RIGA TECHNICAL UNIVERSITY

Ilze Zariņa-Cīrule

POSSIBILITIES AND SOLUTIONS FOR APPLICATION OF CAPITAL MANAGEMENT ALTERNATIVE METHODS IN INSURANCE COMPANIES

Summary of the Doctoral Thesis

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RIGA TECHNICAL UNIVERSITY
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DOCTORAL THESIS PROPOSED TO RIGA TECHNICAL UNIVERSITY FOR THE PROMOTION TO THE SCIENTIFIC DEGREE OF DOCTOR OF SCIENCE

To be granted the scientific degree of Doctor of Science (Ph. D.), the present Doctoral Thesis has been submitted for the defence at the open meeting of RTU Promotion Council on 20th June, 2023 at 14:00 at the Faculty of of Engineering Economics and Management of Riga Technical University, 6 Kalnciema Street, Room 209.

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DECLARATION OF ACADEMIC INTEGRITY

I hereby declare that the Doctoral Thesis submitted for the review to Riga Technical University for the promotion to the scientific degree of Doctor of Science (Ph. D.) is my own. I confirm that this Doctoral Thesis had not been submitted to any other university for the promotion to a scientific degree.

Ilze Zariņa-Cīrule …………………………….
Date: ………………………

The Doctoral Thesis has been written in English. It consists of an introduction, 4 parts, conclusions and proposals, 68 figures, 28 tables, 10 appendices; the total number of pages is 170, including appendices. The Bibliography contains 194 titles.

LIST OF MAIN ABBREVIATIONS

EIOPA	European Insurance and Occupational Pensions Authority which is part of European System of Financial Supervision
Baltic	is used to group countries: Estonia, Latvia, and Lithuania
EOF	eligible own funds that can cover solvency capital requirement
ΔEOF	changes in eligible own funds
SCR	solvency capital requirement
SR	solvency ratio, capital margin
GWP	gross written premium – price per risk
$ReWP$	reinsurance written premium
TR	technical provisions consist of both premium, claim reserve
TC	total costs
CR	claim reserves
SII	Solvency II framework
IFRS	International Financial Reporting Standards
SFCR	solvency and financial condition report
FA	free capital or surplus
EBS	economic balance sheet
ERM	enterprise risk management
GDP	gross domestic product
M&A	mergers and acquisitions
GTPL, MTPL	general third party liability, motor third partly liability
ROA	return on assets
ROE	return on equity
ROI	return on investment
EUR thous.	EUR thousand
NIC	net incurred claims
NAC	net acquisition expenses
LoB	line of business, product
FKTK	Financial and Capital Market Commission in Latvia
BE	best estimate
BE and ΔBE	changes in the reserve
mkt	market
def	counterparty
nl	non-life
IM, PIM	internal or partial internal model
SF	standard formula

CONTENTS

INTRODUCTION

Topicality of the research

As in any industry, the key aims of insurance company management are to increase shareholder value and to implement a strategy that promotes sustainable, stable, and long-term growth. Well-known key performance indicators and measures are the following: share price, economic value, gross earned premiums and solvency ratio. These measures are important for efficient capital management. Capital costs can be an important cost position depending on risk appetite, the general interest rate environment, and the amount of the required capital to support the insurer's risk profile and business plan. The amount of capital required is very important so that an insurance company can absorb all possible losses, is financially stable, and can satisfy the needs of shareholders. Therefore, a risk assessment of the required capital must comply with regulatory requirements and continuous development is necessary.

Insurance fulfils a basic social function, namely, the financial health of the people. Therefore, the regulator prescribes a minimum amount of capital that it must hold. The Solvency II regime, which came into force in 2016, is a new framework set by EIOPA for the European Union insurance market and adopted as the Solvency II Directive (European Parliament & Council of the European Union, 2014). All non-life insurance companies must have their eligible own funds calculated using a market-consistent assessment at least equal to the solvency capital requirement (SCR) in order to avoid regulatory intervention. The SCR is based on a known risk measure value with a confidence level of 99.5 % over a time horizon of 1 year or with a survival probability of at least 99.5 % for the following 12 months. The calculation approach is referred to as the standard formula.

In most cases, claim reserves in non-life insurance are the largest item on the liabilities side of the balance sheet of non-life insurance companies and are the main reason for insolvencies. Therefore, proper risk assessment is important for any non-life insurance company. There are two main types of reserves: claim reserves (for claims that have occurred) and premium reserves (for events and costs that have not occurred). The claim reserves are highlighted in this Doctoral Thesis. The reserve risk according to the standard formula in the Solvency II Directive is calculated on a factor-based approach from the net claim reserve and standard deviation for each line of business. It is assumed that the underlying distribution for the reserve risk is log-normal (EIOPA, 2014 b). Furthermore, the linear correlation matrix is used to aggregate the reserve risk. Problems with risk aggregation and interdependency between reserve risks for different insurance products are the most frequently cited weaknesses in the literature on the standard approach. The standard formula approach, which uses a linear correlation matrix, cannot solve insurance sector-specific problems, as exhibited by empirical research by other authors. Financial markets that exhibit high volatility are directly interconnected and exhibit strong correlations with each other. Correlation crises in financial markets have been widely studied. Bivariate tail dependence has been studied in many papers, but multivariate tail dependence has not been extensively studied in the insurance sector.

Today's challenges, such as inflationary pressures, economic stagnation, low returns and uncertainty due to pandemics, can lead to strong correlation between different risks, resulting in insufficient capital and reserves that absorb losses or liquidity can worsen.

The relevance of a standard formula for individual companies in the EU and the Baltic non-life insurance market should be examined with regard to their own risk solvency assessment process. If the standard model does not fit the risk profiles of the companies, an alternative capital model, a so-called partial or internal model, should be developed. If a standard formula developed by the supervisory authority is used, the standard methods for capital management are applied. However, companies may use alternative capital management methods, such as the implementation of an internal capital model, after approval by the supervisory authority. The efficient risk assessment of capital management, therefore, goes far beyond compliance in its provision of better insight into the risk analysis and risk profile of the company, ensuring the financial stability and solvency of its development and supporting management in strategic decision-making. There are no existing literature and academic publications that have studied internal capital models for non-life reserve risk and the suitability of the standard model for the Baltic non-life insurance companies.

More than half of the companies (7 out of 12) need capital to also operate through branches in Latvia, Lithuania, and Estonia. Therefore, the development of the Baltic non-life insurance market was studied. The insurance industries in Latvia, Estonia, and Lithuania have grown faster than the economies of the respective countries, which are classified as emerging markets. Claims reserves occupy the most important position in the economic balance sheet of the Baltic insurers, accounting for 90–91 % of total liabilities based on author's research. Therefore, the most important issue for the public sector (including the regulator) is to protect the Baltic policyholders from the unlikely event or events that their insurer becomes insolvent.

Reserve risk is one of the main reasons why insurers become insolvent and fail. Historically, in the insurance sector in Canada and the United States, reserve risk and too rapid and uncontrolled growth have been the main risks for insurer insolvency (Buckham *et al.*, 2011; Kleffner & Lee, 2009; Leadbetter & Stodolak, 2009; Massey *et al.*, 2001). These characteristics of significant reserve volume and rapid growth can also be observed in the Baltic insurance market. Moreover, as found by the researchers, the standard formula only qualifies for large companies under normal market conditions (Biard *et al.*, 2008; Kemaloglu & Gebizlioglu, 2009). It should be noted that the Baltic non-life insurance companies are considered small and medium-sized enterprises in the EU context.

The Doctoral Thesis provides the development of alternative capital management methods, and the author has proposed an algorithm of internal model by taking into account the data specifics and loss distribution functions of a company operating in the Baltic non-life insurance market. Two methods for alternative capital management are developed. First, the present Doctoral Thesis covers the development and application of an alternative capital requirement method as an internal model to better quantify the non-life claim reserve risk for the Baltic non-life insurance market in the context of the Solvency II framework. Second, digitalisation is considered as an alternative capital management method to decrease claim reserves and, therefore, reserve risk.

The appropriateness of the standard capital management method and the standard formula for the Baltic non-life insurance market have not been investigated. A model is developed using a copula approach and through hypothetical testing to determine which type is appropriate for the non-life insurance company. Investing in the digitalisation of claims management has an impact on capital requirements and leads to a reduction in capital requirement and the cost of capital based on a case study included in the Thesis.

The approach in determining how the solvency capital requirement is derived (standard or alternative) has implications for the capital structure of the company. The highest quality of equity (Tier 1), such as ordinary share capital and retained earnings, must be at least half of the solvency capital requirement under the Solvency II framework. Tier 2 and 3 capital can be up to 50 % of the solvency capital requirement. Additionally, the cost of capital and equity depends on their amount. The cost of Tier 3 capital is lower than Tier 2 capital, and Tier 1 and Tier 3 capital must earn less before they create value. Moreover, regulators and shareholders take this as a warning that a company has a riskier capital structure. An optimal and properly valued required capital with a proposed alternative capital management method can reduce the cost of capital and improve the capital structure. Currently, standard approaches are used in the Baltic non-life insurance market, and internal models are not used in reporting and daily decision-making. In terms of using internal models, the medium-term capital planning process for the Baltic non-life insurers should be considered by harmonising between a company and expected market growth relative to the GDP growth.

The research **hypothesis** is that with the application of an alternative capital management methods, a more accurate assessment of capital requirement that covers reserve risk and a reduction in the cost of capital in the Baltic non-life insurance companies is possible.

The aim of the Doctoral Thesis is to develop alternative capital management methods and to propose an algorithm of internal model by taking into account the data specifics and loss distribution functions of a company operating in the Baltic non-life insurance market.

It is determined that the **following tasks** are key to reaching the aim of the Thesis:

1. Analyse the development and financial stability of the Baltic non-life insurance market and identify the overall risk profile, reserve structure and current methods of capital management and volatilities during the pandemic, if any.
2. Evaluate how digitalisation can be applied as alternative capital management method for reserve risk and identify how to assess its impact on claim management in non-life insurance companies.
3. Review the regulatory documents in detail and conduct a literature review on standard capital management methods for reserve risk, summarising the weaknesses that need to be improved when developing an internal model as an alternative capital management method.
4. Build an internal capital model and provide algorithm for the required capital for claim reserve risk of a non-life insurance company in accordance with the Solvency II framework:
   - using copulas;
   - proposing a practical approach on how goodness-of-fit tests can be applied in order to select a copula that is appropriate for a non-life insurance company's data;
   - evaluating the required capital deviations from the standard capital management method.

The **object** of the Thesis is an insurance company that is participant of the Baltic non-life insurance market.

The **subject** of the Thesis is the alternative capital management methods that can be used in the capital management for reserve risk in non-life insurance companies.

The following **limitations** are considered in order to achieve the aim of the research:

1. The Thesis offers an internal capital model for a single risk – the non-life claim reserve risk, one of the most significant risks in the risk profiles of insurance companies.
2. In relation to the solvency capital requirement the European Union's Solvency II framework, alternative capital management methods are addressed. If the insurance company is regulated by a different regulator outside of the EU, adjustments must be applied in the model. With this, the policy for internal model changes and validation, pre-application process steps are not established and investigated (Articles 112–116, 120–126, and 231 of the Directive Solvency II 2009/138/EK).
3. As the empirical results are based on only one company (i.e., certain products) in the Baltic non-life insurance market where the data are private and not publicly available, the empirical results for other insurance companies may differ.
4. The proposed model does not take into account how fluctuations in profits will affect the estimated amount of corporate income tax.
5. There could be a possibility that the application of an alternative capital management method as an internal capital model may be restricted or forbidden in a particular country, necessitating the need to keep track of changes in regulatory requirements and political judgments.
6. Software R and its packages of published papers are used for the choice of copula by performing available goodness-of-fit tests.
7. In Part 4, the 2011 data are included in the calculation as a "tail" coefficient equal to 1, using the chain ladder method of reserve calculation. It is not necessary to include data because the reserve for 2011 and older events is 0 for the insurance company as of 2020, but may change for other companies, other products, and in the event of legal changes.

The **research period** of the empirical study was conducted from 2011 to 2020. Research papers, regulatory documents and regulatory requirements were valid until the end of 2020. The Solvency II framework, which sets out the principles for calculating solvency capital requirements for insurers, came into force in 2016. Therefore, the Part 1 also contains an analysis of the period 2016–2020 of Solvency II figures (solvency ratios, economic balance sheet), which are publicly available as an SFCR report on the companies' homepage up to 9 months after the end of the financial year, ensuring that audited data are used. Since the minimum number of observations for the regression analysis is ten, the data since 2000 are used to forecast market growth, insurance density, and gross premium volume in the first part. The theoretical and methodological bases used in the research were the theoretical and empirical studies by both foreign and Latvian researchers and organisations.

Theoretical and Methodological Foundation of the research

Alternative capital management through internal capital models and insurer risk measurement have been explored on the basis of the papers of the following researchers (37): *Alm J., Araichi S., Arbenz P., Bargès M., Belkacem L., Bermúdez L., Biard R., Bølviken E., Butaci C., Cadoni P., Castellani G., Clemente G., Christy N., Dacorogna M., Diers D., Doff R., England P. D., Ferriero A., Fernandez-Arjona L., Fersini P., Forte S., Fröhlich A., Gatzert N., Green K. C., Hejazi S. A., Kemaloglu S. A., Malyon B., Munroe D., Ohlsson E., Peretti C., Sandström A., Savelli N., Slim N., Stoliarova V., Schwarz G., Valecký J., Wouwe M.*

Technical provisions, claim reserve, and the impact of digitalisation in non-life insurance companies were examined on the basis of the papers of the following researchers (18): *Bohnert A., Buckham D., Bühlmann H., Carsten R., Diers D., Dörner K., Dutang C., Eling M., England P. D., Efron B., Gesmann M., Leppert F., Mack T., Merz M., Schmidt K. D., Tarbel T., Verral R., Wuthrich M. V., Yamamoto R.*

The copula theory and its adaptation and risk measurement for alternative capital management methods were studied by the following foreign researchers (17): *Demarta S., Fermansion J.-D., Genest C., Hofert M., Markowitz H., McNeil A. J., Nelsen R. B., Pellecchia M., Perciaccante G., Romano C., Rémillard B., Roy A. D., Sklar A., Quessy J.-F., Yan J.;* and researchers of the Baltic countries: *Kollo T., Pettere G*.

