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Statistical Analysis of Generalized Linear Model for Dependent Risk and Claim with Ruin Probabilities

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Abstract:

Main trust of this paper presents the premium principles and risk measures, assuming that the risk is known, or at least some features of it like mean and variance, a premium principle assigns to the risk a real number used as a financial recompense for the one who takes over this risk with generalized linear models, many problems in actuarial statistics are Generalized Linear Models (GLM). In-stead of assuming a normally distributed error term, other types of randomness are allowed as well, such as Poisson, gamma and binomial. Also,the predictable values of the dependent variables need not be linear in there gresses. They may also be some function of a linear form of the covariates, for example the logarithm leading to the multiplicative models that are appropriate in many insurance situations. This way, one can for example tack let he problem of estimating the reserve to be kept for IBNR claims, see below. But one can also easily estimate the premiums to be charged for drivers from region in bonus class j with car weight w.

Keywords **—Ruin theory, Insurance claim, Renewal, Dependent risk model, surplus processes..**

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I. INTRODUCTION

Insurance companies maintain solvency via careful design of premium rates. The premium rates are primarily based on the claims history and carefully adjusted to evolving factors, such as the number of customers and/or the returns from the investments in the financial market. Collective risk models, introduced by Lundberg and Cramér, describe the evolution of the surplus of an insurance business when considering constant premium rates, for the simplicity of arguments. This model, a compound Poisson process with drift, is referred to in the actuarial mathematics literature as the Cramér-Lundberg model. In practical situations, risk models with surplus-dependent premiums capture the dynamics of the surplus of an insurance company better. The Reference Lin and Pavlova (2006) advised for a lower premium for higher surplus levels to improve competitiveness, whereas a higher premium is needed for lower surplus levels to reduce the probability of ruin.

Among surplus-dependent premiums, risk models with *risky* investments have been widely analyzed (see e.g., Albrecher et al. 2012; Frolova et al. 2002; Paulsen 1993; Paulsen and Gjessing 1997). See Paulsen (1998) and Paulsen (2008) for surveys on the topic. The special case of risk models with *linearly* dependent premiums can be interpreted as models with *riskless* investments, since the volatility of return on investments, or the proportion of the capital invested in the risky asset is zero.

Under this situation, exact expressions of the ruin probability are derived for compound Poisson risk models with interest on surplus and exponential-type upper bounds for renewal risk models with attentiveness (see Cai and Dickson 2002, 2003). The Reference Cheung and Landriault (2012) investigated risk models with surplus-dependent percentages with dividend strategies and interest earning as a special case. Nirmala and Suresh (2018) proposed Designing of MATLAB Program for Various Fuzzy Quality Regions in CSP-MLP-T-3 Sampling plan. The Reference Czarna et al. (2019) discussed the ruin probabilities with the scale function from the theory of the Lévy process for risk models when the claim arrival process is a spectrally negative Lévy process and the premium rate function is non-decreasing and locally Lipschitz-continuous.

II. LIFE INSURANCE INVESTMENT

In fact Life Insurance corporations are getting the savings of an individual for longer period therefore, the Govt. has arranged the norms how the Insurance companies can invest their funds. The norms are as follows:

Every insurer resonant on the business of life-insurance shall participate and at all times keep invested in the following manner:

1. 25% in Govt. securities
2. Not less than 50% in Govt. security or approved securities (including (1) above)

a) Not less than 15% in Infrastructure and Social Sector

b) Not exceeding 35% in others capital market Investment in "other than accepted Investments" can in no case exceed 15% of the fund From the above, it will be observed that the Govt. has asked the assurance to channel the funds to State and Central Govt. Infrastructure sectors social sector and rural sector and capital market. (For details refer the Investments regulations issued By the Insurance Regulatory Development Authority) Benefits to Govt.

(a) Extended term funds and debt instruments are available to develop the economy.

(b) Substructure funds are available to create roads, bridges, communication housing etc. It reduces the burden of the Govt.

(c) Asset in Rural and Social sector reduces the responsibility of the Govt. as a result of which the financial burden of the Govt. reduces.

(d) Principal market: If the insurer is investing the fund in the capital market then industry can enhance their production volume which will have the multiplier consequence on the growth of the economy.

