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ACTUARIAL ASPECTS OF THE APPLICATION OF ARTIFICIAL INTELLIGENCE IN NON-LIFE INSURANCE PRICING IN THE REPUBLIC OF SRPSKA

ORIGINAL SCIENTIFIC PAPER

Abstract

This paper focuses on the assumptions that AI models must satisfy for the purpose of determining non-life insurance pricing in the Republic of Srpska. When applying Generalized Linear Models, which are most common in modern non-life insurance pricing practice, actuaries are aware of the risk that inadequate choice of variables and their interrelationships will result in poorer model performance. This limitation was one of the reasons why experts in this field began developing models that combine neural networks and Generalized Linear Models for insurance pricing. In this paper, we analyze two hybrid models: the Combined Actuarial Neural Network and LocalGLMnet. Summarizing the results presented in the selected literature, we conclude that these models can deliver better results compared to Generalized Linear Models; however, given the limited transparency of insurance pricing procedures, further research is necessary to develop models aligned with regulations and actuarial practice standards.

Keywords: Generalized Linear Models, neural networks, Combined Actuarial Neural Network, LocalGLMnet, actuarial practice standards.

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I Introduction

The pricing of non-life insurance, characterized by stochastic claim payment processes over time, is a highly complex task for actuaries. For this purpose, actuaries project insurance claims over a specific time horizon using appropriate statistical data and sophisticated mathematical models.

The objective of this paper is to examine the assumptions that must be satisfied in order for artificial intelligence (AI) to be applied in the insurance market of the Republic of Srpska for pricing purposes in compliance with the regulations governing this field. It is essential to emphasize that, while on the one hand, the application of AI algorithms for data analysis increases existing risks and gives rise to new risks related to the use of new data sources and models, on the other hand, it also has the potential to mitigate operational risk by simplifying processes that have a high probability of causing errors. Recognizing potential issues related to the application of AI within the insurance sector, the Institute and Faculty of Actuaries published a document titled *“Risk Alert”* in 2023.² This document warns actuaries to be aware of additional potential risks arising from the increasing use of AI. Actuaries applying AI may face significant uncertainty about how to implement these new techniques in practice, as well as risks of inadequate application and unintended consequences. In order to minimize these risks, actuaries must maintain up-to-date expertise in actuarial methods and adhere strictly to the professional code of conduct.

The second part of the paper examines the current state of the actuarial profession in the Republic of Srpska, with particular emphasis on the challenges of acquiring new AI competencies, thereby enabling an evaluation of both the advantages and potential risks of its application. From the perspective of the implementation feasibility of AI-based models in actuarial practice, careful consideration is given to the statutory responsibilities of authorized actuaries and the applicable regulatory framework governing their activities. For this reason, the third part of the paper analyzes the regulatory framework governing actuarial activities in the field of insurance pricing in the territory of the Republic of Srpska. Subsequently, the fourth part of the paper provides a selective review of recent methodological advances in applying neural networks to insurance pricing, with particular attention to their alignment with emerging standards of model interpretability. The paper concludes with final remarks.

² Institute and Faculty of Actuaries, Risk Alert: AI techniques and outputs by actuaries, 2023, available at: <https://notifications.actuaries.org.uk/t/7C8L-44NR-1EEBF4274018EE51GAJ5F24CB0D35BC68DDCC/cr.aspx>, accessed: 19 March 2025.

II Challenges in the Development of the Actuarial Profession in the Republic of Srpska in Light of Contemporary Advances in AI

Pursuant to the currently applicable Law on Insurance Companies in the Republic of Srpska,³ an insurance company is required, in addition to an internal actuary employed as a professional responsible for performing actuarial tasks within the insurance company, to engage an authorized actuary. An authorized actuary in the Republic of Srpska performs actuarial tasks prescribed by the Law on Insurance Companies and, in particular, provides opinions and assessments on: business policy acts and their implementation; financial statements and the annual business report of the insurance company; whether technical reserves for non-life and life insurance have been established and whether assets covering technical reserves have been invested in accordance with applicable regulations of the Insurance Agency of the Republic of Srpska and professional actuarial standards; the methodology for calculating premium tariffs; reports on the implementation of coinsurance and reinsurance policies; the solvency margin; and the status of technical and guarantee reserve funds, including their investment and safekeeping.

