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Tesi di Laurea Magistrale

Application of GLM Advancements to Non Life Insurance Pricing

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The data scientist is a person who is better at statistics than any software engineer and better at software engineering than any statistician.

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Abstract

This is my abstract …

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1
Non-Life Insurance Pricing

In this chapter I am going to provide an overview on how non-life insurance works from an actuarial point of view with a specific focus on the pricing needs.

1.1 What a Non Life Insurance is

The Italian Civil Code provides the following definition of insurance contract:

Definition 1.1 (Insurance Contract, Art. 1882, Italian Civil Code)**.** The insurance is the contract with which an insurer, in exchange of the payment of a certain premium, obliged himself, within the agreed limits:

1. to pay an indemnity to the insured equivalent to the damage caused by an accident;
2. or to pay an income or a capital if a life-related event occurs.

This definition identifies two parties: the *Insurer* and the *Policyholder*. The policyholder pays to the Insurer a certain *Premium* at the beginning of the insurance coverage and the insurer will pay a benefit if a certain event (*Claim*) occurs. This event could happen zero, one or more than one times, so it is possible to have more than one claim.

Usually, in non-life insurance, the benefit is a capital that could be predetermined (e.g. in motor theft insurance, where the benefit is usually the value of the insured vehicle) or defined by the entity of the claims (e.g. in motor third party liability insurance, it depends on the damage the policyholder has provided to a third party). Regarding the "agreed limits", another peculiarity of non-life insurances is that the coverage period is defined as a fixed amount of time, usually corresponding to 1 year.

Starting from this legal definition, we can formalize a non-life insurance contract as follows. Let's:

- $]t_1, t_2]$, with $t_1 < t_2$, be the coverage period;
- $P > 0$ be the premium payed by the policyholder to the insurer;
- $N \in \mathbb{N}$ be the number of claims occurred during the coverage period (*claims count*);
- $\tau_1, \tau_2, \ldots, \tau_N$, with $t_1 < \tau_1 < \tau_2 < \cdots < \tau_N < t_2$, be the timing of each claim;
- $Z_1, Z_2, \ldots, Z_N > 0$ be the amount of each claim (*claims severities* or *claims sizes*).

The total cost of claims for the insurance is:

$$S = \begin{cases} 0 & \text{if } N = 0 \\ \sum_{i=1}^{N} Z_i & \text{if } N > 0 \end{cases}$$

For semplicity, in the following we are going to just use the notation $S = \sum_{i=1}^{N} Z_i$ with the meaning of 0 if $N = 0$.

Figure 1.1 shows the cash flows corresponding to the insurance contract. From this representation we can interpret the entering into an insurance contract by the policyholder as a way to exchange the negative cash flows $-Z_1, -Z_2, \ldots, -Z_N$ with one single negative cash flow $-P$. On the other hand, the insurer undertakes the negative cash flows $-Z_1, -Z_2, \ldots, -Z_N$ in exchange for a positive cash flow $+P$.

The major difference between these cash flows is that P is a certain amount, while $Z_1, Z_2, \ldots, Z_N$, at the time t_1, are uncertain in the amount, in the count (N) and in the timing ($\tau_1, \tau_2, \ldots, \tau_N$). So the policyholder, paying a premium P, is giving his risk to the insurer.

From a statistical point of view, we can translate this uncertainty saying that N and $Z_1, Z_2, \ldots, Z_N$ are random variables. Therefore, we can say that $\{N, Z_1, Z_2, \ldots\}$ is a stochastic process. Usually, in non-file insurance pricing, the variables $\tau_1, \tau_2, \ldots, \tau_N$ are not taken into account because the coverage span short and from a financial point of view the timing of the claims occurences is negligible.

Previously we said that $Z_1, Z_2, \ldots, Z_N$ are all > 0. This assumption corresponds to the fact that we are excluding the null claims, i.e. the claims that have been opened, but result in no payment due by the insurer. For the values of Z_i with $N < i$ we can use the rule that $N < i \Rightarrow Z_i = 0$. Therefore we can say that $N < i \Leftrightarrow Z_i = 0$.

