

# Loss modeling features of **actuar**

Christophe Dutang  
Université Paris Dauphine

Vincent Goulet  
Université Laval

Mathieu Pigeon  
Université du Québec à Montréal

## 1 Introduction

One important task of actuaries is the modeling of claim amount and claim count distributions for ratemaking, loss reserving or other risk evaluation purposes. Package **actuar** features many support functions for loss distributions modeling:

1. support for heavy tail continuous distributions useful in loss severity modeling;
2. support for phase-type distributions for ruin theory;
3. functions to compute raw moments, limited moments and the moment generating function (when it exists) of continuous distributions;
4. support for zero-truncated and zero-modified extensions of the discrete distributions commonly used in loss frequency modeling;
5. extensive support of grouped data;
6. functions to compute empirical raw and limited moments;
7. support for minimum distance estimation using three different measures;
8. treatment of coverage modifications (deductibles, limits, inflation, coinsurance).

Vignette "distributions" covers the points 1–4 above in great detail. This document concentrates on points 5–8.

## 2 Grouped data

Grouped data is data represented in an interval-frequency manner. Typically, a grouped data set will report that there were  $n_j$  claims in the interval  $(c_{j-1}, c_j]$ ,  $j = 1, \dots, r$  (with the possibility that  $c_r = \infty$ ). This representation is much more compact than an individual data set — where the value of each claim is known — but it also carries far less information. Now that storage space in computers has essentially become a non issue, grouped data has somewhat fallen out of fashion. Still, grouped data remains useful as a means to represent data, if only graphically — for example, a histogram is nothing but a density approximation for grouped data. Moreover, various parameter estimation techniques rely on grouped data.

For these reasons, **actuar** provides facilities to store, manipulate and summarize grouped data. A standard storage method is needed since there are many ways to represent grouped data in the computer: using a list or a matrix, aligning  $n_j$  with  $c_{j-1}$  or with  $c_j$ , omitting  $c_0$  or not, etc. With appropriate extraction, replacement and summary methods, manipulation of grouped data becomes similar to that of individual data.

Function `grouped.data` creates a grouped data object similar to — and inheriting from — a data frame. The function accepts two types of input:

1. a vector of group boundaries  $c_0, c_1, \dots, c_r$  and one or more vectors of group frequencies  $n_1, \dots, n_r$  (note that there should be one more group boundary than group frequencies);
2. individual data  $x_1, \dots, x_n$  and either a vector of breakpoints  $c_1, \dots, c_r$ , a number  $r$  of breakpoints or an algorithm to determine the latter.

In the second case, `grouped.data` will group the individual data using function `hist`. The function always assumes that the intervals are contiguous.

**Example 1.** Consider the following already grouped data set:

Group	Frequency (Line 1)	Frequency (Line 2)
(0, 25]	30	26
(25, 50]	31	33
(50, 100]	57	31
(100, 150]	42	19
(150, 250]	65	16
(250, 500]	84	11

We can conveniently and unambiguously store this data set in R as follows:

```
> x <- grouped.data(Group = c(0, 25, 50, 100,
+                             150, 250, 500),
+                   Line.1 = c(30, 31, 57, 42, 65, 84),
+                   Line.2 = c(26, 33, 31, 19, 16, 11))
```

Internally, object `x` is a list with class

```
> class(x)
[1] "grouped.data" "data.frame"
```

The package provides a suitable `print` method to display grouped data objects in an intuitive manner:

```
> x
      Group Line.1 Line.2
1  (0, 25]    30    26
2  (25, 50]   31    33
3  (50, 100]  57    31
4  (100, 150] 42    19
5  (150, 250] 65    16
6  (250, 500] 84    11
```

□

**Example 2.** Consider Data Set B of [Klugman et al. \(2012, Table 11.2\)](#):

```
27  82  115  126  155  161  243  294  340  384
457 680 855 877 974 1,193 1,340 1,884 2,558 15,743
```

