

Credibility theory features of **actuar**

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1 Introduction

Credibility models are actuarial tools to distribute premiums fairly among an heterogeneous group of policyholders (henceforth called *entities*). More generally, they can be seen as prediction methods applicable in any setting where repeated measures are made for subjects with different risk levels.

The credibility theory facilities of **actuar** consist of matrix `hachemeister` containing the famous data set of [Hachemeister \(1975\)](#) and function `cm` to fit hierarchical and regression credibility models. Furthermore, function `simul` can simulate portfolios of data satisfying the assumptions of the aforementioned credibility models; see the "simulation" vignette for details.

2 Hachemeister data set

The data set of [Hachemeister \(1975\)](#) consists of private passenger bodily injury insurance average claim amounts, and the corresponding number of claims, for five U.S. states over 12 quarters between July 1970 and June 1973. The data set is included in the package in the form of a matrix with 5 rows and 25 columns. The first column contains a state index, columns 2-13 contain the claim averages and columns 14-25 contain the claim numbers:

```
> data(hachemeister)
> hachemeister

      state ratio.1 ratio.2 ratio.3 ratio.4 ratio.5 ratio.6
[1,]      1   1738   1642   1794   2051   2079   2234
```

| | | | | | | | |
|------|----------|----------|----------|-----------|-----------|-----------|------|
| [2,] | 2 | 1364 | 1408 | 1597 | 1444 | 1342 | 1675 |
| [3,] | 3 | 1759 | 1685 | 1479 | 1763 | 1674 | 2103 |
| [4,] | 4 | 1223 | 1146 | 1010 | 1257 | 1426 | 1532 |
| [5,] | 5 | 1456 | 1499 | 1609 | 1741 | 1482 | 1572 |
| | ratio.7 | ratio.8 | ratio.9 | ratio.10 | ratio.11 | ratio.12 | |
| [1,] | 2032 | 2035 | 2115 | 2262 | 2267 | 2517 | |
| [2,] | 1470 | 1448 | 1464 | 1831 | 1612 | 1471 | |
| [3,] | 1502 | 1622 | 1828 | 2155 | 2233 | 2059 | |
| [4,] | 1953 | 1123 | 1343 | 1243 | 1762 | 1306 | |
| [5,] | 1606 | 1735 | 1607 | 1573 | 1613 | 1690 | |
| | weight.1 | weight.2 | weight.3 | weight.4 | weight.5 | weight.6 | |
| [1,] | 7861 | 9251 | 8706 | 8575 | 7917 | 8263 | |
| [2,] | 1622 | 1742 | 1523 | 1515 | 1622 | 1602 | |
| [3,] | 1147 | 1357 | 1329 | 1204 | 998 | 1077 | |
| [4,] | 407 | 396 | 348 | 341 | 315 | 328 | |
| [5,] | 2902 | 3172 | 3046 | 3068 | 2693 | 2910 | |
| | weight.7 | weight.8 | weight.9 | weight.10 | weight.11 | weight.12 | |
| [1,] | 9456 | 8003 | 7365 | 7832 | 7849 | 9077 | |
| [2,] | 1964 | 1515 | 1527 | 1748 | 1654 | 1861 | |
| [3,] | 1277 | 1218 | 896 | 1003 | 1108 | 1121 | |
| [4,] | 352 | 331 | 287 | 384 | 321 | 342 | |
| [5,] | 3275 | 2697 | 2663 | 3017 | 3242 | 3425 | |

3 Hierarchical credibility model

The linear model fitting function of R is named `lm`. Since credibility models are very close in many respects to linear models, and since the credibility model fitting function of **actuar** borrows much of its interface from `lm`, we named the credibility function `cm`.

Function `cm` acts as a unified interface for all credibility models supported by the package. Currently, these are the unidimensional models of [Bühlmann \(1969\)](#) and [Bühlmann and Straub \(1970\)](#), the hierarchical model of [Jewell \(1975\)](#) (of which the first two are special cases) and the regression model of [Hachemeister \(1975\)](#). The modular design of `cm` makes it easy to add new models if desired.

This subsection concentrates on usage of `cm` for hierarchical models.

There are some variations in the formulas of the hierarchical model in the literature. We compute the credibility premiums as given in [Bühlmann and Jewell \(1987\)](#) or [Bühlmann and Gisler \(2005\)](#). We support three types of estimators of the between variance structure parameters: the unbiased estimators of [Bühlmann and Gisler \(2005\)](#) (the default), the slightly different version of [Ohlsson \(2005\)](#) and the iterative pseudo-estimators as found in [Goovaerts and Hoogstad \(1987\)](#) or [Goulet \(1998\)](#). For instance, for a two-level hierarchical model like (??), the best linear prediction for year $n + 1$

based on ratios $X_{ijt} = S_{ijt}/w_{ijt}$ is

$$\begin{aligned}\hat{\pi}_{ij} &= z_{ij}X_{ijw} + (1 - z_{ij})\hat{\pi}_i \\ \hat{\pi}_i &= z_iX_{izw} + (1 - z_i)m\end{aligned}\tag{1}$$

with

$$\begin{aligned}z_{ij} &= \frac{w_{ij\bar{z}}}{w_{ij\bar{z}} + s^2/a}, & X_{ijw} &= \sum_{t=1}^{n_{ij}} \frac{w_{ijt}}{w_{ij\bar{z}}} X_{ijt} \\ z_i &= \frac{z_{i\bar{z}}}{z_{i\bar{z}} + a/b}, & X_{izw} &= \sum_{j=1}^{J_i} \frac{z_{ij}}{z_{i\bar{z}}} X_{ijw}.\end{aligned}$$