The ability to perform the aforementioned activities was acquired gradually through the development of actuarial science and practice, beginning in the mid-nineteenth century. Bühlmann (1997) identified three phases in the development of the actuarial profession.⁴ The first phase refers to life insurance actuaries who applied methods based on deterministic calculations. During the 1960s and 1970s, the second phase emerged, with an emphasis on non-life insurance actuaries using probabilistic methods in their calculations. The growing importance of investment performance in insurance company activities created a need for actuaries to develop new skills in managing assets covering technical reserves. By the late 1980s, this led to the third phase in the development of the actuarial profession, in which actuaries analyzed investment aspects of insurance activities and incorporated stochastic processes into actuarial calculations. Over time, the actuarial profession has focused on risk management, the assessment of insurers' financial stability, and the resolution of business and social issues. Since the realization of insured risks results in financial losses, it can be said that one of the fundamental tasks of actuaries is financial risk management. As a result of this role, a fourth phase is identified, in which actuaries focus on enterprise risk management. Demographic, technological, environmental, political, and legal changes subsequently led to the emergence of actuaries of the

³ Law on Insurance Companies in the Republic of Srpska, *Official Gazette of the Republic of Srpska*, Nos. 17/2005, 1/2006 – Corrigendum, 64/2006, 74/2010, 47/2017, 58/2019.

⁴ Hans Bühlmann, "The actuary: the role and limitations of the profession since the mid-19th century", *Astin bulletin*, Vol. 27, No. 2/1997, 165-171.

so-called *Fifth Kind*, who using data and models, enable financial decision-making in a volatile business environment characterized by uncertainty.⁵

In the insurance market of the Republic of Srpska, the majority of actuaries specialize in non-life insurance activities, as only two insurance companies headquartered in this entity are registered to conduct life insurance activities. However, all authorized actuaries, given the scope and content of their opinions, are required to possess knowledge in the areas of investment and risk management. The Rulebook on the requirements for acquiring and revocation of the title of the authorized actuary stipulates that the examination for acquiring the title of authorized actuary is recognized for postgraduate actuarial studies candidates if they have passed all examinations in accordance with the curriculum and study program.⁶

The next major challenge facing the actuarial profession in the Republic of Srpska is the acquisition of AI-related competencies. In this context, one of the key roles may be played by the Actuarial Association of the Republic of Srpska, established in 2008 to improve, develop, and promote actuarial science and the profession, their practical application, and the professional development and education of actuaries. As of June 2025, the Association had 23 members.⁷ The Association is an associate member of the International Actuarial Association (IAA), whose primary focus includes actuarial education. Continuous professional development of actuaries is essential, and it is common for professional standards to define both foundational and continuing education, which has been the practice to date. Since the criteria for obtaining an authorized actuary license in the Republic of Srpska are not linked to membership in a specific professional organization nor to professional experience, the competence of actuaries, namely, their readiness to perform tasks that, as previously noted, are becoming increasingly complex, also depends on the extent to which university curricula and study programs adapt to current developments.

Based on informal communication with members of the Actuarial Association of the Republic of Srpska, we learn that currently authorized actuaries operating in the Republic of Srpska predominantly limit the application of AI to the use of large language models (LLMs). LLMs are a class of AI models trained on large amounts of textual data, generative models designed to understand and generate human language. They have been successfully used in the development of chatbots such as ChatGPT and Google Bard.⁸ When using these tools, it should be noted that large language models, including

⁵ Paul Embrechts, Mario V. Wüthrich, "Recent challenges in actuarial science", *Annual Review of Statistics and Its Application*, Vol. 9, No. 1/2022, 119–140.

⁶ The Rulebook on the requirements for acquiring and revocation of the title of the authorized actuary (*Official Gazette of the Republic of Srpska*, 57/06)

⁷ Actuarial Association of the Republic of Srpska, *Members of the Association*, available at: <https://uars.rs.ba/clanovi-udruzenja/>, accessed: 3 June 2025.

⁸ Samuel R. Bowman, *Eight Things to Know about Large Language Models*, 2023, available at: <https://arxiv.org/abs/2304.00612>, accessed: 16 February 2025.

GitHub Copilot and ChatGPT, are not reliable for assisting actuaries in writing Python code, as discussed in more detail in a study by Ballon published in 2024⁹. In accordance with professional standards, holders of the actuarial function in the Republic of Srpska should consider the potential impacts that the use of Large Language Models may have on business operations and should adopt procedures for reviewing generated outputs and decisions made based on them.¹⁰ In addition, there are concerns regarding the validation of these models and the issue of so-called hallucinations, that is, situations in which model outputs are not connected to the source text.¹¹

It is crucial to understand that the objective of incorporating AI into traditional actuarial tasks is to improve the efficiency of models and methods. Artificial intelligence can simplify various actuarial processes, including data processing and reporting, thereby enabling actuaries to focus on activities such as strategic planning, supervision, and risk management.