We can represent this data set as grouped data using either an automatic or a suggested number of groups (see `?hist` for details):

```
> y <- c( 27,  82,  115,  126, 155, 161, 243, 294,
+         340, 384, 457, 680, 855, 877, 974, 1193,
```

```

+      1340, 1884, 2558, 15743)
> grouped.data(y)
      y
1  (0, 2000] 18
2 (2000, 4000] 1
3 (4000, 6000] 0
4 (6000, 8000] 0
5 (8000, 10000] 0
6 (10000, 12000] 0
7 (12000, 14000] 0
8 (14000, 16000] 1
> grouped.data(y, breaks = 5)
      y
1  (0, 5000] 19
2 (5000, 10000] 0
3 (10000, 15000] 0
4 (15000, 20000] 1

```

The above grouping methods use equi-spaced breaks. This is rarely appropriate for heavily skewed insurance data. For this reason, `grouped.data` also supports specified breakpoints (or group boundaries):

```

> grouped.data(y, breaks = c(0, 100, 200, 350, 750,
+      1200, 2500, 5000, 16000))
      y
1  (0, 100] 2
2 (100, 200] 4
3 (200, 350] 3
4 (350, 750] 3
5 (750, 1200] 4
6 (1200, 2500] 2
7 (2500, 5000] 1
8 (5000, 16000] 1

```

□

The package supports the most common extraction and replacement methods for "grouped.data" objects using the usual `[` and `[<-` operators. In particular, the following extraction operations are supported. (In the following, object `x` is the grouped data object of [Example 1](#).)

- i) Extraction of the vector of group boundaries (the first column):

```
> x[, 1]
[1] 0 25 50 100 150 250 500
```

- ii) Extraction of the vector or matrix of group frequencies (the second and third columns):

```
> x[, -1]
  Line.1 Line.2
1     30     26
2     31     33
3     57     31
4     42     19
5     65     16
6     84     11
```

- iii) Extraction of a subset of the whole object (first three lines):

```
> x[1:3, ]
  Group Line.1 Line.2
1 (0, 25]     30     26
2 (25, 50]    31     33
3 (50, 100]   57     31
```

Notice how extraction results in a simple vector or matrix if either of the group boundaries or the group frequencies are dropped.

As for replacement operations, the package implements the following.

- i) Replacement of one or more group frequencies:

```
> x[1, 2] <- 22; x
  Group Line.1 Line.2
1 (0, 25]     22     26
2 (25, 50]    31     33
3 (50, 100]   57     31
4 (100, 150]  42     19
5 (150, 250]  65     16
6 (250, 500]  84     11
> x[1, c(2, 3)] <- c(22, 19); x
```

	Group	Line.1	Line.2
1	(0, 25]	22	19
2	(25, 50]	31	33
3	(50, 100]	57	31
4	(100, 150]	42	19
5	(150, 250]	65	16
6	(250, 500]	84	11

ii) Replacement of the boundaries of one or more groups:

```
> x[1, 1] <- c(0, 20); x
```

	Group	Line.1	Line.2
1	(0, 20]	22	19
2	(20, 50]	31	33
3	(50, 100]	57	31
4	(100, 150]	42	19
5	(150, 250]	65	16
6	(250, 500]	84	11

```
> x[c(3, 4), 1] <- c(55, 110, 160); x
```

	Group	Line.1	Line.2
1	(0, 20]	22	19
2	(20, 55]	31	33
3	(55, 110]	57	31
4	(110, 160]	42	19
5	(160, 250]	65	16
6	(250, 500]	84	11

It is not possible to replace the boundaries and the frequencies simultaneously.

The mean of grouped data is

$$\hat{\mu} = \frac{1}{n} \sum_{j=1}^r a_j n_j, \quad (1)$$

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

$$\frac{1}{n} \sum_{j=1}^r n_j (a_j - \hat{\mu})^2. \quad (2)$$

The standard deviation is the square root of the variance. The package defines methods to easily compute the above descriptive statistics:

```

> mean(x)
Line.1 Line.2
 188.0  108.2
> var(x)
Line.1 Line.2
 25050  14945
> sd(x)
Line.1 Line.2
 158.3  122.3

```

Higher empirical moments can be computed with `emm`; see [section 4](#).