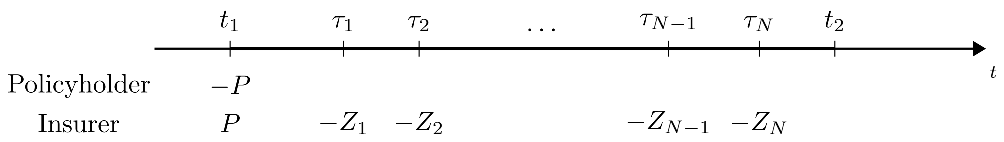

Figure 1.1: Insurance Contract cash flows.

1.2 Non-Life insurance pricing

In insurances, the premium that the the insurer offers to the policyholder in exchange for the insurance coverage is not the same for every policyholder. The insurer evaluate the risk related to that policy and determine a "proper" premium taking into account risk related factors and commercial related factor. The process of *pricing* corresponds in defining the set of rules for determining this "proper" premium P_i for a specific policyholder i, given the known information on him. In the next sections I am going to better explain what "proper" means.

1.2.1 Compound distribution hypotesis

The first step for evaluating the stochastic process $\{N, Z_1, Z_2, \dots\}$ is to introduce some probabilistic hypotesis. The usual hypotesis assumed are the following:

Definition 1.2 (Compound distribution)**.** Let's assume that:

1. for each $n > 0$, the variables $Z_1|N = n,\ Z_2|N = n,\ \dots,\ Z_n|N = n$ are stochastically independent and identically distributed;
2. the probability distribution of $Z_i|N = n,\ i \leq n$ does not depend on n.

Under these hypothesis we say that:

$$S = \sum_{i=1}^{N} Z_i$$

has a compound distribution.

The variables $Z_i|N = n$ used in this definition can be interpreted as the *claim severity for the* i^{th} *claim under the hypotesis that n claims occurred*. The two hypotesis provided in definition 1.2 imply that the distribution of $Z_i|N = n,\ i < n$ does not depend from i nor from n. In the following, we are going to use the notation Z to represent a random variable with the $Z_i|N = n,\ i < n$ distribution and $F_Z(\cdot)$ for its cumulative distribution function (i.e. $F_Z(z) = P(Z \leq z)$).

Let's consider the variabile $Z_i|N > i$. We can interpret it as the *claim severity for the* i^{th} *claim under the hypotesis that the* i^{th} *claim occurred*. From the hypotesis provided in definition 1.2 we can obtain that also $Z_i|N > i$ has the same distribution of $Z_i|N = n,\ i < n$. This can be easily obtained as follows:

$$\begin{aligned}
P(Z_i|N \geq i) &= P\left(Z_i \middle| \bigvee_{n=i}^{+\infty} (N = n)\right) = && (1.1)\\
&= \sum_{n=i}^{+\infty} \underbrace{P(Z_i \leq z|N = n)}_{=F_Z(z)} P(N = n|N \geq i) = && (1.2)\\
&= \sum_{n=i}^{+\infty} F_Z(z) P(N = n|N \geq i) = && (1.3)\\
&= F_Z(z) \underbrace{\sum_{n=i}^{+\infty} P(N = n|N \geq i)}_{=1} = && (1.4)\\
&= F_Z(z)
\end{aligned}$$

Where:

- the step (1.1) and the step (1.2) are given by the fact that the event $\{N \geq i\}$ can be decomposed as $\{N \geq i\} = \left\{\bigvee_{n=i}^{+\infty} (N = n)\right\}$ and that the events $\{N = n\}, n \in \{i, i+1, i+2, \ldots\}$ are two-by-two disjoint, so they constitute a partition of $\{N \geq i\}$, that allows us to use the disintegrability proprierty of the probability;
- the step (1.3) is due to the fact that the distribution of $Z_i \leq z|N = n$ depends neither on i nor on n;
- the equivalence $\sum_{n=i}^{+\infty} P(N = n|N \geq i) = 1$ at step (1.4) is due to the fact that the events $\{N = n\}, n \in \{i, i+1, i+2, \ldots\}$ are a partition of $\{N \geq i\}$.

Therefore, Z can be considered as the *claim severity for a claim under the hypotesis that that claim occurred.*

1.2.2 Distribution of the total cost of claims

Under the hypotesis defined in definition 1.2, it is possible to obtain the full distribution of S given the distribution of N and Z. In this chapter we are going to provide only the formula of the expected value $E(S)$, but, with the same aproach one can obtain all the moments.