Many new technologies used for risk assessment and as support for policyholder risk reduction, particularly those related to the application of AI and machine learning in creating, redesigning, and pricing insurance products, require a high level of technical skills.¹² As a result, it is essential for actuaries to acquire skills in programming, large-scale data manipulation, and the design and implementation of artificial intelligence algorithms, in order to remain key stakeholders in the risk management process and in the preparation of analyses and conclusions necessary for decision-making.

III Regulations Governing Insurance Pricing by Insurance Companies Headquartered in the Republic of Srpska

Pursuant to the Decision on the Content of the Opinion of an Authorized Actuary (Article 2), it is stipulated that the authorized actuary shall provide an opinion on business policy acts, which include, *inter alia*, decisions on the technical bases of insurance; general and special insurance terms and conditions; and premium tariffs.¹³

⁹ Balona Caesar, "ActuaryGPT: applications of large language models to insurance and actuarial work", *British Actuarial Journal*, Cambridge University Press, 2024, Vol. 29, 1-1.

¹⁰ Mirela Mitrašević, Nataša Tešić, Kristina Bradić, "Challenges in applying machine learning for predictive modelling", *Innovations in insurance - from traditional to modern market*, (eds. Jelena Kočović, Marija Koprivica, Zorica Mladenović, Radmila Dragutinović Mitrović, Biljana Jovanović Gavrilović), Belgrade, 2025, 367-384.

¹¹ Weijia Xu *et al.*, "Understanding and Detecting Hallucinations in Neural Machine Translation via Model Introspection", *Transactions of the Association for Computational Linguistics*, 2023, Vol. 11, 546-564.

¹² OECD, "Leveraging Technology in Insurance to Enhance Risk Assessment and Policyholder Risk Reduction", *OECD Business and Finance Policy Papers*, 2023, available at: https://www.oecd.org/en/publications/leveraging-technology-in-insurance-to-enhance-risk-assessment-and-policyholder-risk-reduction_2f5c18ac-en.html, on 19 February 2025.

¹³ Decision on the Content of the Opinion of the Authorized Actuary, *Official Gazette of the Republic of Srpska*, No. 15/07.

An insurance company is obliged to submit amendments and supplements to business policy acts to the Insurance Agency of the Republic of Srpska within fifteen days from the date of their adoption, together with the opinion of the authorized actuary. Unlike this approach, insurance companies from the Republic of Srpska that are authorized to operate in the territory of the Federation of Bosnia and Herzegovina through branch offices are, pursuant to Articles 10 and 11 of the Insurance Law, required to submit a request for prior approval to the Insurance Supervision Agency of the Federation of Bosnia and Herzegovina regarding the insurance conditions that the insurance company intends to apply in its business operations with policyholders in the territory of the Federation of Bosnia and Herzegovina, including any subsequent amendments or supplements.¹⁴ The insurance company must submit the premium tariffs to be applied in its business with policyholders, as well as any amendments thereto, to the Supervisory Agency at least 30 days prior to their implementation. According to the "Instruction on the content and submission of the opinion of an authorized actuary",¹⁵ the authorized actuary provides an opinion as to whether insurance premium tariffs are in accordance with the law, actuarial professional standards, and insurance practice. The opinion also includes information on the statistical data used to calculate premium rates, as well as data on the technical bases and methods applied. These provisions also apply to amendments and supplements to premium tariffs, with the authorized actuary obligated to submit an opinion on the technical results achieved over the last three years during which the tariffs subject to change or amendment were applied. When providing an opinion, the authorized actuary is required to substantiate that the opinion is supported by analyses demonstrating that premium rates are rational, adequate, and non-discriminatory. The Supervisory Agency may require corrections to premium tariffs in order to ensure compliance with insurance conditions within 30 days of receipt. According to Article 118 of the same Law, the appointed authorized actuary is obliged to ensure that insurance premium tariffs are consistent with actuarial practice and applicable regulations and that they are structured in such a manner as to enable the continuous fulfillment of all obligations arising from insurance contracts. Of particular relevance to the subject of this paper is the provision of Article 141 of the Insurance Law, as part of the regular reporting obligation, which stipulates that insurance companies are required to inform the Supervisory Agency about the technical basis used in the calculation of premium tariffs.