The R function `hist` splits individual data into groups and draws an histogram of the frequency distribution. The package introduces a method for already grouped data. Only the first frequencies column is considered (see [Figure 1](#) for the resulting graph):

```

> hist(x[, -3])

```

*Remark 1.* One will note that for an individual data set like `y` of [Example 2](#), the following two expressions yield the same result:

```

> hist(y)
> hist(grouped.data(y))

```

R has a function `ecdf` to compute the empirical cdf  $F_n(x)$  of an individual data set:

$$F_n(x) = \frac{1}{n} \sum_{j=1}^n I\{x_j \leq x\}, \quad (3)$$

where  $I\{\mathcal{A}\} = 1$  if  $\mathcal{A}$  is true and  $I\{\mathcal{A}\} = 0$  otherwise. The function returns a "function" object to compute the value of  $F_n(x)$  in any  $x$ .

The approximation of the empirical cdf for grouped data is called an ogive ([Klugman et al., 2012](#); [Hogg and Klugman, 1984](#)). It is obtained by joining the known values of  $F_n(x)$  at group boundaries with straight line segments:

$$\tilde{F}_n(x) = \begin{cases} 0, & x \leq c_0 \\ \frac{(c_j - x)F_n(c_{j-1}) + (x - c_{j-1})F_n(c_j)}{c_j - c_{j-1}}, & c_{j-1} < x \leq c_j \\ 1, & x > c_r. \end{cases} \quad (4)$$

The package includes a generic function `ogive` with methods for individual and for grouped data. The function behaves exactly like `ecdf`.

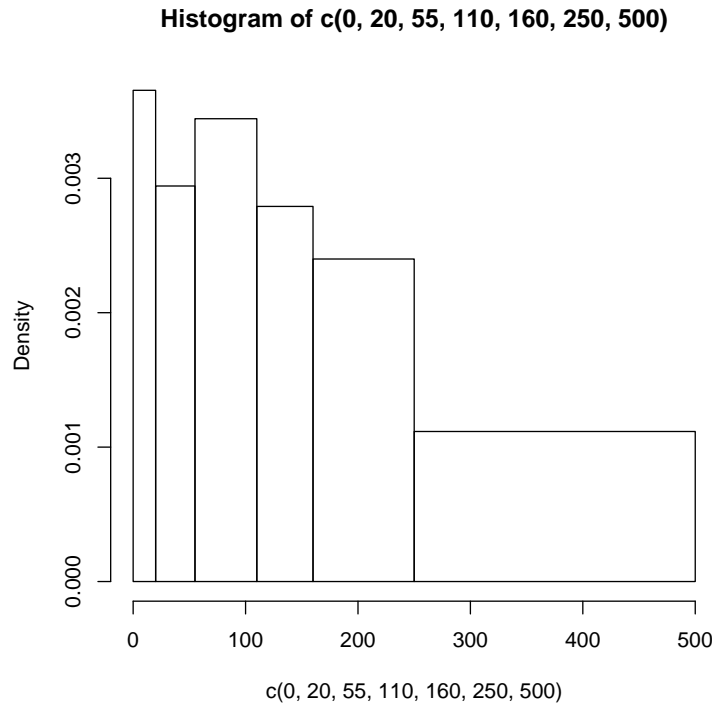


Figure 1: Histogram of a grouped data object

**Example 3.** Consider first the grouped data set of [Example 1](#). Function `ogive` returns a function to compute the ogive  $\tilde{F}_n(x)$  in any point:

```
> (Fnt <- ogive(x))
Ogive for grouped data
Call: ogive(x = x)
  x =  0,  20,  55,  ..., 2.5e+02, 5e+02
 F(x) =  0, 0.073, 0.18,  ..., 0.72,  1
```