The financial analysis and analyses of the financial stability and market concentration of the Baltic non-life insurance market were performed on the basis of the papers of the following researchers (15): *Abaluck J., Brainard L., Chant J., Dell'Atti S., Enz R., Ferguson R., Franchon G., Feyen E., Gini C., Handel B. R., Hussels S., Large A., Linartas A., Romanet Y., Spinnewijn J.*

Among them, there are no researchers who have published papers on non-life claim reserve risk, alternative capital management methods and copula theory for the Baltic non-life insurance market. The informative basis of the work consists of scientific literature, international publications and methodological literature. In conducting the research, the author used the insurance statistical database of the Baltic countries and Baltic non-life insurance companies (public annual reports, solvency and financial condition reports) and the European Union regulator's (EIOPA) statistical database of insurers and pension funds. In the development of the alternative capital management methods, such as internal capital model, the author used a primary data source in the study – that is, the 10-year data of insurance company. The empirical study was mainly conducted using the statistical software packages in R. Primary data from claims databases of a Baltic insurer were used to build and validate the model. The author studied EIOPA's regulatory documentation to analyse the theoretical and legal aspects of the Solvency II framework in the field of non-life insurance sector to summarise standard method in assessing required capital.

The research design

The logical structure of the research was determined on the basis of the purpose of the research and the logical sequence of the research objectives. The logical structure of the Thesis is shown in Fig. 1.

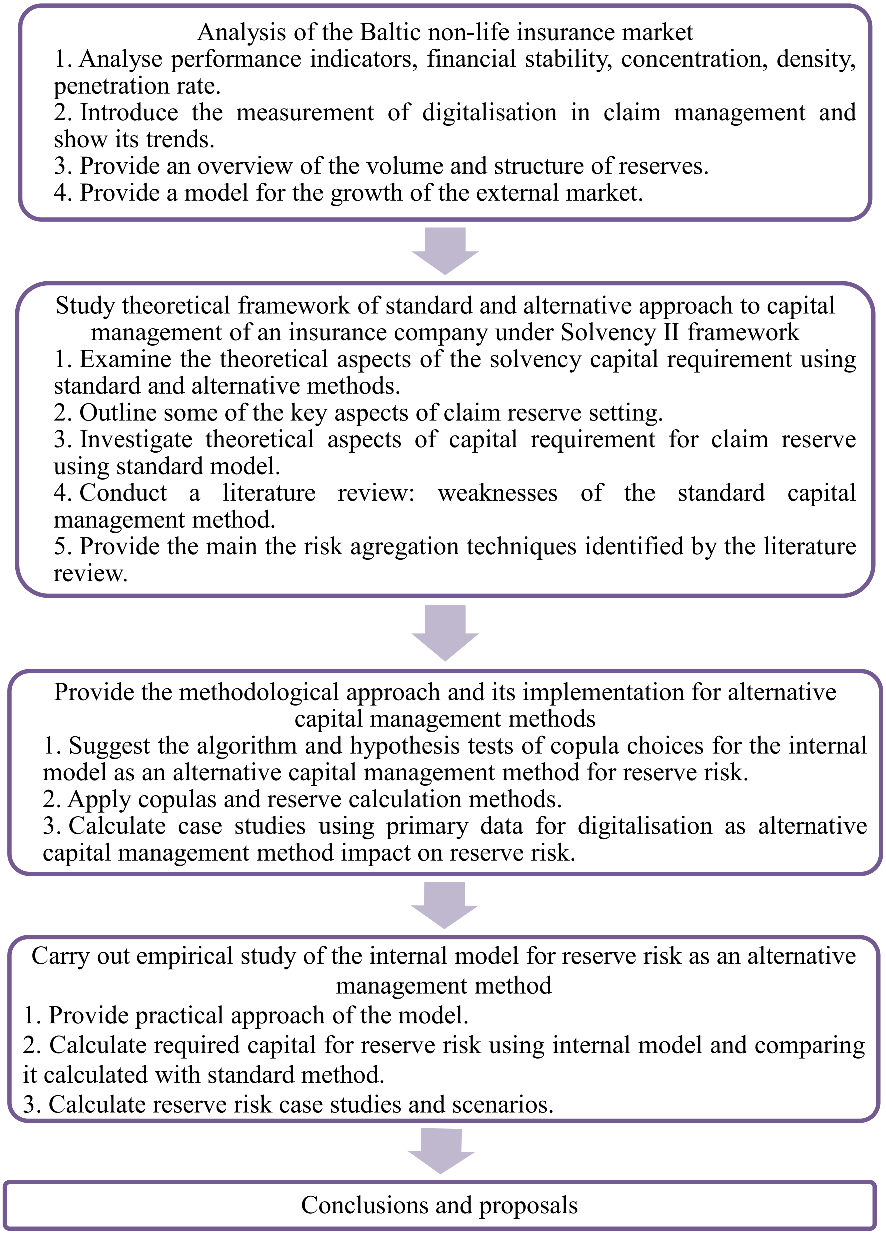

Fig. 1. Research design. Source: Created by the author.

Research methods

Generally accepted theoretical research methods of actuarial science, economic mathematics, and management science were used in the development of the research. The author of Doctoral Thesis used the following general methods:

1. Analysis and compilation of information, grouping, comparison, graphical representation

and qualitative data processing were employed.
2. Statistical analysis methods were used for data grouping according to different characteristics, descriptive statistical indicators analysis (median and variation indicators), linear regression, correlation analysis methods (Pearson's and Spearman's rank correlation coefficients) and Gini coefficient.
3. Quantitative research methods were utilized in obtaining the empirical results, including the following:
   - Non-parametric and parametric statistical methods (AIC test and student's t-test for quantile-quantile [*Q*–*Q*] graphs).
   - The theory of copulas and the actuarial methods of technical reserves (deterministic and stochastic chain ladder methods).
   - Monte Carlo simulations and the value at risk and non-parametric Bootstrap methods.

Scientific novelty

1. Assessment of the financial stability and development of Baltic non-life insurance market based on various indicators, matrix synthesis analysis and its adaptation to the Solvency II framework.
2. A method that measures the impact of digitalisation on claim management and required capital for reserve risk in a non-life insurance company.
3. A new alternative capital management method as an internal model that measures the non-life claim reserve risk for the Baltic non-life insurance company based on the copula theory using *t*-copula and normal copula, which provides an estimate of the amount of capital required to cover liabilities for events that have occurred.
4. Practical approach in determining the best-fit copula in capital management based on hypothesis testing and selecting the plausible copula for the Baltic non-life insurance company.

Value

The proposed model of the Thesis helps to solve practical problems in the insurance industry, such as the following:

- how to develop and improve capital management by implementing an internal capital model;
- how to use capital optimally by using copula that take into account insurance product specifics, interaction, and diversification between risks;
- how to achieve financial stability for the insurance sector;
- how digitalisation can be measured in the insurance sector for reserve risk and how it affects claim reserves and the solvency capital requirement.

The **Thesis statements for defense** are as follows:

1. The standard formula of the Solvency II framework as the standard method for capital management for non-life claim reserve risk is not always appropriate when the characteristics of the data and loss distribution functions of the Baltic non-life insurer are different from those defined in Solvency II regime.

2. Digitisation affects the speed of claims payments, reduces unreported claims reserves and reserve risk, and can therefore be used as an alternative method of capital management.
3. An internal model created by using copulas as an alternative capital management method through the accurate identification of the risk profile in accordance with the Solvency II framework after approval by the supervisory authority is the basis for a stable implementation and development of a capital management system in non-life insurance companies.

Scientific Publications

The results of the research have been presented at 7 international scientific conferences and seminars and published in 9 articles and conference papers in international scientific journals and books. Publications of the author of the Doctoral Thesis:

1. Zariņa-Cīrule, I., Pettere, G., Voronova, I. (2022). Efficient Capital Management with Internal Model: Case of Non-Life Insurance. *Proceedings of the Estonian Academy of Sciences*, Vol. 71, No. 3, pp. 289–306. Available at: https://doi.org/10.3176/proc.2022.3.08 (Scopus)
2. Zariņa, I., Voronova, I., Pettere, G. (2022). Improved Insurer's Capital Adequacy of Reserve Risk Using Copula Approach and Hypothesis Tests. In: Skiadas, C. H., Skiadas, C. (eds.) Quantitative Methods in Demography. The Springer Series on Demographic Methods and Population Analysis, Vol. 52. Springer, Cham. Available at: https://doi.org/10.1007/978-3-030-93005-9_28. (Scopus)
3. Zariņa, I., Voronova, I., Pettere, G. (2020). Improved Insurer's Capital Adequacy of Reserve Risk Using Copula Approach and Hypothesis Tests. In: 6th Stochastic Modelling Techniques and Data Analysis International Conference with Demographics Workshop: Proceedings, Spain, Barcelona, 2–5 June 2020. Greece: ISAST: International Society for the Advancement of Science and Technology, pp. 593–602.
4. Zariņa, I., Voronova, I., Pettere, G. (2021). Alternative capital requirement for insurers: possibilities and issues. *International Journal of Economics and Business Research,* Vol. 21, No. 1, pp. 41–61. Available at: https://doi.org/10.1504/IJEBR.2021.112004 (Scopus)
5. Zariņa, I., Voronova, I., Pettere, G. (2019). Internal Model for Insurers: Possibilities and Issues. In: *International Scientific Conference „Contemporary Issues in Business, Management and Education"*, Lithuania, Vilnius, 9–10 May 2019. Vilnius: VGTU Press "Technika", 2019, pp. 255–265. Available at: https://doi.org/10.3846/cibmee.2019.026.
6. Zariņa, I., Voronova, I., Pettere, G. (2019). Digitalisation Impact Measuring on Claim Management for the Insurance Sector. In: Perspectives of Business and Entrepreneurship Development: Digital Transformation of Corporate Business: Economic, Management, Finance and System Engineering from the Academic and Practitioners Views: Proceedings of Selected Papers, Czech Republic, Brno, 29–30 April, 2019. Brno: Brno University of Technology, pp. 105–114.
7. Pettere, G., Zariņa, I., Voronova, I. (2018). Behaviour of Multivariate Tail Dependence Coefficients. *Acta et Commentationes Universitatis Tartuensis de Mathematica,* Vol. 22, No. 2, pp. 299–310. Available at: https://doi.org/10.12697/ACUTM.2018.22.25 (Scopus)

8. Zarina, I., Voronova, I., Pettere, G. (2018). Assessment of the stability of insurance companies: the case of Baltic non-life insurance market. *Economics and Business*, Vol. 32, pp. 102–111. Available at: https://doi.org/10.2478/eb-2018-0008 (EBSCO)
9. Jansons, V., Didenko, K., Jurenoks, V., Zarina, I. (2016). Computer Realization of Algorithms for Minimisation of Financial Risks. *International Conference on Systems Informatics, Modelling and Simulation (SIMS)*, Riga, 2016, pp. 161–166. Available at: https://doi.org/10.1109/SIMS.2016.26 (Scopus)

The results of the research have been presented at the following international scientific conferences:

1. Participation with research Assessment of the stability of insurance companies: the case of Baltic non-life insurance market, RTU 58th Scientific Conference on Economics and Entrepreneurship, September 27–28, 2017, Riga, Latvia.
2. Participation with research Empirical Study of Multivariate Tail Dependence, 5th Stochastic Modeling Techniques and Data Analysis International Conference (SMTDA2018) and the Demographics, 2018 Workshop, June 12–15, 2018, Chania, Crete, Greece.
3. Participation with research Digitalisation Impact Measuring on Claim Management for the Insurance Sector, 17th International Scientific Conference, Faculty of Business and Management, Brno University of Technology, April 30, 2019, Brno, Czech Republic.
4. Participation with research Internal Model for Insurers: Possibilities and Issues, CIBMEE-2019, May 9–10, 2019, Vilnius, Lithuania.
5. Participation with research Improved Insurer's Capital Adequacy of reserve risk using copula approach and hypothesis tests, 6th Stochastic Modeling Techniques and Data Analysis International Conference and Demographics 2020 Workshop. June 2–5, 2020, Barcelona, Spain.
6. Participation with research Assessment of capital adequacy and efficiency of insurers: the case of Baltic non-life insurance market., Riga Technical University 61st International Scientific Conference on Economics and Entrepreneurship (SCEE'2020), 14–16 October 2020, Riga, Latvia.
7. Participation with research Financial stability projecting: the case of the Baltic non-life insurance, 40th EBES Conference – Istanbul, July 6–8, 2022, Istanbul, Turkey.

Practical value

1. Instead of the standard capital management method for reserve risk (which is the same for all EU insurers), a company may use an alternative capital management method that provides the required capital based on individual data and risk profile, if approved by the local supervisory authority.
2. The theoretical and practical results of the Doctoral Thesis can also be used in the educational process, conducting classes in RTU within the study course "Entrepreneurship and Business Planning" and programme "Financial Engeneering", in Vilnius University in programme "Financial and Actuarial Mathematics", in the University of Tartu in programme "Actuarial and Financial Engineering" and in the guest lectures on

entrepreneurship organized by RTU FEEM in various universities. Also, the Thesis results can be used in the lectures of European national actuaries association.

Volume and content of the Doctoral Thesis

The Thesis consists of an introduction, four parts, conclusions and proposals, a bibliography and nine appendices. The Thesis is dedicated to the field of capital and risk management in non-life insurance that ensure financial stability and efficient capital management and sustainable growth of an insurance company.

Part 1 examines and analyses the Baltic non-life insurance market part of which is the insurance company that is the object of the Thesis. The study covers the nature of the insurers' risk profile, solvency position, capital structure and key performance indicators. An assessment of financial stability with matrix synthesis is developed, and it is shown how to measure the impact of digitalisation on the speed of claims payment and its changes as a result of digitalisation in the Baltic non-life insurance market. Finally, a model that forecasts external market growth and the growth of required capital is proposed.

Part 2 explores the theoretical aspects of standard and alternative capital management methods, covering the general concepts and identified weaknesses by the researchers for standard capital management approach under the Solvency II framework for reserve risk and possible solutions. The summary of theoretical non-life claim reserve and reserve risk and risk aggregation techniques are presented.

Part 3 describes and proposes the alternative capital management method with the methodology of internal model and application, and selection of methods for more accurate capital allocation. Two alternative capital management methods are proposed: an internal model using copulas and digitalisation. A case study examines the impact of digitalisation on the required capital for reserve risk.

Part 4 contains the approbation and application of the internal model using a company's data, as the implementation of the model requires sensitive data. The calculated capital requirements to cover non-life claim reserve risk under Solvency II were compared with the internal model and the standard approach, also under different scenarios.

The Doctoral Thesis is written in English. The volume of the Thesis is 170 pages, including the appendices. It presents 68 figures, 28 tables and 10 appendices. The Thesis consists of an introduction, four parts, conclusions and proposals, ten appendices and 194 references have been used.