The Insurance Agency of the Republic of Srpska does not grant prior approval for the introduction of insurance products; however, in accordance with Article 13

¹⁴ Insurance Law, *Official Gazette of the Federation of Bosnia and Herzegovina*, Nos. 23/17 and 103/21.

¹⁵ Instruction on the Content and Submission of the Authorized Actuary's Opinion, *Official Gazette of the Federation of Bosnia and Herzegovina*, No. 106/18.

of the Law on Insurance Companies, it may limit the scope of insurance activities performed by a company for a specified period if this is necessary to protect the company's financial soundness. Furthermore, Article 54 of the Insurance Law stipulates that if the Insurance Agency of the Republic of Srpska determines that an insurance company is in breach of risk management rules and policyholder protection requirements, it may order the company to suspend the application of, or amend, insurance terms and conditions and premium tariffs, and to undertake other measures necessary to improve risk management procedures. The Insurance Agency of the Republic of Srpska may order an increase or decrease in the premium amount for a specific type of insurance if, in the opinion of the Agency, such premiums are not appropriate. In the process of tariff control and its application, the Insurance Agency of the Republic of Srpska may require amendments to provisions related to discounts if it is established that subjective elements have been introduced into the pricing process that are not linked to actual and identifiable characteristics of the insured risk, and whose effects cannot be quantified and controlled in accordance with generally accepted actuarial methods. This position becomes particularly significant when considering pricing practices that are not based on the insurance risk profile and service costs, commonly referred to as "price differentiation". Contemporary trends in AI and increased data availability enable ever-greater customization of premiums based on policyholder behavior and characteristics, even when these are not directly related to insured risks. The European Insurance and Occupational Pensions Authority (EIOPA) published information a series of working papers on differential pricing practices. The report published in 2023 on the EIOPA website states that in recent years, the European non-life insurance sector has experienced increasing competition not only in terms of services and coverage offered, but also in pricing, leading to the emergence of differential pricing practices. This increasingly widespread practice has triggered supervisory and regulatory activities and studies in several countries, including the United Kingdom and European Union Member States such as Germany, Ireland, Italy, the Netherlands, and Sweden.¹⁶ The report of the National Association of Insurance Commissioners (NAIC), an American organization that sets standards and provides regulatory support, states that according to a 2013 survey by Earnix conducted on 73 large insurance companies, approximately 45% were using some form of price optimization, while 29% of the surveyed companies reported plans to implement such practices in the future. However, the NAIC report published in 2015 notes that price optimization was identified in very few cases based on submitted premium tariffs, potentially because price optimization was not defined in the documentation

¹⁶ EIOPA, Supervisory statement on differential pricing practices in non-life insurance lines of business, 2023, available at: https://www.eiopa.europa.eu/document/download/1e9a8fb2-e688-4bf5-a347-ee0a-1ec3aab3_en?filename=EIOPA-BoS-23-076-Supervisory-Statement-on-differential-pricing-practices_0.pdf, accessed: 20 March 2025.

submitted to regulators.¹⁷ Similar practices have also been identified through regular and extraordinary inspection supervisions conducted by the Insurance Agency of the Republic of Srpska in the insurance market of the Republic of Srpska.

Given the above, it can be concluded that under the current regulations, insurance companies are required to ensure adequate records of data management processes and modeling methodologies in order to enable transparency and effective supervision.

The absence of specific regulations and governance principles for AI is currently compensated to some extent by existing regulations in the areas of risk management, insurance pricing, technical reserves, and capital adequacy. However, recognizing both the potential of AI to improve actuarial efficiency in the Republic of Srpska and the risks associated with its application (as discussed by Preez *et al.*¹⁸), the regulation of this area should be considered one of the priority objectives in the insurance market of the Republic of Srpska. The *Artificial Intelligence Act*, which establishes a set of requirements applicable to providers and users of high-risk AI systems within the European Union,¹⁹ as well as the six principles of AI governance (proportionality; fairness and non-discrimination; transparency and explainability; human oversight; data governance and record-keeping; and robustness and performance) published by EIOPA in 2021,²⁰ together with existing implementation experience, may serve as one of the starting bases for regulating this area in the Republic of Srpska.