Methods for functions `knots` and `plot` allow, respectively, to obtain the knots  $c_0, c_1, \dots, c_r$  of the ogive and to draw a graph (see [Figure 2](#)):

```
> knots(Fnt)
[1]  0  20  55 110 160 250 500
> Fnt(knots(Fnt))
[1] 0.00000 0.07309 0.17608 0.36545 0.50498 0.72093
```



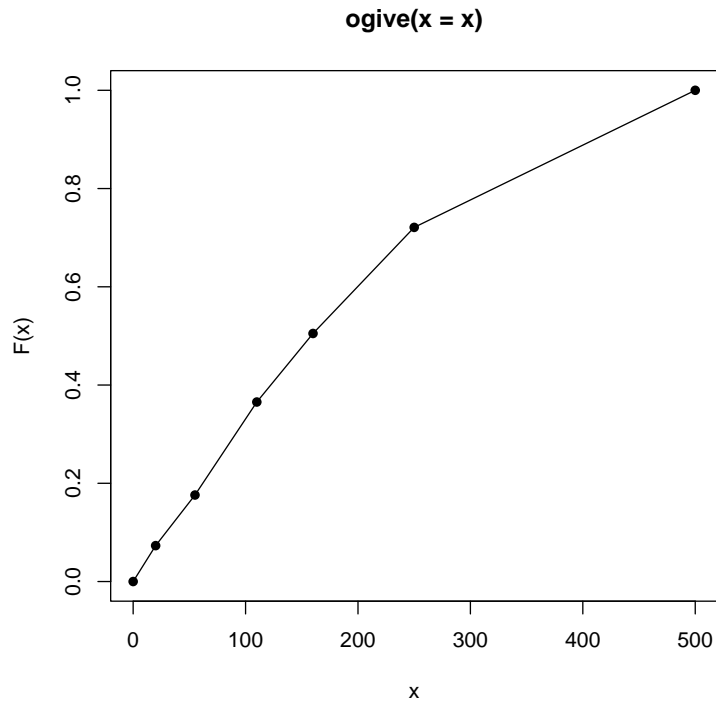


Figure 2: Ogive of a grouped data object

```
[7] 1.00000
> plot(Fnt)
```

To add further symmetry between functions `hist` and `ogive`, the latter also accepts in argument a vector individual data. It will call `grouped.data` and then computes the ogive. (Below, `y` is the individual data set of [Example 2](#).)

```
> (Fnt <- ogive(y))
Ogive for grouped data
Call: ogive(x = y)
  x =  0, 2e+03, 4e+03, ..., 1.4e+04, 1.6e+04
  F(x) =  0, 0.9, 0.95, ..., 0.95,  1
> knots(Fnt)
[1]  0 2000 4000 6000 8000 10000 12000 14000
[9] 16000
```

□

A method of function `quantile` for grouped data objects returns linearly smoothed quantiles, that is, the inverse of the ogive evaluated at various points:

```
> quantile(x)
  0%   25%   50%   75%  100%
0.00  76.47 158.21 276.04 500.00
> Fnt(quantile(x))
[1] 0.00 0.25 0.50 0.75 1.00
```

Finally, a summary method for grouped data objects returns the quantiles and the mean, as is usual for individual data:

```
> summary(x)
  Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
  0.0   76.5   158.2   188.0   276.0   500.0
```

### 3 Data sets

This is certainly not the most spectacular feature of **actuar**, but it remains useful for illustrations and examples: the package includes the individual dental claims and grouped dental claims data of [Klugman et al. \(2012\)](#):

```
> data("dental"); dental
[1] 141  16  46  40 351 259 317 1511 107
[10] 567
> data("gdental"); gdental
      cj nj
1   (0, 25] 30
2  (25, 50] 31
3  (50, 100] 57
4 (100, 150] 42
5 (150, 250] 65
6 (250, 500] 84
7 (500, 1000] 45
8 (1000, 1500] 10
9 (1500, 2500] 11
10 (2500, 4000] 3
```

