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ERHARD KREMER, Hamburg

## A Very Practical Solution to the Retention Problem for an Excess-of-Loss Treaty

### 1 Introduction

A quite old problem of reinsurance mathematics is the fixing of the retention for a given reinsurance cover. Already de Finetti dealt with the problem in 1940, at the 1954 International Congress of Actuaries at least three essential contributions were given (see *Bjerreskov* [1954], *Pentikäinen* [1954] and *Wilhelmsen* [1954]).

Different criteria were used for determining the adequate or optimal retention. Many authors use the *loss probability* for one year and choose the retention such that this probability is equal to a given value (see *Pentikäinen* [1954], *Russell* et al. [1980]). Some authors use the concept of *utility theory* (see *Röbbert* [1976], *Boyle* et al. [1982] and *Stuart* [1983]), others ideas of the *consumption theory* (see *Moffet* [1977]) and *reliability theory* (see *Heilmann* [1982]). Also *cost theoretical* arguments were applied (see *Heilmann* [1986] and *Schmitter* [1984]). Nevertheless most authors use models and results of a classical branch of risk theory, the so-called *ruin theory*. Worth mentioning are e.g. the publications of *Wilhelmsen* (1954), *Bühlmann* (1970), *Straub* (1978) and *Andreadakis* et al. (1980). They all propose to calculate the retention such that the ruin probability is equal to a given value or is minimized under some additional constraints or conditions. In the author's opinion this last approach is quite elegant, but it's results often are not practicable enough from the reinsurer's point of view. Some fundamental distributions and parameters are not known to the reinsurer and the important interest rates are not included in the basic models. These drawbacks led the author to reconsider the problem of retention determination and to develop a comparably simple, more practicable procedure, based on a relatively unknown result of the Swiss Professor *Gerber* (1971).

### 2 The Basic Result

We look at a collective of insurance risks, producing claims each year. The *number of claims* until time point  $t$  shall be denoted by the random variable

$N_t$ , the corresponding *claims amounts* by the i.i.d. random variables  $X_1, X_2, X_3, \dots$ . We assume that  $N_t$  is independent of the claims sizes and *Poisson-distributed* with parameter  $\lambda \cdot t > 0$ , this means

$$\text{Prob}(N_t = n) = \frac{(\lambda \cdot t)^n}{n!} \cdot \exp(-\lambda \cdot t)$$

for  $n = 0, 1, 2, \dots$ . The yearly premium income is denoted by  $c$ , the mean claims size by

$$\mu = E(X_i).$$

Finally we use the symbol  $F$  for the distribution function of the individual claim size, this means

$$F(x) = \text{Prob}(X_i \leq x)$$

and especially

$$E(X_i) = \int x F(dx).$$

We take the model like in *Gerber* (1971). This means we assume in addition to the above classical conditions that the surplus produces interest gains, continuously with the *interest rate* of  $i \cdot 100\%$  (with  $i > 0$ ) per period. *Ruin* of the (risk) business then means that the cumulative difference between the *initial reserve*  $u$ , the premium income minus claims payments, inclusively interest payment gains or losses, becomes negative at one time point  $0 \leq t < \infty$ . More formally we define the *surplus* (including interest income) up to the time point  $t$  according

$$R(t) = u \cdot \exp(i \cdot t) + \left( \frac{c}{i} \right) \cdot \left( \exp(i \cdot t) - 1 \right) - \sum_{j=1}^{N_t} \exp\left(i \cdot (t - T_j)\right) \cdot X_j \quad (2.1)$$

with the occurrence time point  $T_j$  of the  $j$ -th claim (see formula (11) in *Gerber* [1971]). So we have a risk process of deflated surpluses  $(R(t), t \geq 0)$  and the event *ruin* according

$$\{T < \infty\}$$

with the *time point of ruin*

$$T = \inf\{t : R(t) < 0\}.$$

For the *ruin probability*

$$\psi(u) = \text{Prob}(T < \infty).$$

*Gerber* (1971) showed in his Theorem 2 the practicable result

$$\lim_{(\lambda/i) \rightarrow \infty} \psi(u) = 1 - \Phi\left(\frac{u + (c - \lambda \cdot \mu)/i}{\sqrt{(\lambda/2) \cdot v^2/i}}\right) \quad (2.2)$$

with the standard normal distribution function  $\Phi$ , the above defined parameters  $u, c, \lambda, \mu, i$  and

$$v^2 = E(X_i^2).$$

Since in practice  $(\lambda/i)$  is usually quite large, the right hand side of (2.2) can be used as a good approximation to the ruin probability in the above model, which includes the important interest incomes.

### 3 The Retention Problem and a Solution

We assume that the insurer reinsurance his collective by an excess-of-loss treaty with priority  $P > 0$ . This means that the insurer retains the total claims amount until time point  $t > 0$

$$S_t = \sum_{j=1}^{N_t} Y_j$$

with the truncated claims sizes

$$Y_j = \min(X_j, P)$$

for  $j = 1, 2, \dots$ . These have the mean value

$$E(Y_j) = \mu - \mu_P$$

with the mean excess claim

$$\mu_P = \int_{[P, \infty]} (x - P) F(dx).$$

Applying the so-called expectation principle (see *Kremer* [1985]), the *reinsurer's yearly risk premium* is given according

$$c_P = (1 + l) \cdot \lambda \cdot \mu_P$$

with the loading factor  $l$ . The yearly premium remaining by the insurer obviously is