IV Application of Artificial Intelligence in Non-Life Insurance Pricing

An insurance contract is specific in that the premium, or insurance price, is collected in advance, while the insurer undertakes to pay future claims that may arise during the term of the insurance contract. The pricing process includes numerous components, each of which may play a crucial role in ensuring the profitability and solvency of the insurance company. The insurance premium should provide coverage

¹⁷ National Association of Insurance Commissioners, Casualty Actuarial and Statistical Task Force, Price Optimization White Paper, November 2015, 1-16. available at: https://content.naic.org/sites/default/files/inline-files/committees_c_catf_related_price_optimization_white_paper.pdf, on 20 March 2025.

¹⁸ Valerie du Preez *et al.*, "From Bias to Black Boxes: Understanding and Managing the Risks of AI – an Actuarial Perspective", *British Actuarial Journal*, 29, 2024.

¹⁹ European Parliament, Artificial Intelligence Act: MEPs adopt landmark law, 2024. available at: <https://www.europarl.europa.eu/news/en/press-room/20240308IPR19015/artificial-intelligence-act-meps-adopt-landmark-law>, accessed: 29 March 2025.

²⁰ EIOPA, Artificial intelligence governance principles: towards ethical and trustworthy artificial intelligence in the European insurance sector, 2021, available at: <https://www.eiopa.europa.eu/system/files/2021-06/eiopa-ai-governance-principles-june-2021.pdf>, accessed: 20 March 2025.

for: the risk assumed by the insurer under the insurance policy, that is, the claim costs, the projection of which determines the net insurance premium; overhead costs (administrative and acquisition costs); and the target profit. Although a profit loading is included in premium tariff calculations, in practice profit will be realized only if collected premiums exceed total costs.²¹ It is of paramount importance that the actuary, based on available information, correctly estimates the size of claims and determines the net insurance premium accordingly. In contemporary actuarial practice of non-life insurance pricing, the most widely used models are Generalized Linear Models (GLMs), whose theoretical foundations can be found in the works of Nelder and Wedderburn²² as well as McCullagh and Nelder.²³ A paper available on the website of the Institute and Faculty of Actuaries emphasizes that Generalized Linear Models were first introduced into actuarial education in 1980 at Cass Business School, as Bayes Business School was officially called until September 2021, which is a member of City, University of London, and has a mutual recognition agreement with the Institute and Faculty of Actuaries.²⁴

The 1990 curriculum of the Casualty Actuarial Society (CAS) included, in its literature list, a paper by Brown on the application of GLMs for insurance pricing.²⁵ Kuo and Lupton²⁶ note that these models were mentioned only in passing until 2006, when the CAS curriculum literature list officially included the manual "A Practitioner's Guide to Generalized Linear Models" authored by Anderson *et al.*²⁷

Authorized actuaries in the insurance market of the Republic of Srpska were formally introduced to GLM within the framework of continuing professional development programs organized by the Actuarial Association of the Republic of Srpska in 2015 and 2016.²⁸

It is worth noting that machine learning methods and GLM were developed in parallel during the mid-twentieth century. One of the key reasons for the popularity

²¹ Mirela Mitrašević, "Aktuarska i finansijska analiza adekvatnosti kapitala kompanija za neživotna osiguranja" (doctoral dissertation), Faculty of Economics, University of Belgrade, 2010.

²² John Ashworth Nelder, Robert William MacLagan Wedderburn, "Generalized linear models", *Journal of the Royal Statistical Society*, 1972, 135, 370-384.

²³ Peter McCullagh, John Ashworth Nelder, *Generalized linear models*. London, 1983.

²⁴ Steven Haberman, Arthur Edward Renshaw, "Generalized Linear Models in Actuarial Work", *Journal of the Staple Inn Actuarial Society*, 32, 1990, 171-172., available at: <https://www.actuaries.org.uk/system/files/documents/pdf/glm.pdf>.

²⁵ Robert L. Brown, "Minimum Bias with Generalized Linear Models", *Casualty Actuarial Society*, 1988, 187-217.

²⁶ Kevin Kuo, Daniel Lupton, "Towards Explainability of Machine Learning Models in Insurance Pricing", *Variance*, 2023, 16 (1).

²⁷ Duncan Anderson *et al.*, "A Practitioner's Guide to Generalized Linear Models", *CAS Study Note*, 2005, 4-39.