## 4 Calculation of empirical moments

The package provides two functions useful for estimation based on moments. First, function `emm` computes the  $k$ th empirical moment of a sample, whether in individual or grouped data form. For example, the following expressions compute the first three moments for individual and grouped data sets:

```
> emm(dental, order = 1:3)
[1] 3.355e+02 2.931e+05 3.729e+08
> emm(gdental, order = 1:3)
[1] 3.533e+02 3.577e+05 6.586e+08
```

Second, in the same spirit as `ecdf` and `ogive`, function `elev` returns a function to compute the empirical limited expected value — or first limited moment — of a sample for any limit. Again, there are methods for individual and grouped data (see [Figure 3](#) for the graphs):

```
> lev <- elev(dental)
> lev(knots(lev))
[1] 16.0 37.6 42.4 85.1 105.5 164.5 187.7 197.9
[9] 241.1 335.5
> plot(lev, type = "o", pch = 19)
> lev <- elev(gdental)
> lev(knots(lev))
[1] 0.00 24.01 46.00 84.16 115.77 164.85
[7] 238.26 299.77 324.90 347.39 353.34
> plot(lev, type = "o", pch = 19)
```

## 5 Minimum distance estimation

Two methods are widely used by actuaries to fit models to data: maximum likelihood and minimum distance. The first technique applied to individual data is well covered by function `fitdistr` of the package **MASS** ([Venables and Ripley, 2002](#)).

The second technique minimizes a chosen distance function between theoretical and empirical distributions. Package **actuar** provides function `mde`, very similar in usage and inner working to `fitdistr`, to fit models according to any of the following three distance minimization methods.

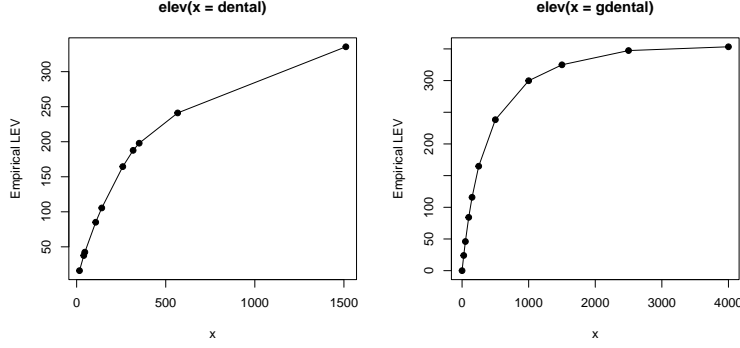


Figure 3: Empirical limited expected value function of an individual data object (left) and a grouped data object (right)

1. The Cramér-von Mises method (CvM) minimizes the squared difference between the theoretical cdf and the empirical cdf or ogive at their knots:

$$d(\theta) = \sum_{j=1}^n w_j [F(x_j; \theta) - F_n(x_j; \theta)]^2 \quad (5)$$

for individual data and

$$d(\theta) = \sum_{j=1}^r w_j [F(c_j; \theta) - \tilde{F}_n(c_j; \theta)]^2 \quad (6)$$

for grouped data. Here,  $F(x)$  is the theoretical cdf of a parametric family,  $F_n(x)$  is the empirical cdf,  $\tilde{F}_n(x)$  is the ogive and  $w_1 \geq 0, w_2 \geq 0, \dots$  are arbitrary weights (defaulting to 1).

2. The modified chi-square method (chi-square) applies to grouped data only and minimizes the squared difference between the expected and observed frequency within each group:

$$d(\theta) = \sum_{j=1}^r w_j [n(F(c_j; \theta) - F(c_{j-1}; \theta)) - n_j]^2, \quad (7)$$

where  $n = \sum_{j=1}^r n_j$ . By default,  $w_j = n_j^{-1}$ .