III. THE MODEL

The over-all surplus or risk process of the insurance portfolio is defined as follows: Let $u > 0$ represents the initial capital, and c denotes the premium which is assumed to be a positive constant, then the left-over process of an insurance company, $U(t)$ can be expressed as

$$U(t) = u + ct - X(t)$$

where the aggregated claim process $X(t)$ can be expressed as $X(t) = \sum_{i=1}^{N(t)} X_i$, with X_i is the i^{th} claim size and $N(t)$ is a Poisson process with intensity λ counting the number of rights up to time t [8,9,10]. Let $\{T_i, i = 1,2,..\}$ be a sequence of claim inter occurrence times with threshold $\{A_i\}$, where $\{A_i, i = 1,2,..\}$ be a sequence of i.i.d non negative random variables. Assume that claim sizes are determined in such a way that X_i has distribution function $F_1(x)$ with parameter β_1 if $T_i < A_i$, otherwise claim size X_i is distributed as $F_2(x)$ with limitation β_2. We also assume that the random variables from the set $\{A_i, i = 1,2,..\}$ are cooperatively independent with $\{T_i, i=1,2,..\}$ and $\{F_i, i=1,2\}$.

Since $N(t)$ is a Poisson process with intensity λ, it is obvious that $\{T_i, i=1,2,..\}$ are exponentially distributed with parameter λ since homogeneous Poisson process is a regeneration process with exponentially distributed inter-arrival times. Let us assume that $\{A_i, i=1,2,..\}$ also distributed exponentially with parameter γ, since T_i have a threshold value A_i *for* i=1,2,.... Then a positive expected net profit condition is that

$$\frac{c}{\lambda} > \frac{2P(A>T)}{\beta_1} + \frac{2P(A\le T)}{\beta_2}$$

where A represents the equal distribution for all $A_i, i=1,2,..$ and $P(A>0) = P(T>0) = 1$. Let $\Phi(u)$ denotes the probability of survival with initial capital u given that the first claim inter occurrence time distributed exponentially with rate λ. The time of ruin is a stopping time given by $T = \inf\{t>0 : U(t) < 0\}$ and the probability of ultimate ruin be denoted by $\Psi(u)$ where $\Psi(u)$ is defined as

$$\Psi(u) = P\{Ruin / U(0) = u\} = P\{T < \infty\}$$

Recall the fact that the ruin probability can be explicitly calculated from $1-\Phi(u)$, and hence the survival probability can also be expressed in terms of the general surplus as

$$\Phi(u) = P\{U(t) \ge 0, \forall\, t \ge 0\} = P(T = \infty)$$

The availability of analytical solution for the survival probability helps to identify the dependency structure within the model, indeed corresponding independent structure can easily be deduced. Hence we obtain an analytical procedure to derive explicit expression.

for the defined model with Erlang(2) distribution having mean $\frac{2}{\beta_i}$, i=1,2 for the claim size X_i, i=1,2 under threshold condition.

THEOREM 1: The survival probability on the first jump time of the surplus process can be expressed in terms of an integral equation as

$$\Phi(u) = \frac{\beta_1^2\lambda}{c}\int_u^\infty \exp\left\{-\frac{\lambda(s-u)}{c} - \frac{\gamma(s-u)}{c}\right\}\int_0^s \Phi(s-x)xe^{-\beta_1 x}\,dx\,ds$$

$$+\frac{\beta_2^2\lambda}{c}\int_u^\infty\left[\exp\left\{-\frac{\lambda(s-u)}{c}\right\} - \exp\left\{-\frac{\lambda(s-u)}{c} - \frac{\gamma(s-u)}{c}\right\}\right]\int_0^s \Phi(s-x)xe^{-\beta_2 x}\,dx\,ds \quad (1)$$

where $\Phi(u)$ represents the ultimate survival probability and $\Re(s) \ge 0$, the premium rate c can be expressed as $c = \frac{s-u}{t}$, u be the initial capital at time t.

Proof: For having positive expected profit, the net profit condition should satisfy

$$\frac{c}{\lambda} > E(F_1 \backslash A > T).P(A>T) + E(F_2 \backslash A \le T).P(A \le T)$$

where F_i, $i=1,2$ are the threshold distribution corresponds to A when $T<A$ and $T \ge A$ respectively. Assume that A_i follows Exponential (γ), F_1 and F_2 are Erlang distributions with parameter β_1 and β_2 respectively. By considering the first jump time of the surplus process at time t, we get the following integral equation.