²⁸ The Actuarial Association of the Republic of Srpska, Seminar on Insurance Rate-Making, 2015, available at: <https://uars.rs.ba/foto-galerija-seminar-mart-2015/>, and The Actuarial Association of the Republic of Srpska, Pricing of MTPL Insurance, 2016, available at: <https://uars.rs.ba/odredjivanje-cijene-osiguranja-motorna-vozila/>, accessed: 2 June 2025.

of GLM can be found in the fact that machine learning methods are often perceived as a complete “black box” and, in the field of insurance pricing, which is governed by numerous regulations and requires a certain level of model transparency, were therefore unable to achieve wider application. In addition, high implementation costs may represent a limiting factor. Actuaries should be able to explain to regulators and auditors the principles on which tariff models are based, while consumers should be informed about the main factors influencing the level of insurance premiums in order to enable informed decision-making. Achieving this requires a high level of transparency and explainability of the systems, models, and data used. In this paper, we first explain Generalized Linear Models and subsequently present three models that combine Generalized Linear Models with neural networks.

1. Application of Generalized Linear Models in Non-Life Insurance Pricing

Generalized Linear Models enable modeling relationships between a target variable, whose outcome is to be predicted, and one or more explanatory variables. In non-life insurance, the target variable is most commonly:

- claim frequency (number of claims per exposure);
- claim severity (loss amount per individual claim or per loss event);
- pure premium (loss amount per exposure);
- loss ratio (ratio of incurred losses to earned premium).

This is because insurance claims are typically modeled as a combination of claim frequency and claim severity, or directly through the modeling of the pure premium or the loss ratio. When modeling claim severity, the Gamma and Inverse Gaussian distributions are commonly used, while claim frequency is most often modeled using the Poisson or Negative Binomial distribution. For modeling the pure premium (or loss ratio) at the policy level, the Tweedie distribution is traditionally used.²⁹

Generalized Linear Models are based on the assumption that we have a series of independent random variables Y_1, \dots, Y_n belonging to the exponential family of distributions, whose density (discrete or continuous) has the form:³⁰

$$f_{y_i}(y_i; \theta; \omega_i / \varphi) = \exp \left\{ \frac{y_i \theta_i - b(\theta_i)}{\varphi / \omega_i} + c(y_i, \omega_i / \varphi) \right\} \quad (1)$$

where:

$\omega_i > 0$ - risk exposure factor (weight) $1 \leq i \leq n$;

²⁹ Mark Goldburd et al., *Generalized Linear Models for Insurance Rating*, Casualty Actuarial Society, Arlington, 2020.

³⁰ Esbjörn Ohlsson, Björn Johansson, *Non-Life Insurance Pricing with Generalized Linear Models*; Springer: Berlin/Heidelberg, 2010.; Steven Haberman, Arthur E. Renshaw, “Generalized Linear Models and Actuarial Science”, *Journal of the Royal Statistical Society. Series D (The Statistician)*, Vol. 45, No. 4/1996, 407-436.

$\Phi > 0$ - dispersion or scale parameter, which is the same for each i ;
 $\theta_i \in \Theta$ - canonical parameter $1 \leq i \leq n$;
 $b: \Theta \rightarrow \mathbb{R}$ - cumulant function.

It is assumed that the cumulant function $b(\theta_i)$ is twice continuously differentiable. In the theory of Generalized Linear Models, no particular attention is paid to the function $c(\cdot, \cdot)$, as it does not depend on the canonical parameter θ .

In practice, an appropriate link function g is often selected so that we can express systematic effects as follows:

$$x_i \mapsto g(\mu_i) = \langle \beta, x_i \rangle \quad (2)$$

where:

$\beta \in \mathbb{R}^{q+1}$ - regression parameter,
 $x_i \in \{1\} \times \mathbb{R}^q$ - information on predictor variables;
 $\langle \cdot, \cdot \rangle$ - scalar product in the Euclidean space \mathbb{R}^{q+1} .

It is important to note that the information on predictor variables includes an intercept as its first component; therefore, the previous formula can be written in the following form:³¹

$$x_i \mapsto g(\mu_i) = \beta_0 + \langle \beta, x_i \rangle \quad (3)$$

The canonical parameter θ_i then takes the following form:

$$\theta = (b')^{-1} \left(g^{-1} \left(\beta_0 + \langle \beta, x_i \rangle \right) \right) \quad (4)$$

where:

$(b')^{-1}$ - canonical link of the selected exponential family distribution.

Predictor variables in Generalized Linear Models may be continuous or categorical. A categorical variable may be numeric or non-numeric. In pricing practice, most explanatory variables are categorical in nature, and as a result, statistical analysis encounters complications such as sparsity of the basic model matrix or the so-called design matrix. It should be emphasized that the previously mentioned pricing approach relies on information about policyholders that is available at the time of contract inception.