The expected value of the total cost of claims $E(S)$ can be obtained from the expected value of the claims count $E(N)$ and the expected value of the claim severity $E(Z)$ as follows:

$$\begin{aligned}
E(S) &= \sum_{n=0}^{+\infty} P(N=n)E(S|N=n) = && (1.5)\\
&= \sum_{n=0}^{+\infty} P(N=n)E\left(\sum_{i=1}^{n} Z_i \middle| N=n\right) = && (1.6)\\
&= \sum_{n=0}^{+\infty} P(N=n)\sum_{i=1}^{n} \underbrace{E(Z_i|N=n)}_{=E(Z)} = && (1.7)\\
&= \sum_{n=0}^{+\infty} P(N=n)nE(Z) = && (1.8)\\
&= E(Z)\underbrace{\sum_{n=0}^{+\infty} nP(N=n)}_{=E(N)} = && (1.9)\\
&= E(N)E(Z) && (1.10)
\end{aligned}$$

Where:

- the step (1.5) is given by the fact that the events $\{N=0\},\{N=1\},\{N=2\},\dots$ constitute a partition of the certain event Ω, that allows us to use the disintegrability property of the expected value;
- the step (1.6) is due to the definition of S;
- the step (1.7) is due to the linearity of the expected value;
- the steps (1.8) and (1.9) are due to the fact that, as assumed by the compound distribution hypothesis, $E(Z_i|N=n)$ does not depends on i and n;
- the step (1.10) is due to the definition of the expected value $E(N)=\sum_{n=0}^{+\infty} nP(N=n)$.

This result tells us that, under the hypothesis of the compound distribution, it is possible to easily obtain $E(S)$ from $E(N)$ and $E(Z)$. That means that we can model separately $E(N)$ and $E(Z)$ and, from them, obtain $E(S)$. That result is particularly useful in personalization (paragraph 1.2.4), because, for each individual i, given the information we have on him $x_i=(x_{i1},x_{i2},\dots,x_{ip})$, we can estimate his expected claim size $E(N_i)$ and his expected claim severity $E(Z_i)$ and obtain his expected total cost of claims as $E(S_i)=E(N_i)E(Z_i)$.

1.2.3 Risk premium and Technical Price

The expected cost of claims $E(S)$ is important because it gives us a first interpretation of what “proper” premium means.

Definition 1.3 (Risk Premium)**.** Said S the total cost of claims of a policyholder, his *Risk Premium* is given by:

$$P^{(risk)} = E(S)$$

The *Risk Premium* is the premium that on average covers the total cost of claims. As mentioned above, as the coverage spans are usually short, we are not taking into account the timing of the claims and we don't discount the fact that the claims occur later than the premium payment.

It is clear that this premium, that only cover the cost of claims, is not "proper" in the practice.

First of all the insurer has to cover also the expenses related to the policy (commission on sales and expenses related to the claim settlement) and the general expenses of the company. Adding the expenses we obtain what is called *Technical Price*.

Definition 1.4 (Technical Price)**.** Said S the total cost of claims of a policyholder and E the expenses related to his policy, his *Technical Price* is given by:

$$P^{(tech)} \ = \ E(S) + E \ = \ P^{(risk)} + E$$

Secondly, even if the policyholder would pay a premium that on average covers claims and expenses, it would not make sense for the insurer undertaking that risk with nothing in return. So, to the Technical Price, a loading must be added. This loading can be justified as a loading for the risk or as a profit loading.

The result of the Technical Price with these loadings can be further modified based on business logic, as I am going to discuss later.

1.2.4 Personalization

In this section I am going to better explin how pricing based on policyholder information works.

Usually for every policyholder we have a set of pices of information on him that are considered relevant for his risk evaluation. This information must be reliable and observable at the moment of the underwriting of the policy.

In motor insurances these pices of information could be:

- Information on the insured vehicle: make, model, engine power, vehicle mass, age of the vehicle;
- General information of the policyholder: age, sex, address (region, city, postcode);

- Insurance specific information of the policyholder: number of claims caused in the previous years, how long he has been covered, bonus-malus class;
- Policy options: amount of the maximum coverage, presence and amount of the deductible, presence of other insurance guarantees.