Keywords: capital management, financial stability, non-life insurance, claim reserve, reserve risk, capital management alternative method, digitalisation, internal capital model, copula.

1. BALTIC NON-LIFE INSURANCE MARKET DEVELOPMENT, CHALLENGES AND CAPITALISATION

The part comprises 34 pages and includes 10 tables and 29 figures.

1.1. Analysis of Baltic non-life insurance market development

In 2020, the market shares of the life insurance business and non-life insurance business in the Baltic insurance market were 25 % and 75 %, respectively, and those proportions had been stable (i.e. 22 %–25 %) over the 2016–2020 period (EIOPA, 2020b). The development of the Baltic non-life insurance market has been investigated since the implementation of the Solvency II framework. A risk-based capital framework has been in force for more than six years. The investigation involves the collection of gross written premium volumes and the calculation of the growth rates for the market (in gross written premium) and the economy at market prices (see Fig. 1.1).

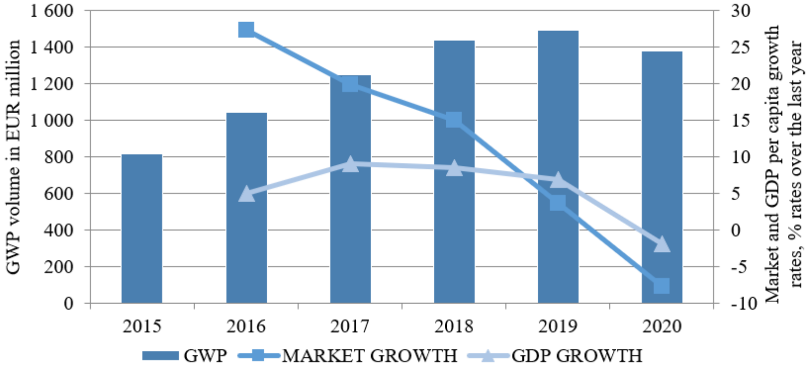

Fig. 1.1. Baltic non-life insurance market volume of business (in EUR million), market and economic growth rates (% rates over the previous year) in 2016–2020.

Source: Calculations by the author based on the Baltic non-life insurance companies' annual and SFCR reports, 2015–2020 (AB Lietuvos draudimas, 2020; BALCIA, 2020; BALTA, 2020; BAN, 2020; BTA, 2020; COMPENSA, 2020; ERGO, 2020; GJENSIDIGE, 2020; IF, 2020; INGES, 2020; SALVA, 2020; SEESAM, 2019; SWEDBANK, 2020) and GDP at market prices (EUROSTAT, 2021).

The Baltic non-life insurance market has grown rapidly, with an average annual growth in gross written premiums of 11 % during 2015–2020, which is higher than the average annual growth in the Baltic GDP of 5 %. The analysis shows that the average per capita expenditure on insurance (known as insurance density) in the Baltic has also increased. The market has huge growth potential (based on the analysis of average premiums and a comparison with other EU countries). As a relatively young market (over 20 years), the Baltic insurance market is classified under the emerging market.

A summary of all the gross written premiums in the Baltic market indicates a high concentration level in the market, which in equal market is assessed by the Gini concentration ratio. The Gini coefficient was proposed by Gini (1912). Half of the Baltic non-life market participants (six companies in total) had more than 80 % of the market share in total gross written premiums. The total market share per entity in the market varies from 0.4 % to 18.4 %, whereas 8.3 % indicate perfect equality in the market. The index of dissimilarity is the most widely used measure of segregation defined by Duncan & Duncan (1955). It was stable in 2016–2020. Overall, both measure of segregation and inequality signals low premiums and high competition between market leaders. Such trend is especially evident in 2020, when the drop in premium was higher than the drop in GDP at market price due to the intense competition.

The market has been profitable in 2016–2020, with an average combined ratio of 93 %. The improvement of performance indicator results for the past four years has been significant, which could be explained by average premium increase compared to labour and services costs. The positive gains are evident in 2020 due to the COVID-19 pandemic and low frequency rate of claims, as well as low inflation for claims. In addition, business interruption losses have not heavily affected the market.

1.2. Analysis of reserves for Baltic non-life insurance companies

Claims reserves occupy the major position in the economic balance sheet for the Baltic non-life insurers, with a 90–91 % share in total liabilities, whereas the remaining positions account for a 9–10 % share in total liabilities. Understanding the impact of digital transformation on claims patterns and their developments is crucial to avoid an insufficient claim reserve. It is also important as an alternative management method as the internal model is proposed in the Thesis for the capital requirement to cover the claim reserve risk. The technical provisions of non-life insurers under Solvency II are divided into 2 sections: non-life technical provisions and life technical provisions (in the Baltic from motor third party liability insurance). The technical provisions consist of the best estimate of the claims provisions (referred to as claim reserve in the further text), the best estimate of the premium provisions (referred to as the premium reserve in the further text) and the risk margin. The alternative management method proposed in the Thesis is an internal model for calculating the required capital for the reserve risk using the volume of non-life claims reserves calculated on the basis of the Solvency II framework.

More than half of the reserves (58 62 %) are for the motor third-party liability line of business and long-term liabilities (i.e., annuities from the motor third-party liability line of business), 12–18 % for fire and property damage, 9–11 % for general liability and 6–9 % for other motor (i.e., CASCO for cars and rail vehicles). The other line of business has a structural claim reserve of almost 5 %, while medical expense insurance has less than 2 %. The level of claims reserves under IFRS and the level of claims reserves under Solvency II differs and the differences in the Baltic non-life market are up to 5 percentage points in 2020. The level of reserving can be calculated as gross provision for claims divided by gross premiums written. It shows the reserving practise of the market and the product design. The author has identified the high deviation of reserving ratio and reserving policy in the non-life insurance market between insurers. The median reserve level increased by two percentage points during the pandemic. IF has the highest reserve level with a yearly increasing trend, Gjensidige has the lowest deviation, and Swedbank has the lowest reserve level (see Fig. 1.2). However, it should be noted that differences in product structure and conditions could be the main reason.

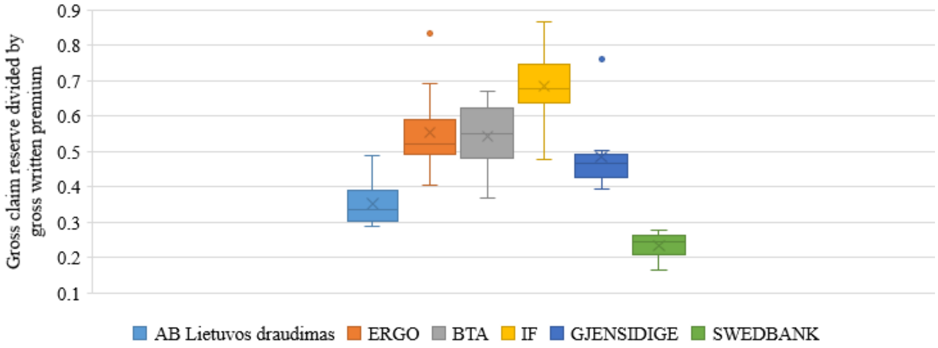

Fig. 1.2. IFRS claim reserving ratio development for the Baltic non-life insurance market as maximum-minimum interquartile distribution in 2011–2020.

Source: Created by the author based on financial reports 2011–2020 (BTA, 2020; ERGO, 2020; GJENSIDIGE, 2020; AB Lietuvos draudimas, 2020; SWEDBANK, 2020; IF, 2020b).

The most important governing subject for the public sector, including regulators, is therefore the protection of Baltic policyholders in the unlikely event that their insurer becomes insolvent, or for multiple events. Reserve risk is one of the main risks why insurers become insolvent and fail (Leadbetter & Stodolak, 2009). The author has identified rapid growth and high volatilities in reserving level in the Baltic non-life insurance market.

1.3. Analysis of financial stability, capital structure and solvency positions of insurance companies in digital age

Development of solvency positions and capital structure

A summary of indicators based on the solvency and financial stability of the Baltic non-life insurance market provides an understanding of the key performance measures in insurance, the role of the risk management function in internal model implementation and capital management. Internal financial stability factors such as solvency and efficiency ratios (ROA, ROE, ROI) are investigated. As shown in Fig. 1.3, the analysis results imply the lack of a significant relationship between solvency ratios and market share during 2016–2020. A wide range of solvency ratios between providers can be seen.

The market is well and strongly capitalised over the five-year horizon, with median solvency ratios of 155 % and 166 % in 2016 and 2020, respectively. However, the Baltic solvency ratio was lower than the EU median in 2016 (209 %) and 2020 (213 %) (EIOPA, 2016; 2020a).

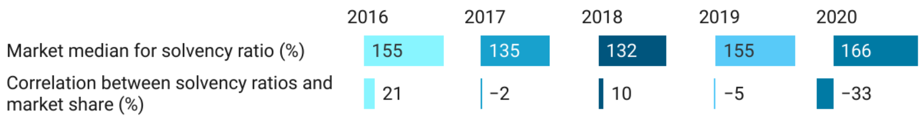

Fig. 1.3. Non-life Baltic insurance market median solvency ratios and their relationship with market share.

Source: Author's calculation based on data from EIOPA, 2016–2020 (EIOPA Statistics, 2021).

The solvency positions of the market were not affected by the outbreak of COVID-19 despite the low interest rate environment, volatility in financial markets and changing customer behaviour. If the required capital is split by underlying risk, then non-life risk has the highest capital need 57 %, followed by market risk (19 %), counterparty (9 %), operational risk (9 %), health underwriting risk (6 %), and finally, life underwriting risk (1 %).

Return on equity (ROE) shows the profit that insurance companies make on the capital invested by the shareholder. In the period 2016–2020, ROE was positive at the aggregate level. Compared to 2016, ROE has increased from 10.03 % to 17.7 % in 2020 due to the overall increase in profitability, higher underwriting profits and growth in business with a stable combined ratio. This result could also be due to the change in customer behaviour during the pandemic. The average annual profit increase was 38 %. The wide range of equity returns in 2016 can largely be explained by M&A activity in the market. The ROE of Baltic non-life insurers is higher on an aggregate level than in advanced markets such as Germany, ranging from 5 % to 10 % (OECD Global Insurance Statistics, 2020).

Impact of digitalisation on claim management

A better understanding of claims and reserving policy, processing speed and future development helps to adequately assess measurable underwriting risk, reserving risk and their main drivers. This also helps in developing and improving other alternative capital management methods such as an internal capital model for reserve risk, which should take into account dynamic market changes, and improves enterprise risk management in a company.

The insurance industry, including the Baltic market, continues to face new trends. Further uncertainties due to the pandemic, digitalisation, climate change, the rise in interest rates and inflationary pressures have disrupted the world's energy system and caused a further slowdown in the economy. These trends have created new risks that the global insurance market is facing. The insurance sector in the Baltic also faces new emerging regulatory requirements. Solvency II is updated at least every three years, and regular reporting is a time-consuming process. IFRS 17 and IFRS 9, which come into force in 2023, are expected to change the way key insurance indicators are measured with more advanced data flows through IT systems (Deloitte, 2017).

The following research questions are therefore addressed in this subsection:

- How can the digitalisation transformation impact be measured in the insurance sector for claim management?
- What is the relationship between the claims handling speed (digitalisation measure), claims paid volume (business growth) and GDP in the Baltic countries?

- Is companies' product and technical provision's structure impacting digitalisation's effectiveness?

Speed of claims processing is used as a digitisation measure in this chapter. The study population comprised seven leading non-life insurance companies in the Baltics. Data were obtained from publicly available annual reports from 2011–2020 and the SFCR in 2020. The time horizon of the pandemic was considered and not analysed separately, as late reported claims, late developed claims and lower claims frequency worldwide cannot be considered as a pure impact of digital transformation and these trends should also be excluded when projecting future claims payment patterns. The main aim of the analysis is to provide an algorithm for measuring the impact of digitalisation on claim reserves. Hypothesis testing and statistical analysis are used to answer the following research questions for this section:

RQ1: Claims handling speed (digitalisation measure) depends on the structure of the claim reserve in a company's portfolio.

RQ2: Claims handling speed (digitalisation measure) depends on the claims paid volume (business growth).

RQ3: A positive relationship exists between quick (in one year) paid claims ratio and the GDP of the Baltic countries.

The relationship between the digitalisation transformation impact on claim management for insurers and the structure of technical provision, total claims paid volume and the GDP per capita of the Baltic countries is examined. All three hypothetical propositions for research questions are accepted using regression analysis and the correlation analysis method with a 0.05 significance level for period 2011–2017. However, hypotheses are rejected for period 2011–2020.

Financial stability assessment via matrix synthesis

The study of financial stability of the Baltic non-life insurance market uses the matrix of the financial strategy of the insurance industry based on the well-known Franchon & Romanet matrix (Franchon & Romanet, 1985) that was adopted for insurers in the Italian market by Dell'Atti *et al*., (2020). In the current study, the method is adopted with indices based on the Solvency II framework: own funds, economic balance sheet positions. The statement of the total profit and loss results of insurance companies consists of two components: technical result or pure insurance business result and non-technical result or investment result that also includes capital costs. The indices used for insurance business (*IB)* and financial business (*FB*) are defined as

$$IB = \frac{GWP - ReWP - NIC - NAC}{Equity + BE - (NIC + TC)} \tag{1.1}$$

and

$$FB = \frac{\Delta EOF + \Delta BE}{Equity + BE - (NIC + TC)}, \tag{1.2}$$

where GWP – gross written premiums;

$ReWP$ – reinsurance written premiums;

NIC – net incurred claims;

NAC – net acquisition expenses;

$Equity$ – Tier 1 capital under SII;

BE and ΔBE – the best estimate reserve and changes in the best estimate reserve;

TC – total costs;

ΔEOF – changes in eligible own funds.

A mix of indices subsequently provides nine different stages depending on a positive, negative or balanced result (see Fig. 1.4).

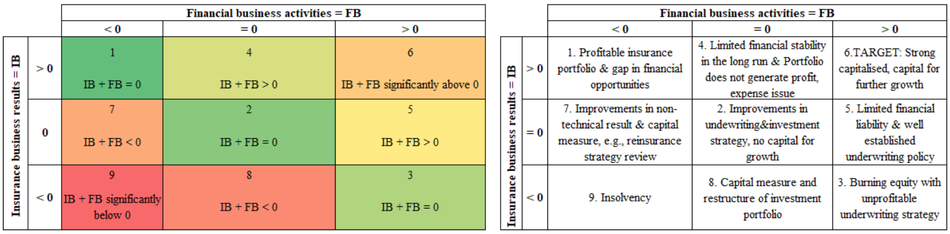

Fig. 1.4. Synthesis of the matrix evaluation.