$$\Phi(u) = \lambda\int_0^\infty e^{-\lambda t}\int_0^{u+ct} P(A>t)\Phi(u+ct-x)F_1(dx)\,dt$$

$$+\ \lambda\int_0^\infty e^{-\lambda t}\int_0^{u+ct} P(A\le t)\Phi(u+ct-x)F_2(dx)\,dt$$

since the initial surplus for the first jump can be represented up to $u+ct$. Assume that $s = u+ct$ where $\Re(s) \ge 0$,

$$\Phi(u) = \frac{\lambda}{c}\int_u^\infty e^{-\lambda t}\int_0^s P(A > \frac{s-u}{t})\, f_1(x)\,\Phi(s-x)\,dx\,ds$$

$$+\ \frac{\lambda}{c}\int_u^\infty e^{-\lambda t}\int_0^s \{P(A \le \frac{s-u}{t})\ f_2(x)\ \Phi(s-x)\ dx\,ds$$

where $f(.)$ denotes probability density function (pdf) corresponding to $F(.)$. For Erlang distribution with $n=2$ and parameter β_1, the pdf is given as $\beta_1^{\,2}xe^{-\beta_1 x}$ for $x \ge 0$ and β_1 being integer.

Substitute the pdf in equation (2) yields the survival probability as in equation (1). Hence the proof.

IV. Explicit expression for the survival probability, $\Phi(u)$

In this section, we derive the explicit expression for the survival probability of an insurance portfolio where the claim inter-arrival time depends on the next claim size that follows an Erlang distribution, using the differential calculus method and by applying Laplace transform properties [25]. For $\Re(s) \geq 0$, the Laplace transform of a function $\phi(.)$ is defined as $\phi(x) = \int_0^\infty e^{-sx}\phi(x)\,dx$.

Throughout the paper $h'(x)$ represents the first derivative of the function $h(.)$ with respect to x and $h''(x)$ represents the second derivative of the function $h(.)$ with respect to x unless specified. Re-arranging the survival probability $\Phi(u)$ in equation (2), we get,

$$\frac{c}{\lambda}\Phi(u) = \beta_1^2 \int_u^\infty \exp\left\{-\frac{\lambda(s-u)}{c} - \frac{\gamma(s-u)}{c}\right\} \int_0^s \Phi(s-x)xe^{-\beta_1 x}\,dx\,ds$$
$$+\beta_2^2 \int_u^\infty \left[\exp\left\{-\frac{\lambda(s-u)}{c}\right\} - \exp\left\{-\frac{\lambda(s-u)}{c} - \frac{\gamma(s-u)}{c}\right\}\right] \int_0^s \Phi(s-x)xe^{-\beta_2 x}\,dx\,ds \quad (3)$$

Now differentiate both sides of equation (3) with esteem to u and re-arranging terms, we get the following integro - differential equation:

$$\frac{c}{\lambda}\Phi'(u) = -\beta_1^2 \int_0^u \Phi(s-x)\,x\,e^{-\beta_1 x}\,dx\,ds$$
$$+\frac{\beta_1^2(\lambda+\gamma)}{c}\int_u^\infty \exp\left\{-\frac{(\lambda+\gamma)(s-u)}{c}\right\}\int_0^s \Phi(s-x)xe^{-\beta_1 x}\,dx\,ds$$
$$+\frac{\beta_2^2\lambda}{c}\int_u^\infty \exp\left\{-\frac{\lambda(s-u)}{c}\right\}\int_0^s \Phi(s-x)\,x\,e^{-\beta_2 x}\,dx\,ds$$
$$-\frac{\beta_2^2(\lambda+\gamma)}{c}\int_u^\infty \exp\left\{-\frac{(\lambda+\gamma)(s-u)}{c}\right\}\int_0^s \Phi(s-x)xe^{-\beta_2 x}\,dx\,ds \quad (4)$$

Replacing $u-x$ as y in equation (4) and consider $\Phi(u)$ as in equation (3). Simplifying and re-arranging terms, we got the following equation:

$$\frac{c}{\lambda}\Phi'(u) = \frac{(\lambda+\gamma)}{\lambda}\Phi(u) - \beta_1^2\int_0^u \Phi(u-x)\,x\,e^{-\beta_1 x}\,dx\,ds$$

Let us consider that $\tilde{\Phi}(s)$ is a ratio of two polynomials such that $\tilde{\Phi}(s) = \frac{h(s)}{f(s)-g(s)}$ where the numerator $h(s) = \frac{c}{\lambda}\Phi'(0) + \frac{c}{\lambda}s\Phi(0) - \left(2+\frac{\gamma}{\lambda}\right)\Phi(0)$ and the denominator $f(s) = \frac{c}{\lambda}s^2 - \left(2+\frac{\gamma}{\lambda}\right)s + \left(\frac{\lambda+\gamma}{c}\right)$ and

$$g(s) = \left(\frac{\lambda}{c}+\beta_1\right)\frac{\beta_1^2}{(s+\beta_1)^2} + \frac{\gamma\beta_2^2}{c(s+\beta_2)^2} - \frac{\beta_1^2}{(s+\beta_1)}$$

. Clearly, $\tilde{\Phi}(s)$ is a proper rational function of s where the degree of numerator function $h(s)$ is less than that of the denominator $f(s)-g(s)$.