Although Generalized Linear Models have numerous advantages, a study by Lovisa Styrud in 2017 found that this model had poorer overall predictive accuracy compared to results obtained using neural networks.³² In addition, GLM is unable

³¹ Ronald Richman, Mario V. Wüthrich, "LocalGLMnet: interpretable deep learning for tabular data". *Scandinavian Actuarial Journal*, 2022, available at: <https://doi.org/10.1080/03461238.2022.2081816>, accessed on 20 March 2025.

³² Lovisa Styrud, *Risk Premium Prediction of Car Damage Insurance Using Artificial Neural Networks and Generalized Linear Models*, Royal Institute of Technology, Stockholm, 2017.

to process different types of data and does not perform well when dealing with nonlinear relationships in the data.

2. Development of Models Combining Neural Networks and GLMs for Insurance Pricing

Deep learning models have gained significant popularity in statistical modeling because they lead to regression models whose performance often surpasses that of classical models, such as GLMs. Embrechts and Wüthrich considered *feed-forward neural networks* as an extension of GLMs, representing the regression function in equation (2) as follows:³³

$$x_i \mapsto g(\mu_i) = \beta_0 + \langle \beta, z^{(d)}(x_i) \rangle \quad (5)$$

where:

$$\beta = (\beta_1, \dots, \beta_{q_d})^T \in \mathbb{R}^{q_d} \text{ - GLM regression parameters;}$$

$$\beta_0 \in \mathbb{R} \text{ - intercept;}$$

$z^{(d:1)}$ - composition of $d \in \mathbb{N}$ ($d \geq 2$) hidden layers of the neural network $z^{(d:1)} = z^{(d)} \circ \dots \circ z^{(1)}$.

In this model, the k -th hidden neural network layers $z^{(k)} : \mathbb{R}^{q_{k-1}} \rightarrow \mathbb{R}^{q_k}$ are nonlinear transformations of the raw covariate data, so that the learned representations $z^{(d:1)}(x) \in \mathbb{R}^{q_d}$ can be incorporated into the GLM as shown in equation (5).

Recognizing that the model in equation (5) does not lead to GLM improvement, the authors of the aforementioned paper refer to research in which Wüthrich and Merz start from a simple generalized linear model with regression function:³⁴

$$x_i \mapsto \mu^{\text{GLM}}(x) = \exp\{\langle x, \beta \rangle\} \quad (6)$$

and neural network regression function:

$$x_i \mapsto \mu^{\text{NN}}(x) = \exp\{b_3 + B_3' z^{(2)}(x)\} \quad (7)$$

with an exponential activation function, intercept b_3 , and weights B_3 in the output layer. The previous functions μ^{GLM} and μ^{NN} are then combined in the CANN (*Combined Actuarial Neural Network*) regression function as follows:

³³ Paul Embrechts, Mario V. Wüthrich, "Recent challenges in actuarial science", *Annual Review of Statistics and Its Application*, 9 (1), 2022, 119–140.

³⁴ Mario V. Wüthrich, Michael Merz, "Yes, we CANN!", *ASTIN Bull*, 49:1–3, 2019.

$$x_i \mapsto \mu^{\text{CANN}}(x) = \exp\{\langle x, \beta \rangle + b_3 + B'_3 z^{(2)}(x)\} \quad (8)$$

CANN approach can be applied to a wide range of standard parametric actuarial models, and one example is the modeling of claim frequency assuming a Poisson distribution, as demonstrated by Schelldorfer and Wüthrich.³⁵

Wilson *et al.* applied this approach to French motor liability insurance datasets, „*freMTPL2freq*“ and „*freMTPL2sev*“, included in the R package *CASdatasets*. Various machine learning methodologies, including GLM, *Gradient Boosted Machines* (GBM), *Artificial Neural Networks* (ANN), and a hybrid model combining GLM and ANN, were tested to develop technical models. Results showed that the hybrid model combining *GLM* and *ANN* was best.³⁶ However, when applying GLMs, it should be kept in mind that they require professional feature engineering to select variables and their interrelationships, and if this is not done, GLMs may achieve weaker results compared to other methods.³⁷ The greater flexibility of neural networks is one reason for their increasing popularity in actuarial practice.³⁸