3. The layer average severity method (LAS) applies to grouped data only and minimizes the squared difference between the theoretical and empirical lim-

ited expected value within each group:

$$d(\theta) = \sum_{j=1}^r w_j [\text{LAS}(c_{j-1}, c_j; \theta) - \tilde{\text{LAS}}_n(c_{j-1}, c_j; \theta)]^2, \quad (8)$$

where  $\text{LAS}(x, y) = E[X \wedge y] - E[X \wedge x]$ ,  $\tilde{\text{LAS}}_n(x, y) = \tilde{E}_n[X \wedge y] - \tilde{E}_n[X \wedge x]$  and  $\tilde{E}_n[X \wedge x]$  is the empirical limited expected value for grouped data.

The arguments of `mde` are a data set, a function to compute  $F(x)$  or  $E[X \wedge x]$ , starting values for the optimization procedure and the name of the method to use. The empirical functions are computed with `ecdf`, `ogive` or `elev`.

**Example 4.** The expressions below fit an exponential distribution to the grouped dental data set, as per example 2.21 of [Klugman et al. \(1998\)](#):

```
> mde(gdental, pexp, start = list(rate = 1/200),
+     measure = "CvM")
  rate
0.003551

  distance
0.002842
> mde(gdental, pexp, start = list(rate = 1/200),
+     measure = "chi-square")
  rate
0.00364

  distance
13.54
> mde(gdental, levexp, start = list(rate = 1/200),
+     measure = "LAS")
  rate
0.002966

  distance
694.5
```

□

It should be noted that optimization is not always as simple to achieve as in [Example 4](#). For example, consider the problem of fitting a Pareto distribution to the same data set using the Cramér–von Mises method:

```
> mde(gdental, ppareto,
+     start = list(shape = 3, scale = 600),
+     measure = "CvM")
```

```
Error in mde(gdental, ppareto, start = list(shape = 3,
+     scale = 600), measure = "CvM") :
  l'optimisation a échoué
```

Working in the log of the parameters often solves the problem since the optimization routine can then flawlessly work with negative parameter values:

```
> pparetolog <- function(x, logshape, logscale)
+   ppareto(x, exp(logshape), exp(logscale))
> (p <- mde(gdental, pparetolog,
+     start = list(logshape = log(3),
+     logscale = log(600)),
+     measure = "CvM"))
logshape  logscale
    1.581     7.128

distance
0.0007905
```

The actual estimators of the parameters are obtained with

```
> exp(p$estimate)
logshape logscale
    4.861 1246.485
```

This procedure may introduce additional bias in the estimators, though.

## 6 Coverage modifications

Let  $X$  be the random variable of the actual claim amount for an insurance policy,  $Y^L$  be the random variable of the amount paid per loss and  $Y^P$  be the random variable of the amount paid per payment. The terminology for the last two random variables refers to whether or not the insurer knows that a loss occurred. Now, the random variables  $X$ ,  $Y^L$  and  $Y^P$  will differ if any of the following coverage modifications are present for the policy: an ordinary or a franchise deductible, a limit, coinsurance or inflation adjustment (see [Klugman et al., 2012](#), chapter 8 for precise definitions of these terms). [Table 1](#) summarizes the defi-

Coverage modification	Per-loss variable ( $Y^L$ )	Per-payment variable ( $Y^P$ )
Ordinary deductible ( $d$ )	$\begin{cases} 0, & X \leq d \\ X - d, & X > d \end{cases}$	$\begin{cases} X - d, & X > d \end{cases}$
Franchise deductible ( $d$ )	$\begin{cases} 0, & X \leq d \\ X, & X > d \end{cases}$	$\begin{cases} X, & X > d \end{cases}$
Limit ( $u$ )	$\begin{cases} X, & X \leq u \\ u, & X > u \end{cases}$	$\begin{cases} X, & X \leq u \\ u, & X > u \end{cases}$
Coinsurance ( $\alpha$ )	$\alpha X$	$\alpha X$
Inflation ( $r$ )	$(1 + r)X$	$(1 + r)X$

Table 1: Coverage modifications for per-loss variable ( $Y^L$ ) and per-payment variable ( $Y^P$ ) as defined in [Klugman et al. \(2012\)](#).

initions of  $Y^L$  and  $Y^P$ .