The endurance probability, a decisive factor of insurance companies is simulated using R software [30]. We generate values of $\Phi(u)$ for different sequences of initial capital u. The sequence of u are 0,1,...,10 with an increment of 1, 0,2,...,20 with an increment of 2 and 0,5,…,50 with an increment 5, to know the spanning of the survival probability for different values of the surplus in the economy. The average and variance within entire span are also calculated. The following table 1 explain different values of initial capital along with ultimate survival probability for example 1, where we can see that the variance of the surplus process are equal to 0.04 for all span of u.

Its deals with insurance portfolio'swith dependent risks.During the last two decades, dependence has been increasingly playing an important role in the world of risk,especially in the insurance field. The classical Cramer-Lund berg model gives the surplus process of an insurances election and is based on the supposition of independence among privilege sizes.

Clear expression for $\Phi(s)$

Using (11) and (13) and by using limiting conditions of survival probability derived in Lemma $1$and 2 we have the Laplace transform as,

$$\tilde{\Phi}(s)=\frac{\left\{1+\frac{\gamma}{\lambda}-\frac{2\lambda}{c\beta_1}-\frac{2\gamma}{c\beta_2}\right\}\left\{\frac{s-s_0}{s_0}\right\}}{\frac{c}{\lambda}s^2-\left(2+\frac{\gamma}{\lambda}\right)s+\frac{(\lambda+\gamma)}{c}-\frac{\left(\frac{\lambda}{c}+\beta_1\right)\beta_1^2}{(s+\beta_1)^2}-\frac{\gamma\beta_2^3}{c(s+\beta_2)^2}+\frac{\beta_1^2}{(s+\beta_1)}}$$

(14) where s_0 is the positive root which can be calculated as (3.1). Let the denominator of (14) be represented by $Dr(s)$ where,

$$Dr(s)=\frac{c}{\lambda}s^2-\left(2+\frac{\gamma}{\lambda}\right)s+\frac{(\lambda+\gamma)}{c}-\left\{\frac{\left(\frac{\lambda}{c}+\beta_1\right)\beta_1^2}{(s+\beta_1)^2}+\frac{\gamma\beta_2^3}{c(s+\beta_2)^2}-\frac{\beta_1^2}{(s+\beta_1)}\right\}$$

Now let $Dr(s)=\frac{\frac{c}{\lambda}N(s)}{(s+\beta_1)^2(s+\beta_2)^2}$ .Here $N(s)$ can be expressed as a polynomial of degree 6 with leading coefficient 1 . Let the roots of $N(s)$ are 0, s_0, R_1, R_2, R_3 and R_4 which is same as the roots of the denominator of (11) . Therefore, we can express $Dr(s)$ in the form,

$$Dr(s)=\frac{\frac{c}{\lambda}s(s-s_0)(s-R_1)(s-R_2)(s-R_3)(s-R_4)}{(s+\beta_1)^2(s+\beta_2)^2}$$

and from equation (15), the Laplace transform can be expressed in the form,

$$\tilde{\Phi}(s)=B_{s_0}\frac{(s+\beta_1)^2(s+\beta_2)^2}{s(s-R_1)(s-R_2)(s-R_3)(s-R_4)}$$

where $B_{s_0}=\frac{\lambda}{cs_0}\left\{1+\frac{\gamma}{\lambda}-\frac{2\lambda}{c\beta_1}-\frac{2\gamma}{c\beta_2}\right\}$ which is a constant depends on the positive root of the $\tilde{\Phi}(s)$ and parameters of the model. Specifically $\tilde{\Phi}(s)=B_{s_0}\chi(s)$ where $\chi(s)=\frac{(s+\beta_1)^2(s+\beta_2)^2}{s(s-R_1)(s-R_2)(s-R_3)(s-R_4)}$ which can be gained by factoring $\chi(s)$ in such a way that

$$\chi(s)=\frac{A_1}{s}+\frac{A_2}{s-R_1}+\frac{A_3}{s-R_2}+\frac{A_4}{s-R_3}+\frac{A_5}{s-R_4}.$$