Formally this information can be represented as a set of variables $x_i = (x_{i1}, x_{i2}, \dots, x_{ip})$. These variables could be called pricing variables, explanatory variables, covariates, predictors or features.

Definition 1.5 (Pricing Rule)**.** A *Pricing Rule* is a function $f(\cdot)$ that from an istance of a set of pricing variables $x_i \in \mathcal{X}$ returns a price:

$$\begin{aligned} f: \ \mathcal{X} &\longrightarrow R_+ \\ x_i &\longmapsto P_i \end{aligned}$$

The process of pricing consist in defining a Pricing Rule based on observed data from the past and assumptions on the future.

1.2.4.1 Pricing variables encoding

The pricing variables can be of two types:

1. *Quantitative variables*: variables like vehicle mass or policyholder age that can be easily represented as a number;
2. *Qualitative variables*: variables like sex or address that represent a category and are usually represented with strings.

The quantitative variables, except for possible transformation, are already suitable to be used.

To facilitate the use of the qualitative variables, they are usually encoded as sets of binary variables.

If a variable x has only 2 possible modality, it can easily encoded in a binary variable z that assigns 0 to one modality and 1 to the other. For example, if $x =$ sex, it can be encoded this way:

$$z = \begin{cases} 1 & \text{if sex} = \text{'Male'} \\ 0 & \text{if sex} = \text{'Female'} \end{cases}$$

In general, if a variable x has K modality, it can be encoded in $K-1$ binary variables $z_1, z_2, \dots, z_{K-1}$. For example, if $x =$ make, and it could have 4 possible modality ('Fiat', 'Alfa-Romeo', 'Lancia', 'Ferrari') it can be encoded this way:

$$z_1 = \begin{cases} 1 & \text{if make } = \text{ `Fiat'} \\ 0 & \text{otherwise} \end{cases} \quad z_2 = \begin{cases} 1 & \text{if make } = \text{ `Alfa-Romeo'} \\ 0 & \text{otherwise} \end{cases} \quad z_3 = \begin{cases} 1 & \text{if make } = \text{ `Lancia'} \\ 0 & \text{otherwise} \end{cases}$$

The variables z_1, z_2, z_3 are called dummy variables. We can observe that all the information about the make is embedded in just these 3 variables, so a fourth dummy variable that indicate the modality 'Ferrari' is not needed. Indeed:

$$\text{make } = \text{ `Ferrari'} \iff z_1 = z_2 = z_3 = 0$$

In table 1.1 the dummy variable encoding is illustrated.

Table 1.1: Dummy variable encoding.

make	z1	z2	z3
Fiat	1	0	0
Alfa-Romeo	0	1	0
Lancia	0	0	1
Ferrari	0	0	0

For some models it is suggested to use also the dummy variable that indicates the K^{th} modality. This encoding is called one-hot encoding and it is mainly used in Neural Networks. For the models considered in this paper it is preferred the $K-1$ dummy variables encoding, so I am always considering it.

In the following, when I use the notation $x_i = (x_{i1}, x_{i2}, \dots, x_{ip})$, I'll always consider that the qualitative variables have been already encoded as dummy variables, so $(x_{i1}, x_{i2}, \dots, x_{ip}) \in \mathcal{X} \subseteq \mathbb{R}^p$

1.2.4.2 Response variables and models

As we observed in section 1.2.2, under the compound distribution hypotesis, it is not needed to model directly the total cost of claims S, but we can separately model N and Z.

Modeling the claims count N and the claims severity Z means find respectively:

- find a function $r_N : \mathcal{X} \to R_+$ that given a set of explanatory variables x_i will return the expected claims count for that risk $E(N_i)$;
- find a function $r_Z : \mathcal{X} \to R_+$ that given a set of explanatory variables x_i will return the expected severty for that risk $E(Z_i)$.

In this context the variables N and Z are called *response varables*.

1.3 Non-Life Insurance in Italy

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1.4 The actuary role

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Questa è una citazione (Shea et al., 2014; Lottridge et al., 2012)

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2

Statistical models for Non Life Insurance Pricing

2.1 Statistical Models

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2.1.1 GLM

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2.1.2 Elastic Net

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2.1.3 GAM

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2.2 Model comparison

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2.4 Implementation

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3
Practical application

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3.1 Data description

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3.2 Model used

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3.3 Model assessment

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3.4 Results

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