where P is the distribution function.

Value

`dztpois` gives the (log) probability mass function, `pztpois` gives the (log) distribution function, `qztpois` gives the quantile function, and `rztpois` generates random deviates.

Invalid `lambda` will result in return value `NaN`, with a warning.

The length of the result is determined by `n` for `rztpois`, and is the maximum of the lengths of the numerical arguments for the other functions.

Note

Functions `{d,p,q}ztpois` use `{d,p,q}pois` for all but the trivial input values and $p(0)$.

`rztpois` uses the simple inversion algorithm suggested by Peter Dalgaard on the r-help mailing list on 1 May 2005 (https://stat.ethz.ch/pipermail/r-help/2005-May/070680.html).

Author(s)

Vincent Goulet <vincent.goulet@act.ulaval.ca>

References

Klugman, S. A., Panjer, H. H. and Willmot, G. E. (2012), *Loss Models, From Data to Decisions, Fourth Edition*, Wiley.

See Also

`dpois` for the standard Poisson distribution.

Examples

```
dztpois(1:5, lambda = 1)
dpois(1:5, lambda = 1)/ppois(0, 1, lower = FALSE) # same

pztpois(1, lambda = 0)          # point mass at 1

qztpois(pztpois(1:10, 1), 1)

x <- seq(0, 8)
plot(x, dztpois(x, 2), type = "h", lwd = 2, ylab = "p(x)",
     main = "Zero-Truncated Poisson(2) and Poisson(2) PDF")
points(x, dpois(x, 2), pch = 19, col = "red")
legend("topright", c("ZT Poisson probabilities", "Poisson probabilities"),
       col = c("black", "red"), lty = c(1, 0), lwd = 2, pch = c(NA, 19))
```

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