Source: Created by the author based on Dell'Atti *et al*. (2020).

The Baltic insurance market remained at the target stage (Stage 6) in 2017–2020 (see Fig. 1.4 and Table 1.1). The current stage represents both a profitable insurance business and a surplus of capital that can be used for future growth. Such results are also demonstrated by the key performance indicators in Table 1.1.

Table 1.1

Calculated key indices for the Baltic non-life insurance market for 2017–2020, where 2016 is a comparative period based on input data (thousand EUR)

Indicator	**2017**	**2018**	**2019**	**2020**
Insurance business (*IB*)	37.81	11.25	13.77	2.92
Financial business (*FB*)	18.03	7.45	5.01	0.11
Financial development potential	8 717	30 560	26 625	118 134
IB + *FB*	**56**	**19**	**19**	**3**

Source: Calculated by the author.

Projection of market growth for inclusion in capital allocation

Financial stability is driven not only by internal indicators but also by macro-economic indicators. Insurers should plan capital requirement growth at least at a level that is in line with the overall market growth for medium-term financial stability, which is important for society, regulators and investors. The dependent variable premium forecast in period is subsequently calculated using linear regression:

$$Y_i = \alpha \cdot X_i + \beta + \varepsilon_i, \quad (1.3)$$

where Y_i – a dependent variable is premium in period i (2021; 2022; 2023);

X_i – GDP in period i;

α – intercept;

β – an unknown parameter (set as 0);

ε_i – error terms.

Over the past 20 years, the demand for insurance products in the Baltics has increased amid growing risk awareness. However, premiums as a percentage of GDP (i.e., penetration rate) and GDP have not shown any common clear trend since 2020. Econometric estimations yield the so-called *S-curve* that is used for projecting demand in many cases, the most popular model of the evolution of insurance markets by Enz (2000). The yield curve, which is a logistic function, allows income elasticity to vary as the economy matures and any deviations allow identifying factors other than GDP that drive the insurance demand. GDP is used as an explanatory variable in the proposed linear regression model that is used for projecting insurance demand and market growth.

Two models, both having a low p-value, are proposed. A suggestion for insurers is to set aside future capital, equity in line with the market growth in 2021–2023 at least 3–5 % annually and include such growth rates as the default minimum business growth assumption. Such an approach would help maintain financial stability at the same level. Different time horizons and numbers of observations are included in the models. Model one has 21 observations and 21 years of experience. However, model two has 11 observations and 11 years of experience. Use of econometric estimations yield *S-curve* is not required for the Baltic market due to statistically significant p-value, with GDP as an explanatory variable in the proposed linear regression model.

Macroeconomic and pure internal indicators should be considered in the assessment of financial stability, which is important for regulators and investors. To predict the growth of premiums as a percentage of GDP, only a one-factor regression model can be used. Goodness-of-fit tests are passed if GDP as an explanatory variable is used. An annual growth of 3–5 % is projected for 2021–2023. An insurer should recognise the same increase in percentage when planning for solvency capital requirement in the medium-term capital management plan.

Conclusions on the development, challenges and capitalisation of the Baltic non-life insurance market

The Baltic non-life insurance market has grown at a rapid pace, and the average business growth in gross written premiums in 2015–2020 is 11 %, which is higher than the Baltic GDP average growth of 5 %. The market has a huge growth potential (i.e., based on the analysis of average premiums and a comparison with other EU countries), and it is classified under the emerging market. A summary of all the gross written premiums in the Baltic market indicates a high concentration level in the market, inequal market which is assessed by the Gini concentration ratio. Half of the Baltic non-life market participants had more than 80 % of the market share in total gross written premiums. The market had been profitable in 2016–2020, with a stable, average combined ratio of 93 %. The positive gains are evident in 2020 due to the COVID-19 pandemic and low frequency rate of claims; however, business interruption losses have not heavily affected the market.

Claims reserves occupy the major position in the economic balance sheet for non-life insurers with top line of business motor third-party liability. Therefore, also the key governing subject for the public sector should be the main regulator to protect the Baltic policyholders in the unlikely event or multiple events that their insurer becomes insolvent. The high deviation of reserving ratio and reserving policy in the non-life insurance market is evident.

The market is well and heavily capitalised in the five-year horizon; the median solvency ratios in 2016 and 2020 were 155 % and 166 %, respectively. However, the Baltic solvency ratio is lower than the median ratio in the EU. Current financial stability and capital surplus should be used by the Baltic non-life insurers in order to absorb today's shocks such as inflationary pressure on claim cost and uncertainty in interest rate movements. If the required capital is split by underlying risk, then non-life risk has the highest capital need, and the top share is 57 %. Companies in the Baltic non-life insurance market use neither alternative capital management assessment methods nor internal capital models. In fact, the Baltic market does not use them even for significant risk premium and reserve risk identified by the author. An overview of the economic balance sheet implies that the investment structure of the Baltic market is more conservative than that of the EU market, resulting in a low median ROI from -0.2 % to 1.24 % in 2016–2020. ROE on an aggregate level is higher than in advanced markets. The analysis confirms that despite business growth and paid claims increase, the claims handling speed also increases. The analysis likewise indicates a strong positive correlation. Claims handling speed and the first-year claim payment pattern increased by 4 % in 2011–2017.

Next, analysis reveals that the insurance sector has started to use more digitalisation transformation tools with the growing economies in the Baltic countries. Furthermore, the findings of this study show positive digitalisation signs in claim management. The matrix synthesis of financial stability shows that the Baltic non-life insurance market in 2017–2020 is at the stage that represents both a profitable insurance business and a surplus of capital that can be used for future business growth. The regression analysis confirms that an insurer should consider the same percentage increase of GDP in planning for the solvency capital requirement in a medium-term capital management plan.

2. THEORETICAL ASPECTS OF CAPITAL MANAGEMENT OF AN INSURANCE COMPANY

The part comprises 23 pages and includes 3 tables and 20 figures.

2.1. General aspects of the solvency capital requirement under Solvency II framework

The main aim of insurance company management is to increase shareholder value and enforce a strategy that promotes the sustainable growth of a company. Recognised and well-known measures for insurers are share price, economic value, market capitalisation, combined ratio and solvency ratio. These measures consist of efficient capital management and the associated costs, which can be a large cost item depending on the risk appetite and the amount of capital required for this purpose. Alternative capital modelling is essential due to the increase in the cost of capital, low return on capital and low interest rates in the European Union (EU) until the end of 2021. The spread between the cost of capital and EU government bond yields is increasing. In the context of Solvency II framework, an insurer is solvent if a company's own funds are at least as high as the solvency capital requirement (SCR), as shown in Fig. 2.1. Eligible own funds (EOF) are calculated using the economic balance sheet in which both assets and liabilities are valued using market-consistent approaches. First, the excess of assets over liabilities is equal to the difference between assets and liabilities. Secondly, the foreseeable dividends are deducted and the restrictions on capital tiering under solvency II are taken into account. Finally, the solvency ratio is derived by dividing EOF by SCR. The capital surplus can be used for long-term corporate growth and to increase risk appetite.

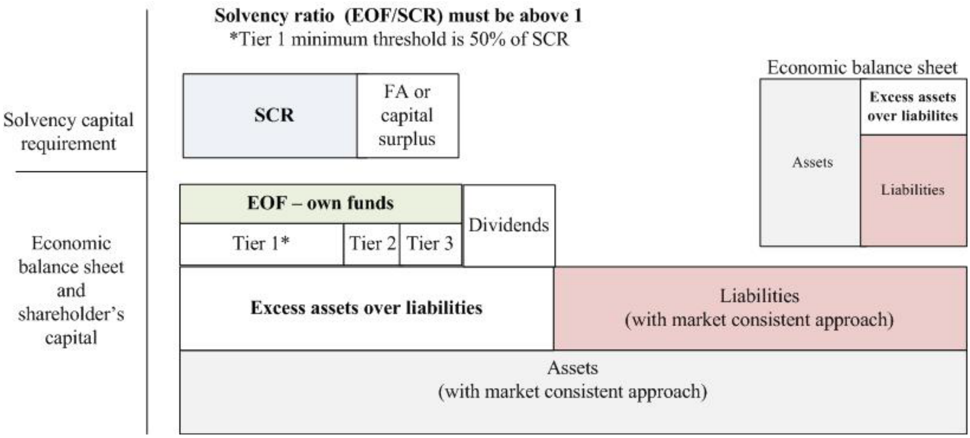

Fig. 2.1. Solvency ratio, free assets or surplus simplified calculation principle.

Source: Created by the author.

SCR equals a volume that can cover an event that occurs no more often than once in every 200 cases or with a surviving probability of at least 99.5 % for the succeeding 12 months. The general concept of modelling capital requirements is shown in Fig. 2.2. Value at risk (*VaR*) is defined as the forecasted potential maximum loss of own funds at a given confidence level over a fixed future time horizon. The measure was introduced by Markowitz (1952) and Roy (1952). The SCR is derived as the difference between VaR and the mean of the distribution (μ) for the required capital to cover risk. SCR' is protentional maximum value of required capital. VaR_α shows the threshold value, such that the probability that risk exceeds this value is α (0.05 %).

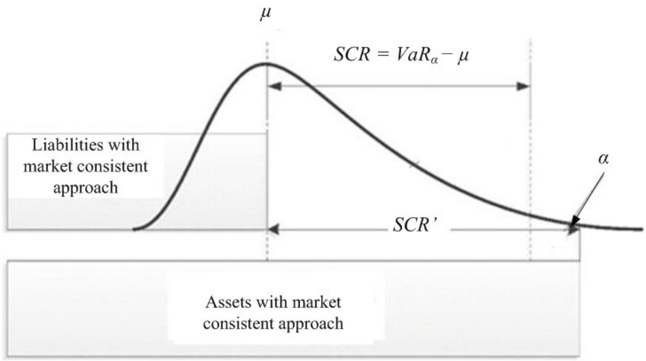

Fig. 2.2. The general concept of modelling capital requirements.
Source: Based on Sandström (2011) and Valecký (2017).

Risk-based capital or SCR covers these risks (sub-module risks), namely market risk (interest rate, equity, property, spread, currency, concentration); health underwriting risks (SLT health, catastrophic risks, non-SLT health); credit default risks; life underwriting risks (mortality, longevity, disability, lapse, expense, revision, catastrophic risks); non-life underwriting risks (premium and reserve, lapse, catastrophic risks); intangible, operational risks; an adjustment for the loss-absorbing capacity of deferred taxes; and technical provisions. Given time horizon for VaR is one year. Therefore, solvency ratio shows stability in the short term. The SCR structure and formula is presented in Fig. 2.3 and Eq. (2.1).

$$SCR = \sqrt{\sum_{ij}(Corr_{i,j} \cdot SCR_i \cdot SCR_j + SCR_{intangibles})} + SCR_{operational}\ , \quad (2.1)$$

where

$Corr_{i,j}$ – correlation matrix between i and j risk;
SCR_i – SCR for market (*mkt*) (or counterparty (*def*), life, health, non-life (*nl*));
$SCR_{intangibles}$ – SCR for intangibles;
$SCR_{operational}$ – SCR for operational risk.

CorrSCR=	SCR_{mkt}	SCR_{def}	SCR_{life}	SCR_{health}	SCR_{nl}
SCR_{mkt}	1	0.25	0.25	0.25	0.25
SCR_{def}	0.25	1	0.25	0.25	0.5
SCR_{life}	0.25	0.25	1	0.25	0
SCR_{health}	0.25	0.25	0.25	1	0
SCR_{nl}	0.25	0.5	0	0	1

Fig. 2.3. Standard formula correlation matrix.
Source: Based on European Parliament & Council of the European Union (2014).

To improve risk management and capital management through capital optimisation, the most appropriate models and methods include: a standard formula (SF) with or without company-specific parameters, a partial internal model (PIM) or a full internal model (IM). The economic capital model chosen can vary from a simple deterministic approach to an overly complex stochastic approach. If SF is used, standard capital management methods are employed. In this case, the required capital can be optimised by applying certain approaches in the insurance sector, such as diversifying risks, reducing net liabilities through reinsurance or transferring claims portfolios, synchronising the investment structure, tightening cost management and reducing the loss ratio as well as the expense ratio, strengthening product pricing and customer relationships. If an internal model is in place, an alternative capital management method is used by reassessing the main risks. Nevertheless, the standard capital optimisation method could be applied and integrated into the insurance company's decision-making process (see Fig. 2.4).

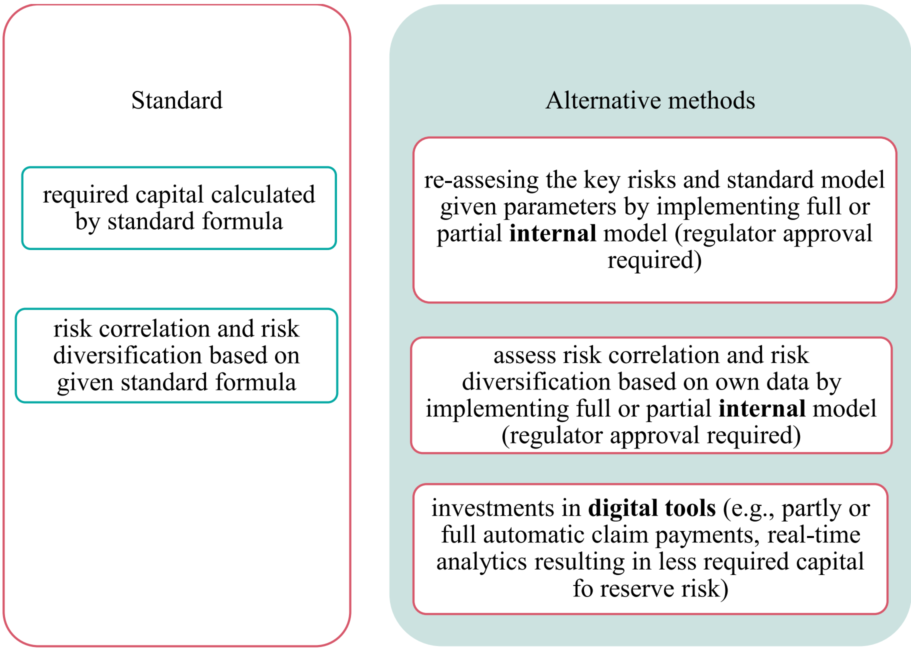

Fig. 2.4. Standard and alternative capital management methods.

Source: Created by the author.