Richman and Wüthrich introduced the so-called *LocalGLMnet*, a neural network architecture that retains many features of GLMs by enabling variable selection, interpretation of the calibrated deep learning model, and also allowing regression parameters $\beta_j = \beta_j(x)$ to become dependent on feature x . Feed-forward neural networks of depth $d \in \mathbb{N}$ with input and output dimensions equal to $q_0 = q_d = q$ are used to model the x -dependent regression parameter:

$$\beta: \mathbb{R}^q \rightarrow \mathbb{R}^q$$

$$x_i \mapsto \beta(x) = z^{(d)}(x) = (z^{(d)} \circ \dots \circ z^{(1)})(x) \quad (9)$$

LocalGLMnet is defined as:

$$x_i \mapsto g(\mu) = \beta_0 + \langle \beta(x), x \rangle \quad (10)$$

for a strictly monotone and smooth link function g .³⁹

³⁵ Jürg Schelldorfer, Mario V. Wüthrich, “Nesting Classical Actuarial Models into Neural Networks”, 2019, available at SSRN: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3320525 or https://papers.ssrn.com/sol3/Delivery.cfm/SSRN_ID3320525_code769240.pdf?abstractid=3320525&mirid=1&type=2, accessed on 12 February 2025.

³⁶ Alinta Wilson *et al.*, “A Comparison of Generalised Linear Modelling with Machine Learning Approaches for Predicting Loss Cost in Motor Insurance”, *Risks*, 12: 62/2024, <https://doi.org/10.3390/risks12040062>.

³⁷ For more details: Alexander Noll, Robert Salzmänn, Mario V. Wüthrich, Case Study: French Motor Third-Party Liability Claims, 2020, available at SSRN: <https://ssrn.com/abstract=3164764> or <http://dx.doi.org/10.2139/ssrn.3164764>.

³⁸ Mario V. Wüthrich, “Bias regularization in neural network models for general insurance pricing”, *European Actuarial Journal*, 10 (1), 2020, 179–202.

³⁹ Mario V. Wüthrich, Michael Merz, *Statistical Foundations of Actuarial Learning and its Applications*, Springer Actuarial, 2022, available at: <https://link.springer.com/book/10.1007/978-3-031-12409-9>.

Harris, Richman, and Wüthrich emphasize that advances in adapting deep learning for actuarial purposes, as illustrated by the *LocalGLMnet* approach, contribute to model transparency. However, it remains necessary to establish clear standards that precisely define what constitutes an acceptable level of compliance with relevant guidelines and regulations in this domain. Given that GLMs are inherently transparent, it is possible to explain how predictions are generated. The coefficients obtained using *LocalGLMnet* can be analyzed collectively, providing better insight into the neural network's learned relationships.⁴⁰

When applying neural networks, it should be kept in mind that they can lead to the occurrence of bias, meaning that the total neural network predictions may not sum to the total observed claims in the portfolio on which they were calibrated. This may make them unsuitable for application in pricing. According to widely accepted actuarial practice standards, actuaries are responsible for ensuring that models are fit for purpose and free of significant biases, which in the case of machine learning models may arise from the data used for training or the chosen algorithm. Understanding the model equips actuaries with the fundamental tools needed to effectively correct model errors and identify potential problems in data processing or model training.

V Concluding Remarks

Summarizing the discussion regarding pricing regulations in the Republic of Srpska, it can be concluded that the current regulatory framework provides actuaries with a foundational basis for applying AI. It needs to be further adapted and continuously updated in line with modern technological developments. It is important to emphasize that actuaries should continue to develop their skills and professional standards to reduce the risks arising from the use of AI. This paper shows that actuaries have relied on Generalized Linear Models (*GLMs*) for pricing non-life insurance for more than four decades. In recent years, there has been growing interest in the application of neural networks, as research indicates they can provide better projections of claims than other models. However, neural network-based models can lead to bias and are often considered a complete "black box", which complicates interpretation and implementation. Consequently, they have not yet seen widespread adoption in actuarial practice. This paper presented *Combined Actuarial Neural Network (CANN)* and *LocalGLMnet* models, in which their authors attempted to overcome certain shortcomings by combining GLMs with neural networks. Given that these

⁴⁰ Roseanne Harris, Ronald Richman, Mario V. Wüthrich, "Reflections on deep learning and the actuarial profession(al)", 2024, available at SSRN: <https://ssrn.com/abstract=4672447> or <http://dx.doi.org/10.2139/ssrn.4672447>.

hybrid models are not fully transparent, further research is needed to assess their ability to meet the regulatory requirements for pricing models.

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