$$c_* = c - c_P. \quad (3.1)$$

Replacing in part 2  $c$  by  $c_*$ ,  $X_j$  by  $Y_j$  we get the risk process  $(R_P(t), t \geq 0)$  for the insurer's collective, reinsured by an excess-of-loss treaty with priority  $P > 0$ . The *retention problem* now consists in how to fix or choose the priority  $P$ . As already written in the introduction, one can take a ruin probability  $\varepsilon$  for the risk process and tries to find  $P$  such that the corresponding ruin probability  $\psi_P(u)$  is equal to the required value  $\varepsilon$ . Since the exact evaluation of  $\psi_P(u)$  is too unhandy, one tries to find practicable approximations to  $\psi_P(u)$ . In the classical risk process (this means (2.1) after taking the limit  $i \rightarrow 0$ ) previous authors took the so-called Lundberg bound (see *Bühlmann* [1970], *Straub* [1978]) as an approximation for  $\psi_P(u)$ . In our above model, which includes interest rates, the author proposes to take simply the result (2.2) with  $c_*$  instead of  $c$ ,

$$\mu_* = \mu - \mu_P \quad (3.2)$$

instead of  $\mu$  and

$$v_*^2 = v^2 - v_P^2 - 2 \cdot P \cdot \mu_P \quad (3.3)$$

with

$$v_P^2 = \int_{[P, \infty]} (x - P)^2 F(dx)$$

instead of  $v^2$ . This means to choose  $P > 0$  such that

$$\Phi\left(\frac{u + (c_* - \lambda \cdot \mu_*)/i}{\sqrt{(\lambda/2) \cdot v_*^2/i}}\right) = 1 - \varepsilon. \quad (3.4)$$

With the quantile  $\Phi_\varepsilon = \Phi^{-1}(1 - \varepsilon)$  and the definitions (3.1)–(3.3) the equation (3.4) means nothing else but

$$\begin{aligned} & \left(u \cdot i + (c - \lambda \cdot \mu) - l \cdot \lambda \cdot \mu_P\right)^2 - \dots \\ & \dots - \frac{\lambda}{2} \cdot i \cdot \Phi_\varepsilon^2 \cdot (v^2 - v_P^2 - 2 \cdot P \cdot \mu_P) = 0. \end{aligned} \quad (3.5)$$

The solution to the retention problem is nothing else but the zero place of the left hand side of (3.5).

This can be determined by standard methods of numerical mathematics, e.g. by the well known *regula falsi method* (see Stoer [1972], chapter 5). Among more than one zero places one can take the largest one.

## 4 Practical Advice

The above method is suited for the situation where the reinsurer has to propose a suitable retention for an individual excess-of-loss contract, which an insurer likes to conclude. The reinsurer only has to know  $u$ ,  $c$ ,  $\lambda$  and  $F$ . Since he chooses  $\varepsilon$ ,  $i$  and  $l$  by himself and can calculate  $\mu$ ,  $v^2$ ,  $\mu_P$ ,  $v_P^2$  for given  $P$ , he can determine the solution of (3.5) on his own computer. Unfortunately in practice  $F$  is not known, the reinsurer only is informed about the claims amounts exceeding a given limit  $P_O$ , smaller than the suitable priority. Furthermore  $\lambda$  is not known exactly. Clearly it is no problem to get estimates  $\hat{\lambda}$ ,  $\hat{\mu}$  and  $\hat{v}^2$  for  $\lambda$ ,  $\mu$  and  $v^2$  from the insurer. So it only remains to compute estimates for  $\mu_P$  and  $v_P^2$  given  $P$ . For this the known past claims amounts have to be adjusted for inflation-, IBNER- and trend-effects in advance, which in practice is already standard. We denote the adjusted claims amounts by  $Z_j$ ,  $j = 1, 2, \dots$ . Then as the estimators  $\hat{\mu}_P$ ,  $\hat{v}_P^2$  for  $\mu_P$ ,  $v_P^2$  one can use

$$\begin{aligned} \hat{\mu}_P &= \left(\frac{1}{N_P}\right) \cdot \sum_{j: Z_j > P} (Z_j - P) \\ \hat{v}_P^2 &= \left(\frac{1}{N_P}\right) \cdot \sum_{j: Z_j > P} (Z_j - P)^2 \end{aligned}$$

with the number  $N_P$  of  $Z_j, j = 1, 2, \dots$  exceeding the given  $P$ . These estimators have to be inserted into (3.5), yielding as the zero place of the left hand side the adequate priority  $P$ . In case that there is no solution above  $P_0$ , one has to reduce the limit  $P_0$ . In case that there are more than one zero places above  $P_0$ , one can take the largest one.

## 5     Outlook

The above method is based on the practical, but special result (2.2) of *Gerber* (1971). In the past years theoretical generalizations of that result were developed by *Harrison* (1977), *Schnieper* (1983) and *Braun* (1986). These might be used to derive more refined results on the above retention problem. In the author's opinion the above method is suitable enough for practical determination of the retention or priority. It can easily be programmed in the language BASIC for each modern micro- computer.

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## **Summary**

The author reconsiders the problem of how to fix the retention for an excess-of-loss treaty. A practicable solution is given, which can be used very well by the reinsurer.

## **Zusammenfassung**

Der Verfasser greift das Problem der Bestimmung des Selbstbehaltes eines Schadenexzedenten-Vertrages auf. Eine praktikable Lösung wird hergeleitet, welche sehr gut vom Rückversicherer verwendet werden kann.

## **Résumé**

L'auteur considère la question de la détermination du plein de conservation dans le cadre d'un traité en "Excess-of-loss". Il propose une solution qui peut fort bien être utilisée par un réassureur.