The estimator of s^2 is

$$\hat{s}^2 = \frac{1}{\sum_{i=1}^I \sum_{j=1}^{J_i} (n_{ij} - 1)} \sum_{i=1}^I \sum_{j=1}^{J_i} \sum_{t=1}^{n_{ij}} w_{ijt} (X_{ijt} - X_{ijw})^2.\tag{2}$$

The three types of estimators for parameters a and b are the following. First, let

$$\begin{aligned}A_i &= \sum_{j=1}^{J_i} w_{ij\bar{z}} (X_{ijw} - X_{i\bar{z}w})^2 - (J_i - 1)s^2 & c_i &= w_{i\bar{z}\bar{z}} - \sum_{j=1}^{J_i} \frac{w_{ij\bar{z}}^2}{w_{i\bar{z}\bar{z}}} \\ B &= \sum_{i=1}^I z_i (X_{izw} - \bar{X}_{zzw})^2 - (I - 1)a & d &= z_{\bar{z}\bar{z}} - \sum_{i=1}^I \frac{z_{i\bar{z}}^2}{z_{\bar{z}\bar{z}}},\end{aligned}$$

with

$$\bar{X}_{zzw} = \sum_{i=1}^I \frac{z_{i\bar{z}}}{z_{\bar{z}\bar{z}}} X_{izw}.\tag{3}$$

(Hence, $E[A_i] = c_i a$ and $E[B] = db$.) Then, the Bühlmann-Gisler estimators are

$$\hat{a} = \frac{1}{I} \sum_{i=1}^I \max\left(\frac{A_i}{c_i}, 0\right)\tag{4}$$

$$\hat{b} = \max\left(\frac{B}{d}, 0\right),\tag{5}$$

the Ohlsson estimators are

$$\hat{a}' = \frac{\sum_{i=1}^I A_i}{\sum_{i=1}^I c_i}\tag{6}$$

$$\hat{b}' = \frac{B}{d}\tag{7}$$

and the iterative (pseudo-)estimators are

$$\tilde{a} = \frac{1}{\sum_{i=1}^I (J_i - 1)} \sum_{i=1}^I \sum_{j=1}^{J_i} z_{ij} (X_{ijw} - X_{izw})^2 \quad (8)$$

$$\tilde{b} = \frac{1}{I - 1} \sum_{i=1}^I z_i (X_{izw} - X_{zzw})^2, \quad (9)$$

where

$$X_{zzw} = \sum_{i=1}^I \frac{z_i}{z_{\Sigma}} X_{izw}. \quad (10)$$

Note the difference between the two weighted averages (3) and (10). See [Goulet and Ouellet \(2008\)](#) for further discussion on this topic.

Finally, the estimator of the collective mean m is $\hat{m} = X_{zzw}$.

The credibility modeling function `cm` assumes that data is available in the format most practical applications would use, namely a rectangular array (matrix or data frame) with entity observations in the rows and with one or more classification index columns (numeric or character). One will recognize the output format of `simul` and its summary methods.

Then, function `cm` works much the same as `lm`. It takes in argument a formula of the form `~ terms` describing the hierarchical interactions in a data set; the data set containing the variables referenced in the formula; the names of the columns where the ratios and the weights are to be found in the data set. The latter should contain at least two nodes in each level and more than one period of experience for at least one entity. Missing values are represented by NAs. There can be entities with no experience (complete lines of NAs).

In order to give an easily reproducible example, we group states 1 and 3 of the Hachemeister data set into one cohort and states 2, 4 and 5 into another. This shows that data does not have to be sorted by level. The fitted model using the iterative estimators is:

```
> X <- cbind(cohort = c(1, 2, 1, 2, 2), hachemeister)
> fit <- cm(~cohort + cohort:state, data = X, ratios = ratio.1:ratio.12,
+ weights = weight.1:weight.12, method = "iterative")
> fit
```

Call:

```
cm(formula = ~cohort + cohort:state, data = X, ratios = ratio.1:ratio.12,
weights = weight.1:weight.12, method = "iterative")
```

Structure Parameters Estimators

Collective premium: 1746

```
Between cohort variance: 88981
Within cohort/Between state variance: 10952
Within state variance: 139120026
```

The function returns a fitted model object of class "cm" containing the estimators of the structure parameters. To compute the credibility premiums, one calls a method of predict for this class:

```
> predict(fit)
```

```
$cohort
[1] 1949 1543
```

```
$state
[1] 2048 1524 1875 1497 1585
```