Alternative capital management methods, e.g., internal models, are currently used in several risk-based capital systems, such as Basel III for the banking sector in the EU, Solvency II for the insurance sector in the EU, LITAC for life insurers in Canada, the LAGIC approach for insurers in Australia, the NAIC standard in the United States, C-ROSS in China and Swiss Solvency Test (SST) in Switzerland. The International Actuarial Association uses the definition of internal model as a mathematical model of an insurer’s operations to analyse its overall risk position, to quantify risks and to determine the capital needed to meet those risks (IAA, 2010).

Internal model can also be explained by an economic balance sheet in normal (pre-stress) and post-stress (after extreme events) situations (Cadoni, 2014). EIOPA adopts the definition of internal model as a statistical tool that uses available historical data, including the company's own business experience or market information, to simulate future financial outcomes (EIOPA, 2022).

The author proposes a procedure for the Baltic non-life insurers for medium-term capital planning and for decision making relating to the use of internal models and by performing harmonisation between a company and the expected market growth in line with the GDP growth, as described in Section 1.2.

2.2. Widely used methods for non-life claim reserve

Two types of technical reserve groups are classified under the Solvency II framework and international financial reporting standard, namely claim reserve and premium reserve. The principles are presented in Table 2.1.

Table 2.1

Types of reserves and underlying risk for calculating the solvency position or profit

	Own funds calculation (SII)	Profit calculation (IFRS)
Premium reserve (Underlying risk: premium risk or insurance product price insufficiency risk)	Considered based on cash flow-based techniques	Considered
Claim reserve (underlying risk: reserve risk)	Considered; theoretical techniques can differ: deterministic and approach by applying probability theory	
Risk margin	Cost of capital techniques	Not considered
Is considered as internal model for non-life claim reserve risk	Yes: Claim reserve → reserve risk model No: Premium reserve → premium risk model	No

The claim reserve is the reserve for incurred claims (reported and unreported), while the premium reserve is the reserve for non-incurred losses, which should also cover all types of costs such as investments and front-office salaries. The calculation methods differ between the international financial reporting standard and the Solvency II. In particular, the SII requires full cash flow methods. The risk underlying the claim reserve under SII is the reserve risk. Different types of techniques have been developed to assess claim reserve amounts to eventually generate reliable, best-practice results and analyse potential deviations and risks.

Deterministic approaches, are used for claim reserve calculation, including the following widely used techniques: Chain Ladder, Bornhuetter-Ferguson, Loss ratio, Average cost, Cape Cod, Fisher Lange, Generalised linear model Chain Ladder (ASTIN, 2016). The deterministic Chain ladder method is one of the key techniques that has been developed for non-life insurance. This method is used for deriving reserve estimates, and it provides a single estimate of reserves to be booked without uncertainty and potential shift assessment around the estimate. Real data sets are organised in a triangle format (e.g., incurred claims) where past development is used as a guide for estimation claims development in future. The concept method was introduced by Tarbell (1934) and it became well known in the early 1970s. The basis of the technique defined by England & Verrall (2002, pp. 446–447) is as follows:

$$\{IC_{ij}: i = 1, \dots, n;\ j = 1, \dots, n - i + 1\}, \tag{2.2}$$

$$D_{ij} = \sum_{k=1}^{j} IC_{ik}, \tag{2.3}$$

$$—\hat{\lambda}_j = \frac{\sum_{i=1}^{n-j+1} D_{ij}}{\sum_{i=1}^{n-j+1} D_{i,j-1}},\ j \in \{2, \dots, n\} \tag{2.4}$$

$$\hat{D}_{i,n-i+2} = D_{i,n-i+1}\hat{\lambda}_{n-i+2},\ i \in \{2, \dots, n\} \tag{2.5}$$

$$\hat{D}_{i,k} = \hat{D}_{i,k-1}\hat{\lambda}_k,\ \ k \in \{n - i + 3, n - i + 4, \dots, n\}, i \in \{3, \dots, n\}, \tag{2.6}$$

where

IC — incremental claims data;

i –refers to the row indicating accident year;

j – refers to the column and indicates the delay in years;

n –years, count of columns;

k – refers to the column for estimates;

D_{ij} – assumed cumulative claims;

$\hat{\lambda}_j$ –the development factors from the chain ladder technique estimates, which are then applied to the latest cumulative claims;

$D_{i,n-i+1}$ –the latest cumulative claims in each row to produce forecasts of future values of cumulative claims.

However, the calculated estimates can be reliable if historical data are sufficient, and historical uncertainty can also be assumed as future uncertainty.

2.3. Theoretical aspects of standard capital setting for reserve risk under the Solvency II framework

The author has investigated that claim reserve has a significant role and share in economic balance sheet. This leads to the importance of required capital calculation for reserve risk with adequate risk assessment and wider sensitivity analysis on impact on own funds. It cannot be done without a proper risk and stability management culture, which includes insurance products risk aggregation assessment. Reserve risk is a sub-component of SCR for non-life underwriting risk; in this study, reserve risk is defined as the risk that the current claim reserve in the economic balance sheet is insufficient to cover its run-off over a 12-month time horizon by being incapable of fulfilling obligations to its customers and settling all the reported claims. Reserve risk is calculated as the net claim reserve and a three-standard-deviation multiplication for each line of business (see Eq. (2.7)). The standard deviation for reserve risk for each line of business is set by Solvency II framework by EIOPA Article 117(1) (EIOPA: European Parliament, 2014). Reserve risk is assumed to follow a log-normal distribution. The linear correlation matrix provided by EIOPA is used for reserve risk aggregation. In this case, capital for reserve risk C_r in case of one product (line of business e) in insurer's portfolio is as follows:

$$C_r = 3 \cdot \sigma_e \cdot CBE_e, \tag{2.7}$$

where σ_e is volatility measure, standard deviation for e product reserve risk; and CBE_e is volume measure or the best estimate of the claim reserve in the economic balance sheet for the product e.

Most of the portfolios of casualty insurers consist of different lines of business. The correlation and diversification effect are then reflected by calculating a standard deviation coefficient σ_{total} for the whole portfolio as follows:

$$\sigma_{total} = \frac{1}{CBE_{total}} \cdot \sqrt{\sum_{e,p} CorrS_{(e,p)} \cdot \sigma_e \cdot \sigma_p \cdot CBE_e \cdot CBE_p)}, \tag{2.8}$$

where CBE_{total} is the sum of claim reserves best estimate after reinsurance for all the lines of business; (e, p) is the sum that covers all possible combinations of the line of business e to p; and $CorrS_{(e,p)}$ is a correlation coefficient between lines of business e and p set out by the EIOPA (EIOPA: European Parliament, 2014).

In the context of capital requirement setting in internal modelling, the interest of this study is on a one-year time horizon and, therefore, with regard to the reserving area, on a one-year claim development and its distributions. Merz & Wuthrich (2014) and Wüthrich *et al.* (2009) have presented the way how claim development for one year can be derived using the bootstrap chain ladder method. Boumezoued *et al.* (2011) and Diers (2008) have summarised the major advantages of the bootstrap methodology.

Figure 2.5 represents the main principle how reserve risk is assessed for next year's payments and outstanding claim reserve. Probability density function can vary from the presented normal distribution density function.

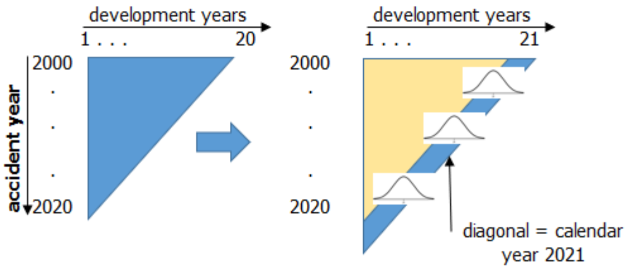

Fig. 2.5. One-year reserve risk in the Solvency II framework.

Source: Based on Boumezoued *et al.* (2011).

The main mathematical criteria in the case of standard formula application are:

- choice of value at risk with confidence level 99.5 % with one-year time horizon,
- risk aggregation by applying correlation matrix,
- log-normal distribution.

Other claim reserve distributions are not considered in standard formula.

2.4. Weakness identification of standard capital setting for reserve risk under the Solvency II framework

An extended literature review and content analysis are performed in the Doctoral Thesis to identify weaknesses in research papers for the required capital calculation of non-life reserve risk. Improvements of the internal model methodology are then proposed based on the literature review. In addition, further classification of weaknesses is conducted and a collection of possible solutions for reserve risk is provided via the use or development of an internal model under the Solvency II framework. The weaknesses are classified into the following four groups: risk aggregation, time horizon used for capital setting, model type, that is, stochastic instead of deterministic, and profitability. Risk aggregation can be interpreted as a formula that suitably works until the risk diversification calculation is made and capital is inappropriately calculated for each line of business. Time horizon can be described as a period during which capital is set in an adequate amount for a one-year horizon, but it must be assessed in a longer time horizon. Meanwhile, model type can be defined as capital in which the risk is not even appropriately calculated for each line of business. Finally, profitability can be interpreted as a state in which risk depends on average claim costs, which can vary when comparing different regions.

Table 2.2 shows the grouping of weaknesses identified by researchers. The result would allow for the avoidance of issues that have already been discussed in research papers. Fourteen of 26 papers have mentioned the dependency problem related to risk aggregation. Non-linear risks mainly exist in the real world but not in a linear manner. The analysed studies (54 %) more refer to the risk aggregation aspect – risk aggregation cannot be calculated using correlation matrix (as it is in standard formula) due to the fact that risks in reality are non-linear and create multivariate distribution not normal distribution.

Table 2.2

Proposed factors for implementation in the internal model methodology for reserve risk

Factors:	Factor 1	Factor 2	Factor 3	Factor 4
Coding group:	Risk aggregation	Time horizon used for capital holding	Model type (deterministic versus stochastic)	Profitability
Total count:	14	4	11	3

Source: Created by the author.

Large insurance groups, chief risk officers, chief executive officers and national financial supervisory authorities must consider this issue by creating and approving internal capital models. Otherwise, the consequences would be insolvency, capital insufficiency and market crisis (for large insurance groups).

The main conclusion of the academic literature review is that in the standard approach, a linear correlation matrix is used in the standard formula; however, non-linear dependency and heavily skewed loss distributions occur in the insurance sector. One solution is to adopt the copula approach for underwriting risks by partly solving the risk aggregation issue with an internal model. To solve the dependency problem, 14 papers propose the copula approach. The main copulas that are mentioned include the Gaussian copula (3 papers), Clayton copula (2 papers), Farcie-Morgenstern copula (1 paper), and non-specific copula (8 papers).

The author has determined whether the copula approach is used in research papers by Baltic researchers. The share of Baltic researchers' publications in copula field for each branch of science (defined as in Latvia) is as follows: 70 % in mathematics, 28 % in economics and entrepreneurship and 2 % in linguistics and literary studies.

2.5. Theoretical aspects of risk aggregation techniques

Investors, regulators and economists often assess a diversification impact and its benefits using a measure of dependence, such as correlation (Chollete *et al*., 2011). Thus, having an appropriate choice of measures for dependence is vital. Measures can be the traditional correlations (Spearman, Pearson) and copulas. Although the approaches individually have advantages and disadvantages, researchers have rarely compared them in the same empirical study, especially for the insurance sector. Natural catastrophes or pandemic events (or both) have occurred in previous years, thereby affecting different lines of business (i.e., property insurance, motor own damage) and resulting in a high correlation between claim developments.

The Spearman correlation is more preferred due to less sensitivity to outliers (Rousseau *et al*., 2018). Spearman's rank relationship coefficient is as a measure of the quality of a relationship between two factors (Thirumalai *et al*., 2017). It is used when the Pearson's relationship coefficient can be misdirecting, for example, claims per insurance product. In the current study, the creation of a correlation matrix and assessment of the correlation between various underlying risks and products from a real data set are performed. Correlation matrix is calculated by using Spearman's front-rank correlation (Spearman, 1904).

To obtain a multivariate distribution of an aggregate risk level considering all the lines of business, the copula approach is used. Copulas are functions that join or "couple" multivariate distribution functions to their one dimensional marginal distribution functions (Nelsen, 2006). Figure 2.6. represents a simple two-dimensional example. The main advantage of copulas comparing with the standard linear correlation concept is ability to capture non-linear relationships among the products and markets. Copulas are applied in different fields of science and engineering.

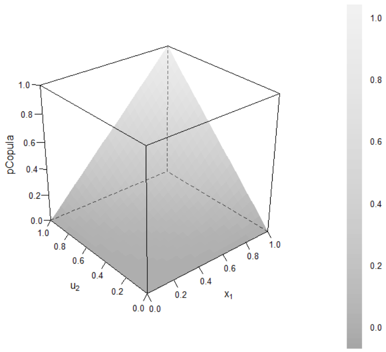

Fig. 2.6. Wireframe plot of copula.

Source: Created by the author based on Hofert *et al.* (2018).

Copulas are a well-known approach for risk aggregation and an assessment method for the banking sector, credit risk and market risk modelling. However, copulas are not yet extensively used in the insurance sector. Copulas are classified into different types, namely Gaussian or normal copula, t-copula, skew t-copula and Archimedean copulas such as Fran, Gumbel and Clayton (Demarta & McNeil, 2007; Hofert *et al.*, 2018). Copulas are certain distribution function of a random d-vector. Let us recall that the distribution function H of a d-dimensional random vector $\boldsymbol{X} = (X_1, \dots, X_d)'$ is the function defined by

$$H(\mathbf{x}) = \mathbb{P}(\boldsymbol{X} \leq \boldsymbol{x}) = \mathbb{P}(X_1 \leq \mathrm{x}_1, \dots, X_d \leq \mathrm{x}_d),\ \boldsymbol{x} = (x_1, \dots, x_d)' \in \mathbb{R}^{\mathrm{d}}. \quad (2.9)$$

The distribution function F_k of $X_k, k \in \{1, \dots, d\}$ can be recovered from the distribution function of a random d-vector H by $F_k(x_k) = H(\infty, \dots, \infty, x_k, \infty, \dots, \infty), x_k \in \mathbb{R}$. This is why $F_1, \dots F_d$ are called the *univariate margins* of H or the *marginal distribution functions* of $\boldsymbol{X}$. Sklar's theorem can be used to create copula families from the existing families of distribution function of a random d-vector. It is a central theorem of copula theory. Proof can be found in Sklar (1996), a probabilistic one in Rüschendorf (2009). For the univariate distribution function F, $ranF = \{F(x): x \in \mathbb{R}\}$ denotes the *range* of F and $F^{\leftarrow}$denotes the quantile function associated with *F*.