Often, one will want to use data  $Y_1^P, \dots, Y_n^P$  (or  $Y_1^L, \dots, Y_n^L$ ) from the random variable  $Y^P$  ( $Y^L$ ) to fit a model on the unobservable random variable  $X$ . This requires expressing the pdf or cdf of  $Y^P$  ( $Y^L$ ) in terms of the pdf or cdf of  $X$ . Function coverage of **actuar** does just that: given a pdf or cdf and any combination of the coverage modifications mentioned above, coverage returns a function object to compute the pdf or cdf of the modified random variable. The function can then be used in modeling like any other dfoo or pfoo function.

**Example 5.** Let  $Y^P$  represent the amount paid by an insurer for a policy with an ordinary deductible  $d$  and a limit  $u - d$  (or maximum covered loss of  $u$ ). Then the definition of  $Y^P$  is

$$Y^P = \begin{cases} X - d, & d \leq X \leq u \\ u - d, & X \geq u \end{cases} \quad (9)$$

and its pdf is

$$f_{Y^P}(y) = \begin{cases} 0, & y = 0 \\ \frac{f_X(y + d)}{1 - F_X(d)}, & 0 < y < u - d \\ \frac{1 - F_X(u)}{1 - F_X(d)}, & y = u - d \\ 0, & y > u - d. \end{cases} \quad (10)$$

Assume  $X$  has a gamma distribution. Then an R function to compute the pdf (10) in any  $y$  for a deductible  $d = 1$  and a limit  $u = 10$  is obtained with coverage as follows:

```
> f <- coverage(pdf = dgamma, cdf = pgamma,
+             deductible = 1, limit = 10)
> f
function (x, shape, rate = 1, scale = 1/rate)
{
  Call <- match.call()
  Sd <- Call
  Sd$lower.tail <- FALSE
  Sd[[1L]] <- as.name("pgamma")
  names(Sd)[2L] <- "q"
  Sd[[2L]] <- 1
  Su <- Sd
  Su[[2L]] <- 10
  f <- Call
  f[[1L]] <- as.name("dgamma")
  res <- numeric(length(x))
  w <- which(0 < x & x < 9)
  f[[2L]] <- x[w] + 1
  res[w] <- eval.parent(f)/(p <- eval.parent(Sd))
  res[x == 9] <- eval.parent(Su)/p
  res
}
<environment: 0x1235b45a8>
> f(0, shape = 5, rate = 1)
[1] 0
> f(5, shape = 5, rate = 1)
[1] 0.1343
> f(9, shape = 5, rate = 1)
[1] 0.02936
> f(12, shape = 5, rate = 1)
[1] 0
```

□

Note how function  $f$  in the previous example is built specifically for the



coverage modifications submitted and contains as little useless code as possible.

The function returned by `coverage` may be used for various purposes, most notably parameter estimation, as the following example illustrates.

**Example 6.** Let object `y` contain a sample of claims amounts from policies with the deductible and limit of [Example 5](#). One can fit a gamma distribution by maximum likelihood to the claim severity distribution as follows:

```
> library(MASS)
> fitdistr(y, f, start = list(shape = 2, rate = 0.5))
      shape      rate
3.7345    0.6806
(0.6569) (0.1259)
```

□

Vignette "coverage" contains more detailed formulas for the pdf and the cdf under various combinations of coverage modifications.

## References

- R. V. Hogg and S. A. Klugman. *Loss Distributions*. Wiley, New York, 1984. ISBN 0-4718792-9-0.
- S. A. Klugman, H. H. Panjer, and G. Willmot. *Loss Models: From Data to Decisions*. Wiley, New York, 1998. ISBN 0-4712388-4-8.
- S. A. Klugman, H. H. Panjer, and G. Willmot. *Loss Models: From Data to Decisions*. Wiley, New York, 4 edition, 2012. ISBN 978-1-118-31532-3.
- W. N. Venables and B. D. Ripley. *Modern applied statistics with S*. Springer, New York, 4 edition, 2002. ISBN 0-3879545-7-0.