One can also obtain a nicely formatted view of the most important results with a call to summary:

```
> summary(fit)
```

```
Call:
cm(formula = ~cohort + cohort:state, data = X, ratios = ratio.1:ratio.12,
  weights = weight.1:weight.12, method = "iterative")
```

Structure Parameters Estimators

```
Collective premium: 1746
```

```
Between cohort variance: 88981
Within cohort/Between state variance: 10952
Within state variance: 139120026
```

Detailed premiums

```
Level: cohort
  cohort Individ. mean Weight Cred. factor Cred. premium
1     1967         1.407  0.9196         1949
2     1528         1.596  0.9284         1543
```

```
Level: state
  cohort state Individ. mean Weight Cred. factor
1      1     2061         100155 0.8874
2      2     1511         19895 0.6103
1      3     1806         13735 0.5195
2      4     1353          4152 0.2463
2      5     1600         36110 0.7398
```

```

Cred. premium
2048
1524
1875
1497
1585

```

The methods of `predict` and `summary` can both report for a subset of the levels by means of an argument `levels`. For example:

```
> summary(fit, levels = "cohort")
```

Call:

```
cm(formula = ~cohort + cohort:state, data = X, ratios = ratio.1:ratio.12,
   weights = weight.1:weight.12, method = "iterative")
```

Structure Parameters Estimators

Collective premium: 1746

Between cohort variance: 88981

Within cohort variance: 10952

Detailed premiums

Level: cohort

| | cohort | Indiv. mean | Weight | Cred. factor | Cred. premium |
|---|--------|-------------|--------|--------------|---------------|
| 1 | 1967 | | 1.407 | 0.9196 | 1949 |
| 2 | 1528 | | 1.596 | 0.9284 | 1543 |

```
> predict(fit, levels = "cohort")
```

```
$cohort
```

```
[1] 1949 1543
```

The results above differ from those of [Goovaerts and Hoogstad \(1987\)](#) for the same example because the formulas for the credibility premiums are different.

4 Bühlmann and Bühlmann–Straub models

As mentioned above, the Bühlmann and Bühlmann–Straub models are simply one-level hierarchical models. In this case, the Bühlmann–Gisler and Ohlsson estimators of the between variance parameters are both identical to the usual [Bühlmann and Straub \(1970\)](#) estimator

$$\hat{a} = \frac{w_{\Sigma\Sigma}}{w_{\Sigma\Sigma}^2 - \sum_{i=1}^I w_{i\Sigma}^2} \left(\sum_{i=1}^I w_{i\Sigma} (X_{iW} - X_{wW})^2 - (I-1)\hat{s}^2 \right), \quad (11)$$

and the iterative estimator

$$\tilde{a} = \frac{1}{I-1} \sum_{i=1}^I z_i (X_{iw} - X_{zw})^2 \quad (12)$$

is better known as the Bichsel–Straub estimator.

To fit the Bühlmann model using `cm`, one simply does not specify any weights:

```
> cm(~state, hachemeister, ratios = ratio.1:ratio.12)
```

Call:

```
cm(formula = ~state, data = hachemeister, ratios = ratio.1:ratio.12)
```

Structure Parameters Estimators

Collective premium: 1671

Between state variance: 72310

Within state variance: 46040

In comparison, the results for the Bühlmann–Straub model using the Bichsel–Straub estimator are:

```
> cm(~state, hachemeister, ratios = ratio.1:ratio.12,  
+     weights = weight.1:weight.12)
```

Call:

```
cm(formula = ~state, data = hachemeister, ratios = ratio.1:ratio.12,  
    weights = weight.1:weight.12)
```

Structure Parameters Estimators

Collective premium: 1684

Between state variance: 89639

Within state variance: 139120026

5 Regression model of Hachemeister

The regression model of [Hachemeister \(1975\)](#) is a generalization of the Bühlmann–Straub model. If data shows a systematic trend, the latter model will typically under- or over-estimate the true premium of an entity. The idea of [Hachemeister](#) was to fit to the data a regression model where the parameters are a credibility weighted average of an entity's regression parameters and the group's parameters.

In order to use `cm` to fit a credibility regression model to a data set, one has to specify a vector or matrix of regressors by means of argument `xreg`. For example, fitting the model

$$X_{it} = \beta_0 + \beta_1(12 - t) + \varepsilon_t, \quad t = 1, \dots, 12$$

to the original data set of [Hachemeister](#) is done with

```
> fit <- cm(~state, hachemeister, xreg = 12:1, ratios = ratio.1:ratio.12,
+         weights = weight.1:weight.12)
> fit
```

Call:

```
cm(formula = ~state, data = hachemeister, ratios = ratio.1:ratio.12,
   weights = weight.1:weight.12, xreg = 12:1)
```

Structure Parameters Estimators

Collective premium: 1885 -32.05

Between state variance: 145359 -6623.4
-6623 301.8

Within state variance: 49870187

Computing the credibility premiums requires to give the “future” values of the regressors as in `predict.lm`, although with a simplified syntax for the one regressor case:

```
> predict(fit, newdata = 0)
```

```
[1] 2437 1651 2073 1507 1759
```

References

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