Conclusions on capital management with a standard capital approach

The main aim of insurance company management is to increase shareholder value and enforce a strategy that promotes the sustainable growth of a company. Recognised realisable measures for insurers include share price, economic value, market capitalisation, gross earned premiums and solvency ratio. These measures consist of efficient capital management and the associated costs, which can be a large cost position depending on the risk appetite and the amount of capital required for this purpose. The optimisation of capital is essential due to the increase in the cost of capital, the low rate of return and the low interest rates in the EU till 2021. In the Solvency II framework, an insurer is solvent if a company's own funds are at least as high as its SCR. Efficient capital management can be achieved through SCR revaluation, which is also known as internal modelling and is a method of alternative capital management. In this Thesis, the significant role of claim reserve is explored and its share in the economic balance sheet is examined. The importance of calculating the required capital for reserve risk with an appropriate risk assessment and a broader sensitivity analysis of the impact on own funds is also explored. Therefore, this leads for importance of required capital calculation for reserve risk with adequate risk assessment and wider sensitivity analysis on impact on own funds. Alternative capital management methods, e.g., internal models, are currently used in several risk-based capital systems, such as Basel III for the banking sector in the EU, Solvency II for the insurance sector in the EU, the NAIC standard in the United States and SST in Switzerland.

Any internal model within the framework of Solvency II should have these five characteristics and offer certain possibilities. First, the model follows the principles of the standard formula of the SII regulation: it incorporates market-consistent valuation techniques using the VaR measure with a confidence level of 99.5 % for a one-year horizon. Secondly, reserves and capital are properly provisioned and allocated to individual business lines to enable the observation of pure risk profiles of all portfolios. Third, accurate capital allocation should maintain a sound reputation. Fourth, a balance between accuracy and simplicity should be achieved, and the process should be neither too costly nor time-consuming. Finally, the model should avoid all the issues that have been intensively discussed in academic journals. Risk aggregation and dependency issues between reserve risk for different insurance products are the most frequently mentioned factors according to other authors' empirical research.

The results of the literature review indicate that the internal model methodology should solve the dependency problem and adopt stochastic approaches. The standard formula approach using a linear correlation matrix cannot resolve insurance sector-specific problems. According to researchers, the standard formula fits only large companies in the case of normal market conditions. Baltic non-life insurance companies are deemed to fall within the scope of small and medium-sized companies in the EU context. The Baltic market density rates from 2016 to 2020 show that the spending on insurance coverage per inhabitant is at least three times lower than in advanced insurance markets. Hypothesis testing on "how to choose the most appropriate type of copula for non-life reserve risk for different lines of business" in the context of object of the Doctoral Thesis – the Baltic non-life insurance market – is not examined by researchers.

3. PROPOSED METHODOLOGICAL APPROACH AND ITS IMPLEMENTATION FOR ALTERNATIVE CAPITAL MANAGEMENT METHODS

The part comprises 19 pages, 3 tables and includes 10 figures.

3.1. General considerations before developing an alternative capital approach and planning capital measure

Capital can be seen as a guarantee to each client that the insurer will meet all its obligations up to a certain level of probability. The customer's obligations, in turn, are claims, such as the cost of repairing motor vehicle damage to their own car or fire damage to company property. Insurance fulfils a basic social function and the regulator prescribes a minimum amount of capital that it must hold. Moreover, the insurance sector is strongly intertwined with the banking sector, as it holds a non-negligible part of the assets issued by banks, which are valued as part of the public interest assessment (Single Resolution Board, 2022). In various papers, the minimum amount of capital required is referred to as risk-adjusted capital or regulatory capital or solvency capital requirement (SCR). The capital actually held by the insurer is called economic capital or available capital. It is higher than regulatory capital and is driven by many considerations, such as protecting the company from insolvency and maintaining the rating assigned by major rating agencies (e.g., S&P) to be attractive to investors or to increase the number of customers, especially corporate customers. The company's solvency ratio (SR) is then defined as follows:

$$SR = \frac{C_a}{C_{rT}} > 1, \tag{3.1}$$

where SR is solvency ratio; C_a is economic capital or available capital; and C_{rT} is regulatory capital, the required capital for all risks.

The ratio between the capital actually held by the insurer and the regulatory capital should be greater than one. The minimum solvency ratio in the company's risk management policy can be set even higher. The available capital is provided by the insurer's investors, who demand a certain return on the capital that is higher than the level of almost risk-free return that could be obtained with government bonds. The required return depends on the level of risk. The next performance measure is the return on required capital (RORC), which should be maximised by management to achieve the highest return for a given level of risk, expressed as the required capital for all risks and annual profit. The RORC is defined as follows

$$RORC = \frac{Profit_a}{C_{rT}}, \tag{3.2}$$

where $Profit_a$ is annual profit; the aim of management is to maximise function

$$f(Profit_a, C_{rT}) = \frac{Profit_a}{C_{rT}}, \tag{3.3}$$

where $C_{rT} > 0$.

Formula (3.3) explains a well-known principle of the efficient frontier in modern portfolio theory, which was first formulated by Markowitz (Markowitz, 1952). The aim of the Thesis is to provide the detailed algorithm of the model for required capital C_{rT}, which is called an internal or a partial model under the Solvency II framework. The proposed model reflects reserve risk assessment. Claim reserving is the main process in non-life insurance companies, which:

- determines what is held on the balance sheet for claims that are not yet settled;
- affects the level of risk premium;
- influences the capital that is held to support the solvency position;
- impacts dividend distribution and its frequency and stability.

Thus, the additional amount of capital that must be held for reserve risk is crucial for both society and investors of the company. Decision-making should be based on the required capital model. It is therefore important that it is as close as possible to the risk profile. This is also mandated by the policy on auditing the use of the internal model, which requires that the same model be used for internal decision-making in board meetings and for public financial reporting. The 2008 economic recession provoked a regulatory onslaught against the use of internal models (Embrechts, 2017). The Basel committee for the Basel III regime has started to permit the restricted use of internal modelling approaches (Bank for International Settlements, 2017) for specific risk categories as an argument that internal models are non-transparent (Gillespie *et al.*, 2008). Similar discussions in the EU financial regulatory institutions have yet to transpire, but national regulators can disallow the use of an alternative model. The UK regulator has started discussions on the UK insurers' capital models that might be underestimating the risks that they encounter (Financial Times, 2019).

Alternative capital modelling also helps in the implementation of new upcoming risks that have not been implemented yet by the EIOPA, such as cybercrime, accurate natural catastrophe risk, risk arising from the process of using digital technologies, extreme inflationary pressure and spread risk for government bonds, fixed income assets due to political risk. A summary of the current aspects and considerations of how much qualifying capital a non-life insurer on the alternative calculation method (i.e., developing quantitative approach) must hold to protect its solvency is shown in Fig. 3.1.

The results of Accenture's research (2019) reveal that cyber risk could lead to additional costs amounting to EUR 4.6 trillion and a lost revenue drop could be significant in the next five years. Only 30 % of listed companies are confident of internet security. The system for the accumulation risk control of natural hazards (CRESTA, 2013) is also changing and could be different compared to the Solvency II framework. In 2021, cybersecurity authorities in the United Kingdom observed an increase in high-impact ransomware incidents against critical infrastructure organizations globally (CISA, 2022).

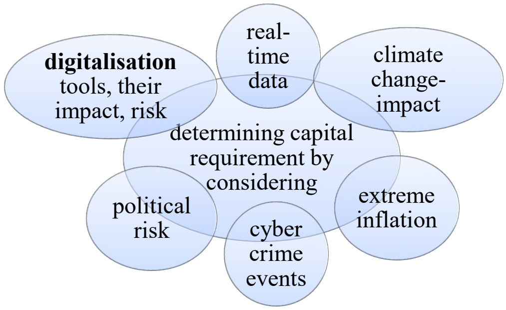

Fig. 3.1. Proposed risks for modelling required capital with an alternative capital management methods.
Source: Created by the author.

McKinsey underscores that pricing is still based on the simplified SME claim-data model published by the German insurance trade association rather on real-time tariff updates and the idea of capturing real market data that could be used for further improving the internal models (Binder *et al.*, 2022). The author believes that following recommendation is relevant also for the Baltic non-life insurance market.

3.2. Practical aspects of new internal model as alternative management method

As mentioned in the section above, alternative capital requirement for reserve risk should be calculated by using formula

$$C_{r_e} = VaR^{e}_{99.5\%} - CBE_e, \tag{3.4}$$

where $VaR^{e}_{99.5\%}$ is value at risk (VaR) at 99.5 % confidence level for line of business e; CBE_e is the best estimate of claim reserve for line of business e or VaR at 50 % confidence level, which represents fair value of liabilities in economic balance sheet.

The same principle works for aggregated reserve risk for many business lines, which is difference between value at risk at 99.5 % and the mean or the best estimate booked in economic balance sheet. Actuary, reserve risk holder should know the value at risk at certain confidence levels. In order to get multivariate distribution on an aggregate risk level taking into account all lines of business, a copula approach is used. Diversification effect can be calculated as difference between sums of all risks and aggregated risk from multivariate distribution.

Findings of literature review performed by the author showed that the risk aggregation technique with copula approach would solve dependency and capital allocation issues. It is by far the most popular copula (Fang & Madsen, 2013).

Normal copula is the most well-known copula and can be defined as follows. The distribution function of a random d-vector normal copula C^n_d is the copula derived from Sklar's theorem from the multivariate normal distribution $N_d(\mathbf{0},\boldsymbol{P})$, where $\boldsymbol{P}$ is correlation matrix of $X \sim N_d(\mathbf{0},\boldsymbol{P})$. If Φ_d denotes the distribution function of the latter, $C_d^n(\boldsymbol{u})$ is given, for any $\boldsymbol{u} \in [0,1]^d$ by

$$C_d^n(\boldsymbol{u}) = \Phi_{\boldsymbol{d}}\left(\Phi^{-1}(u_1), \dots, \Phi^{-1}(u_d)\right) = \int_{-\infty}^{\Phi^{-1}(u_d)} \dots \int_{-\infty}^{\Phi^{-1}(u_1)} \frac{\exp(-(\frac{1}{2})\boldsymbol{x}'\boldsymbol{P}^{-1}\boldsymbol{x}}{(2\pi)^{\frac{d}{2}}\sqrt{\det \boldsymbol{P}}} dx_1 \dots d_{x_d}, \quad (3.5)$$

where Φ^{-1} denotes the quantile function of $N(0,1)$ (Hofert *et al.*, 2018).

The author advises using at least two copulas and conducting copula hypothesis and goodness-of-fit tests. The normal copula and the *t*-copula were chosen because built-in goodness-of-fit tests are available in the R software.

The *t*-copula $C_{d,v}^t$ is the distribution function of a random d-vector defined by Sklar's theorem from the multivariate *t* distribution with location vector $\mathbf{0}$, correlation matrix $\boldsymbol{P}$ and $v > 0$ degree of freedom. If $t_{d,v}$ denotes the distribution function of the latter, $C_{d,v}^t(\boldsymbol{u})$ is given for any $\mathbf{u} \in [0, 1]^d$, by (Hofert *et al.*, 2018)

$$C_{d,v}^t(\boldsymbol{u}) = t_{d,v}\left({t_v}^{-1}(u_1), \dots, {t_v}^{-1}(u_d)\right) =$$

$$= \int_{-\infty}^{{t_v}^{-1}(u_d)} \dots \int_{-\infty}^{{t_v}^{-1}(u_1)} \frac{\Gamma\left(\frac{v+d}{2}\right)}{\Gamma\left(\frac{v}{2}\right)(\pi v)^{\frac{d}{2}}\sqrt{\det\boldsymbol{P}}} \left(1 + \frac{\boldsymbol{x}'\boldsymbol{P}^{-1}\boldsymbol{x}}{v}\right)^{-\frac{v+d}{2}} \mathrm{d}x_1 \dots \mathrm{d}x_d, \quad (3.6)$$

where ${t_v}^{-1}$ denotes the quantile function of the univariate Student *t* distribution; v denotes the degree of freedoms.

In case hypothesis testing shows that *t*-copula cannot be rejected, the author suggests to do further testing with the skew *t*-copula.

Copula has a major effect on the shape of the joint distribution (Li *et al*., 2015). Therefore, also impact of required capital and choice of copula should be reasonable. Li *et al.* (2015) summarised that if years of daily data are available, identifying the copula that can best model the dependence structure is relatively simple and the data offered for capital assessment is always inadequate in bank risk aggregation.

Other copulas are not used in empirical studies because goodness-of-fit tests are not built into the R software.

The author uses 2 statistical hypothesis and model selection tests for copula approach, which are available in statistical packages. The author uses hypothesis tests in order to validate various copula models. Basic graphical diagnostics can be sufficient in practice for finding risk assessment approximation. But it is not a sufficient argument of internal capital model methodology, documentation package for national regulators, and financial market authorities. Formal statistical tests, which compute *p*-values that can help as to guide the choice of the hypothesized copula family, play an important role. The author assumes this goodness-of-fit issue for adequate parametric copula family amounts formally by testing

$$\text{Ƕ}_0\colon \mathrm{C} \in \mathcal{C} \; versus \; \text{Ƕ}_1\colon \mathrm{C} \notin \mathcal{C}, \quad (3.7)$$

where Ƕ$_0$ states that the choice of the hypothesised copula family $\mathcal{C}$ cannot be rejected and Ƕ$_1$ states that the choice of the hypothesised copula family $\mathcal{C}$ can be rejected.

The first used hypothesis testing is Parametric Bootstrap (Fermanian, 2005; Genest & Rémillard, 2008; Quessy, 2005).

The second used test is cross-validation copula information criterion. Grønneberg and Hjort (2014) have defined cross-validation copula information criterion. This test leaves out and penalises copula families with too many parameters that tend to overfit. Papers (Grønneberg & Hjort, 2014; Jordanger & Tjøstheim, 2014; Karagrigoriou *et al*., 2011; McNeil *et al*., 2015) help to improve the AIC formula approach and historical development in the copula theory in a more detailed way.

Approaches and algorithm for reserve and reserve risk with internal model

The internal capital modelling team must consider the types of uncertainty errors in the model that will improve reality. Figure 3.2 shows a summary of uncertainty errors, which includes also the importance of using expert judgment during the reserving process.