Obviously A_1, A_2, A_3, A_4, A_5 are constants obtained by limiting the values of s to 0, R_1, R_2, R_3 and R_4 in $\chi(s)$. That implies,

$$A_1 = \frac{(\beta_1\beta_2)^2}{R_1R_2R_3R_4}$$

$$A_2 = \frac{(R_1+\beta_1)^2(R_1+\beta_2)^2}{R_1(R_1-R_2)(R_1-R_3)(R_1-R_4)},$$

$$A_3 = \frac{(R_2+\beta_1)^2(R_2+\beta_2)^2}{R_2(R_2-R_1)(R_2-R_3)(R_2-R_4)}$$

$$A_4 = \frac{(R_3+\beta_1)^2(R_3+\beta_2)^2}{R_3(R_3-R_1)(R_3-R_2)(R_3-R_4)}$$

$$A_5 = \frac{(R_4+\beta_1)^2(R_4+\beta_2)^2}{R_4(R_4-R_1)(R_4-R_2)(R_4-R_3)}$$

V. **THEOREM 2:** The exact expression of the survival probability for Erlang distributed claim sizes is given by

$$\Phi(u) = 1 + B_{s_0}A_2e^{R_1u} + B_{s_0}A_3e^{R_2u} + B_{s_0}A_4e^{R_3u} + B_{s_0}A_5e^{R_4u}$$

where A_i, $i = 1,2,3,4$ are given in the equation (16).

Proof: Reversing the Laplace transform, $\tilde{\Phi}(s) = B_{s_0}\chi(s)$, we get survival probability given as

$$\Phi(u) = B_{s_0}A_1 + B_{s_0}A_2e^{R_1u} + B_{s_0}A_3e^{R_2u} + B_{s_0}A_4e^{R_3u} + B_{s_0}A_5e^{R_4u}$$

Moreover $\Phi(\infty) = 1 \Rightarrow B_{s_0}A_1 = 1$ we get survival probability.

VI. NUMERICAL EXAMPLES

This segment illustrates the use of the model attached with the integral–differential equation to clearly obtain the ultimate survival probability for the surplus process U . Examples provided, which satisfies the positive net profit condition. From Lemma 2, it is obvious that s_0 is a positive root by applying the net profit condition. The survival probability $\Phi(\infty)=1$ and hence from Lemma 2, $\frac{\lambda}{c}\left\{1+\frac{\gamma}{\lambda}-\frac{2\lambda}{c\beta_1}-\frac{2\gamma}{c\beta_2}\right\}$ must be strictly positive which reduces to $\frac{c}{2} > \frac{\lambda}{\lambda+\gamma}\left\{\frac{\lambda}{\beta_1}+\frac{\gamma}{\beta_2}\right\}$.

Here we considered two simple examples to illustrate the model for changed surplus values. Figure of survival probability $\Phi(u)$ is given below using R software.

VII. GENERALIZEDLINEARMODELSHAVETHREECHARACTERISTICS:

Claimsizeandclaimbreak time. Anderson [6] generalized the compound Poisson model by assuming that inter claim times of randomvariablesareonlyindependentlyidenticallydistributed.Whileliberationcanbedefined in only one way, dependence can be formulated in an unlimited number of ways. Traditionally, risk theoryassumesindependencebetweenthedifferentvariablesofinterest.However,inmanysituations insured risks usually behave in a similar manner.

Then use the function t apply tocompute the sums in extending over only subsets of all four values. Its firstargumentisavectorofvaluestobeprocessed.Itssecónddisagreementgivesafactororalistofaspects,splittinguptheelementsofthevectorintodifferentassemblies withdifferent levels of the factor(s).

VIII. CONCLUSION

The probability of ruin enables one to compare portfolios, but cannot attach any absolute meaning to the probability of ruin, as it does not actually represent the probability that the insurer will go bankrupt in the near future. First of all, it might take centuries for ruin to actually happen. Second, obvious interventions in the process such as paying out dividends or raising the premium for risks with an unfavourable claims performance are ruled out in the definition of the probability of ruin. Furthermore, the effects of inflation and return on capital are supposed to cancel each other out exactly.

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Declaration of competing interest

All authors declare that they have no conflict of interests

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