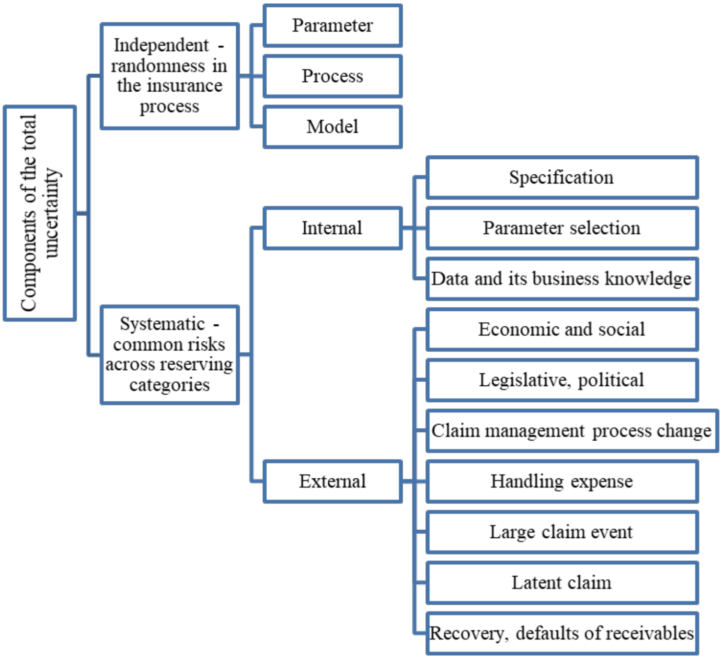

Fig. 3.2. Types of uncertainty for reserve setting and its capital requirements.

Source: Created by the author based on Hindley (2017).

Bootstrapping (Efron & Tibshirani, 1993) is a powerful and a simple simulation technique, and the methodology is based on sampling with replacement from the observed data sample to create a large number of pseudo-samples that are consistent with the underlying distribution (England & Verrall, 2002).

3.3. Performance management and validation process of alternative capital management methods

For insurers, managing volatility is critical to the efficient use of capital. Traditionally, insurers have attempted this process through diversification across lines of business, geographic exposures, or across companies in an insurance group (Kielholz, 2000). The Baltic non-life insurance market usually operates in Estonia, Latvia, and Lithuania, and it has the possibility to geographically diversify the portfolio. However, understanding the risk-adjusted cost of capital for each business activity is important for efficient capital allocation. To properly assess whether an activity adds or destroys value, capital must be allocated to individual business activities in relation to risk. An insurer can improve profitability by simply moving capital to more productive activities and reducing the capital needed to support the less productive activities (Kielholz, 2000). Management shall answer to questions "how insurers can optimize their capital structure with changes in risk profile" and "what are the sources of capital and how insurers optimize their capital structure, scenarios with underestimated and overestimated economic capital". Wilson (2015) concludes that used capital efficiency key performance indicators can be return on minimum capital required and return on actual capital (eligible own funds under Solvency II directive) to minimum capital required (MCR). By combining all observations, a fair conclusion can be derived, that is, insurers traditionally encounter a far more dynamic, complex, and constrained capital allocation decision and a static constrained optimisation problem.

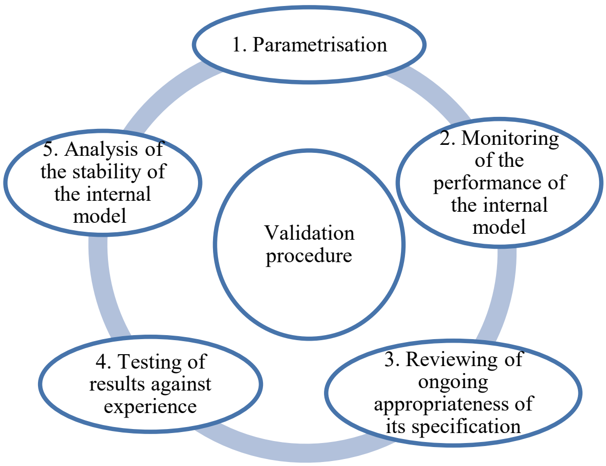

Fig. 3.3. Validation process.
Source: Created by the author based on European Parliament (2009).

The author proposes during the development of procedure to implement actuarial control cycle, which is a conceptual framework for describing the processes needed for the development and ongoing management of product. Framework via cycle should be extended and implemented in validation process of alternative capital management methods. Figure 3.3 illustrates the validation process stages.

3.4. Digitalisation as alternative capital management method for reserve risk

For all insurers (including the Baltic non-life insurers), digitalisation means more than just upgrading mobile applications and information technology systems. It also has a direct impact on the capital needed, key performance indicators and the value of the company. When digitisation tools and digital technologies are integrated and in place, alternative management methods are used by reassessing key risks. For example, automatic claims payments or faster claims settlement result in a lower claims reserve on the economic balance sheet and thus a lower capital requirement for reserving risk. The author believes that digitalisation of claims management shall be a top priority for companies by making it customer-centric. This can improve performance on key performance indicators such as loss ratio (fraud is detected), cost ratio (less manual intervention, human error) and return on solvency capital requirement (especially for reserve risk).

In this subsection, the author used a case study to examine how the required capital for reserve risk at an insurance company has changed over the last 10 years as a result of digitalisation. Required capital for reserve risk is calculated using Formula (2.7). Standard deviation of reserves for a property product based on standard capital management method, standard formula is 8 %. The key method applied is given in Formulas (2.2)–(2.6). Table 3.1 shows the results of case study.

Table 3.1

Required capital for reserve risk and required capital savings due to digitalisation, EUR million

Development factors (digitalisation stage) application scenario	Required capital for reserve risk	Digitalisation effect for 2020 claim reserve risk
Scenario 1: 2011–2014	0.34	–0.10 (–17 %)
Scenario 2: Highest – all	0.59	–0.35 (–60 %)
Real: 2017–2020	0.24	0.00

Source: Calculated by the author.

Table 3.1. shows that the required capital for reserve risk can be improved through alternative capital management methods such as digitalisation. In this case study, the required capital for a property product has been reduced in a range of EUR 0.10–0.35 million (or 17–60 %). The same process can be applied to other products to assess the effectiveness of the digitalisation tools. Investments in the digitalisation of claims management have an impact on the required capital and lead to a reduction in the required capital and the cost of capital.

Conclusions on the practical aspects of alternative approaches to capital management and practical aspects of implementation

Alternative capital modelling helps in the implementation of new upcoming risks that have not been implemented yet by the EIOPA, such as cybercrime, accurate natural catastrophe risk, risk arising from the process of using digital technologies, inflationary pressure, spread risk for government bonds, fixed income assets due to political risk. The internal capital modelling team should consider the types of uncertainty errors in the model that will improve reality. Uncertainty errors include also the importance of using expert judgment during the reserving process.

The author has described two alternative management methods for reserve risk in detail: internal model and digitalisation. Risk aggregation calculation and diversification effect splitting by products afterwards constitute an important part of the alternative model. An improper risk aggregation approach and split by products can result in wrong business decisions by stopping the underwriting for a certain product and inadequate capital planning during the budgeting process. The important procedural steps include finding an appropriate type of copula for risk modelling in the insurance sector and determining stability tests for choosing an appropriate copula model. The backtesting process is limited due to the fact that the required capital is set at a high confidence level requiring 200 years of experience. The authors advice is to apply reserve run-off experience if internal model is used as alternative capital management method. There is a great lot of control over which parts of the distributions are more strongly connected with the choice of copula. Controlling the strength of the link in the distributions tails is one issue that should be highlighted. For instance, there are copulas with this type of behaviour where liability and property losses could be associated in the extreme tails but not elsewhere in the distributions. The dependence between different insurance lines of business is mostly described by a multivariate distribution. Therefore, the author plans to apply normal copula and *t*-copula as an alternative method in model for risk assessment under the Solvency II framework for insurance internal models in simulation in next part.

An internal capital model with a copula approach can be assessed with goodness-of-fit tests – cross-validation (AIC principle), Parametric Bootstrap (method-of-moments estimation principle). Both tests are easily implemented in R software, but the calculation is computationally time consuming for a large scale of insurance data. The copula theory is in development stage (e.g., goodness of fit tests, choice of degree of freedoms), therefore, it is important to follow and set up alerts for new papers. Other copulas as skew *t*-copula are not applied due to not built-in goodness-of-fit tests in R software in empirical study.

Investments in the digitalisation of claims management have an impact on the required capital and lead to a reduction in the required capital and the cost of capital. The case study results show that the required capital for a given product has decreased by 60 % over the period 2011–2020.

4. APPLICATION OF INTERNAL MODEL TO CALCULATE NON-LIFE RESERVE RISK OF THE INSURANCE COMPANY

The part comprises 20 pages and includes 12 tables and 9 figures.

4.1. Required capital calculation algorithm and calculation results using proposed internal model

Claim reserve in economic balance sheet

Only four lines of business are described in this section in detail, namely property insurance (fire), motor third-party liability (MTPL), general third-party liability (GTPL), and credit and suretyship (C&S). The characteristics of each product are described in Table 4.1. The selected business lines are those whose losses have strong correlation and those whose losses are not correlated. For example, MTPL and GTPL drivers of severity could be wage inflation or cost of repair materials. However, credit and surety line encounter an increase in the amount of claims in the economy during the economy recession and there is no strong correlation with other line of business.

Table 4.1

General description of insurance products and lines of business

Line of business (LoB)	General description of insured events	Digitalisation impact, speed of claim settling, final claim known after	Example drivers for reserve risk, claim inflation
Property	Provides protection against loss or damage to a building damaged or destroyed by fire.	Quick reporting, medium or fast term for knowing final claim cost.	Cost of repair materials, cost of repair labour.
MTPL	Protects the interests of third parties who have suffered damage as a result of a traffic accident.	Quick reporting, long term for knowing final claim cost.	The same as Property, GTPL. Development of road infrastructure.
GTPL	Covers any loss or damage imposed to life, health or property of third parties as a result of fire, explosion, or construction collapse at a public gathering place. Also, the damage to property of entrepreneurs.	Quick reporting, long term for knowing final claim cost.	Wage inflation, court inflation, increasingly favourable for claimants.
C&S	Guarantees scheduled payments on a bond or other security in the event of a payment, issuer default by the of the bond or security.	Quick reporting, medium or fast term for knowing final claim cost.	Credit ratings, economic downturn, quality and cost of repair labour.

Source: Created by the author.

In accordance with the Chain Ladder model described in Section 2.2, input data are as follows: paid and reported claim amounts, claim accident, reporting and payment year and reserve change year when reported size of claim have changed. The author has examined cases that have an accident year in the period 2011–2020 (reserve for accident year 2011 is 0 as of end 2020, applied tail is 1, no further reserve risk, capital required and 2011 presented), which fall within the scope of further calculations, and triangles have been created from paid and reported claims data for the last ten years, and reserve development is based on the accident year and development year for four lines of business. The author has collected primary claims data sets from a Baltic insurer from the last ten years, including accident years and development years. The dataset also includes pandemic trends that have affected the economy and consumer behaviour. It is important that the data is organised by homogeneous risk groups. As can be seen in Fig. 4.1, the dataset corresponds to the needs of the Chain Ladder for the selected business sectors.

Property

Accident Year	12m	24m	36m	48m	60m	72m	84m	96m	108m	Total incurred claims
2012	3459.02	178.82	2.93	0.00	0.00	0.00	0.00	0.00	0.00	**3640.78**
2013	4593.95	64.70	320.10	0.00	0.10	0.00	0.00	0.00		**4978.86**
2014	5489.42	35.58	0.00	0.98	0.00	0.00	0.00			**5525.98**
2015	5851.31	52.57	0.15	0.30	0.00	0.00				**5904.33**
2016	6359.60	123.62	3.45	0.77	0.00					**6487.44**
2017	7546.27	162.40	3.83	9.59						**7722.09**
2018	12477.77	214.13	14.60							**12706.51**
2019	17824.33	170.33								**17994.66**
2020	16901.76									**16901.76**

MTPL

Accident Year	12m	24m	36m	48m	60m	72m	84m	96m	108m	Total incurred claims
2012	20150.38	1486.83	940.99	257.08	34.63	6.58	0.00	0.00	4.38	**22880.87**
2013	23073.71	1817.44	377.89	170.69	142.11	0.55	0.00	61.10		**25643.50**
2014	25073.35	2784.85	440.46	354.88	15.11	23.97	131.76			**28824.39**
2015	36531.68	2272.35	211.88	310.04	164.88	1.09				**39491.92**
2016	35245.13	3190.39	1066.12	264.79	113.44					**39879.87**
2017	32362.22	3640.20	804.05	179.00						**36985.47**
2018	37262.85	5790.18	359.09							**43412.12**
2019	42845.26	4293.97								**47139.23**
2020	40975.78									**40975.78**

GTPL

Accident Year	12m	24m	36m	48m	60m	72m	84m	96m	108m	Total incurred claims
2012	453.14	265.49	137.15	9.73	62.83	0.42	39.02	0.00	4.17	**971.95**
2013	759.99	406.45	54.54	6.78	3.05	8.87	0.00	4.17		**1243.85**
2014	1325.49	167.42	32.11	25.98	55.05	66.71	3.86			**1676.61**
2015	1859.26	266.00	65.34	193.30	50.28	118.58				**2552.75**
2016	1445.41	280.68	103.26	192.08	34.33					**2055.76**
2017	1556.99	477.09	209.52	105.13						**2348.72**
2018	3173.05	506.80	212.81							**3892.66**
2019	2166.21	494.20								**2660.40**
2020	2965.31									**2965.31**

C&S

Accident Year	12m	24m	36m	48m	60m	72m	84m	96m	108m	Total incurred claims
2012	1246.38	64.41	2.31	0.00	0.00	0.00	0.00	0.00	0.00	**1313.11**
2013	3738.94	426.82	37.09	14.04	1.80	0.00	0.00	0.00		**4218.70**
2014	953.28	564.90	14.25	15.69	0.00	0.30	0.00			**1548.43**
2015	535.17	361.57	16.14	13.37	4.86	0.00				**931.12**
2016	3738.04	418.96	2644.11	2.71	1.28					**6805.10**
2017	2934.99	926.60	85.73	6.45						**3953.78**
2018	3610.04	5734.85	9.38							**9354.27**
2019	3766.78	258.72								**4025.49**
2020	1157.13									**1157.13**

Fig. 4.1. Primary data set during data collection (in thousand EUR).
Source: Collected by the author.

The reserve is subsequently calculated for each line of business using the Chain Ladder model using Formulas (2.2)–(2.6) given in Section 2.2. The analysis is conducted in statistical software R 3.5 (R Core Team, 2018) and figures are produced using the package "actuar" (Dutang *et al*., 2008).

The calculation process of claims reserving is at the core of the financial and capital management of non-life insurers. It determines what is set on the balance sheet for not settled claims, affects calculated future premiums that are charged from the customer in future, and impacts the capital held to support the financial stability. The higher the reserve volume, the higher the overall risk and the higher the required capital. Table 4.2 shows the calculated claim reserve for each line of business, which is set in an economic balance sheet.

Table 4.2

General description of insurance products and lines of business (in thousand EUR).

	Property	MTPL	GTPL	C&S	Total
Reserve	574.65	8 352.98	2 859.77	1 180.26	12 967.65

Source: Calculated by the author.

Reserve volume also describes the share in the Baltic non-life insurance market. More than half of the reserves are for the MTPL line of business and then the GTPL and property lines of business. The choice of claim distribution and summary of reserves in the balance sheet constitute the crucial next step for economic capital, that is, alternative capital management.

The author of the Doctoral Thesis subsequently performs an assessment of the specific distribution with the best fit for claims of a particular line of business. The author has used R package *ChainLadder* (Gesmann, 2015) and its key functions *CDR* (calculates the standard deviation of the claim development result after one year), as well as *BootChainLadder* for real non-life data sets. The obtained one-year potential best estimate is later tested to determine whether it follows a certain distribution by using the R package MASS (Venables & Ripley, 2004).

The probability distribution that real data follow, its histograms, theoretical densities and numerical results of hypothesis tests, and Q-Q plots are presented in Fig. 4.2. Many claim distributions are possible. However, the important aspect is that the claim has a positive value; distributions such as gamma and log-normal are therefore widely used in assessments.

Log-normal distribution is applied in the case of the standard model, whereas the standard capital management method is used for required capital calculations. However, in some situations, such choice is not valid.

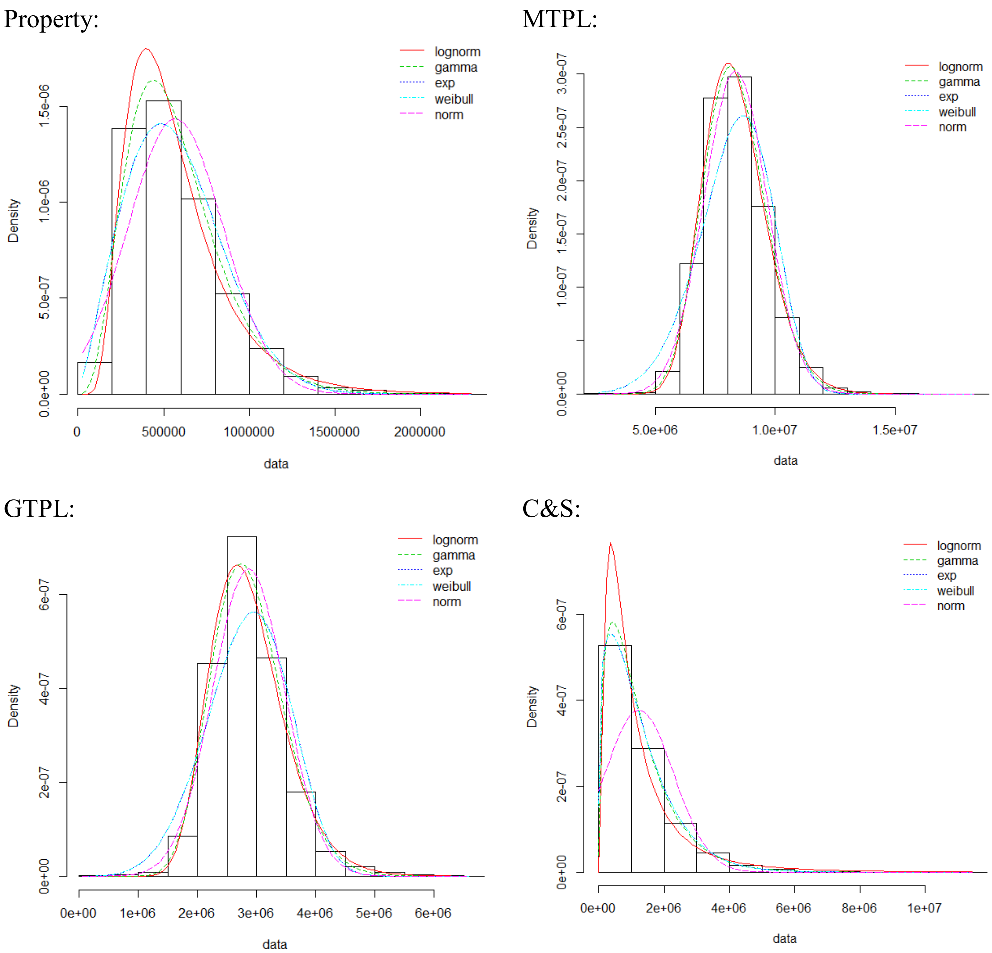

Fig. 4.2. Histogram and theoretical densities for insurance products.

Source: Created by the author.

Methods for the choice of the claim distribution for property product using the AIC test and the best fit based on the visual Q-Q plot can be seen in Table 4.3

Table 4.3

AIC information score values for distribution selection for property line of bussiness

	AIC information score	Interpreting AIC	Visual test Q-Q plot	Decision
Gamma	276 579	best fit	best fit in tail	Gamma
Weibull	277 323			
Normal	278 719			
Lognormal	276 711	second best fit	second best	
Exponentional	277 323			

Source: Calculated by the author.

Calculation of the correlation matrix between the lines of business

The primary data for each accident year are outlined in Table 4.4. The amounts represent paid claims and reported but unsettled claims. Considering the time series of nine years, the correlation matrix is derived with Pearson and Spearman method.

A significant difference between correlation matrices is apparent, resulting in a potential capital shift compared to the use of standard and alternative capital management methods.

Table 4.4

Correlation matrices between the lines of business

	Pearson correlation matrix				Spearman's rank correlation matrix			
	MTPL	C&S	GTPL	Property	MTPL	C&S	GTPL	Property
MTPL	1	0.40	0.86	0.78	1	0.28	0.90	0.93
C&S	0.40	1	0.48	0.18	0.28	1	0.10	0.18
GTPL	0.86	0.48	1	0.72	0.90	0.10	1	0.88
Property	0.78	0.18	0.72	1	0.93	0.18	0.88	1

Source: Calculated by the author.

The author proposes the application of sensitivity analysis for the correlation coefficient and the performance of a hypothesis test of the significance of the correlation coefficient to decide whether the linear relationship in the sample data is strong enough to use to model the relationship in capital allocation and insurance risk aggregation. Evidence to conclude the presence of a significant linear relationship between GTPL and MTPL, property and MTPL, and property and GTPL is sufficient.

Proposed algorithm and calculation of capital with the internal model

The algorithm of calculation proposed by the author is demonstrated in Fig. 4.3. The first step is data collection. The second step is the calculation of the reserves. Then follows the analysis of the correlation and the distribution of the reserves and, finally, the risk aggregation with copula and copula goodness of fit and model selection tests. The key elements of the data collection are as follows. First, it is necessary to determine availability. Secondly, it is necessary to determine eligibility. Thirdly, the reservation of groups and classes is determined.

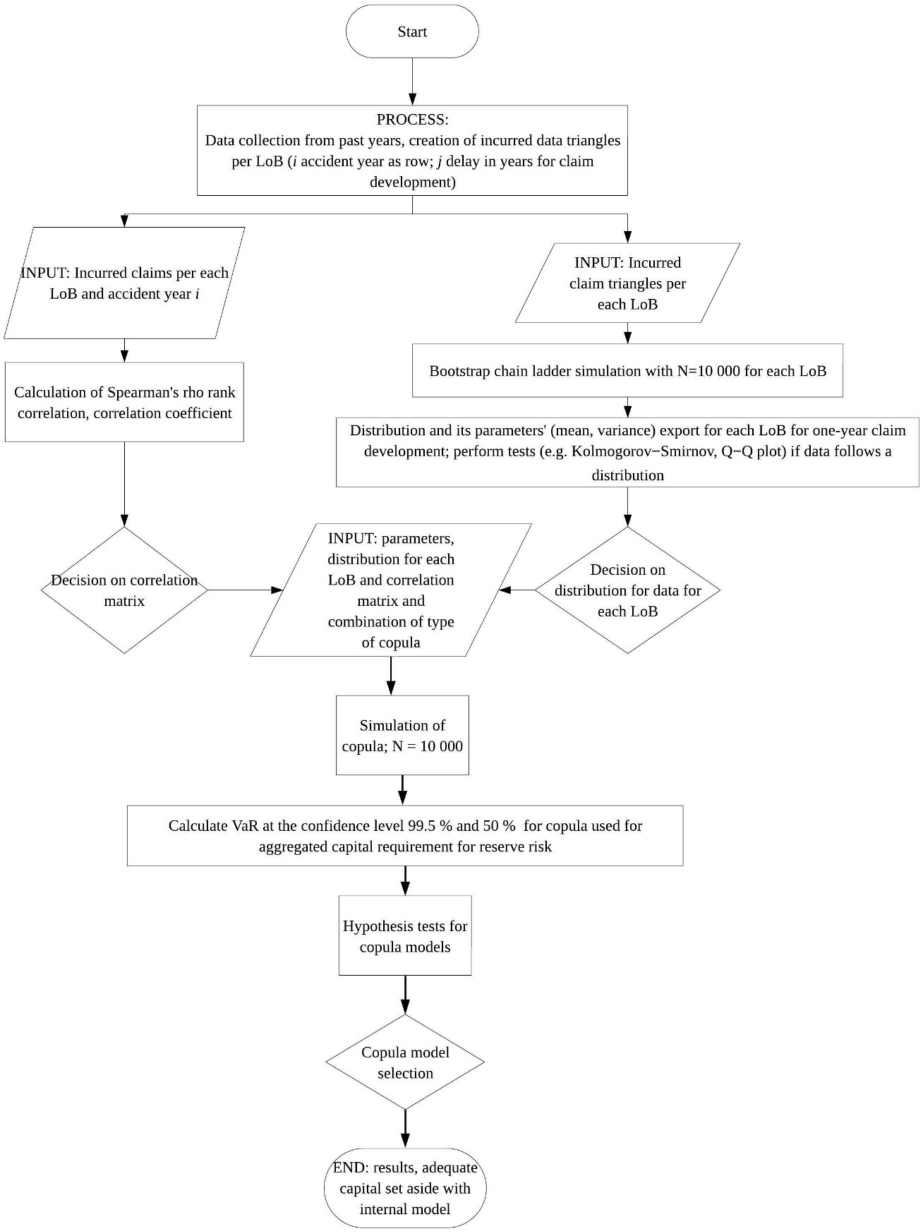

Fig. 4.3. Algorithm for alternative capital management via internal capital modelling.

Source: Created by the author.

R documentation with packages and key functions are shown in Fig. 4.4.

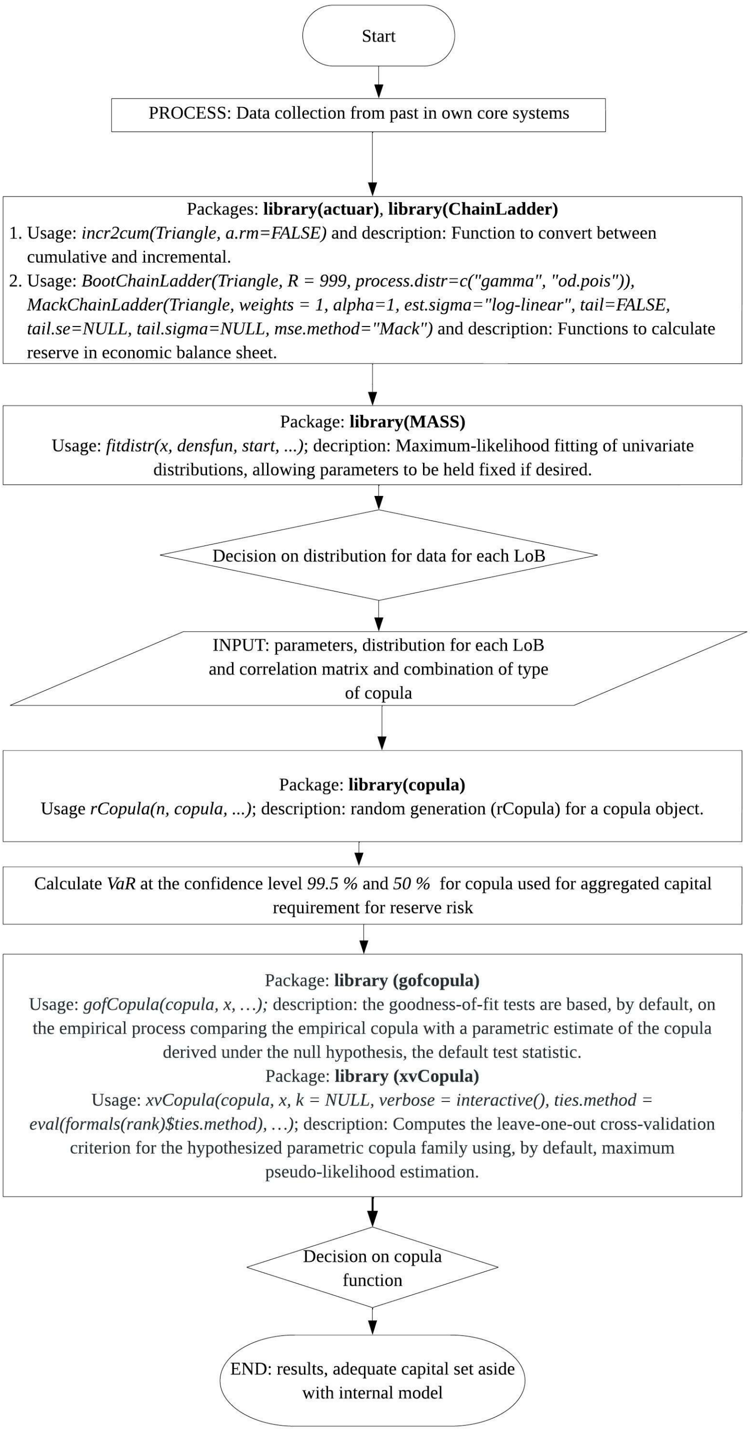

Fig. 4.4. Key functions and packages applied for the new model.
Source: Created by the author.

The input summary and decision made on distributions (previously presented in Fig. 4.2) are presented in Fig. 4.5.

	Distribution	meanlog/scale	sdlog/shape
MTPL	Log-normal	15.9257	0.1575
GTPL	Log-normal	14.8430	0.2191
C&S	Gamma	789 143.6	1.5513
Fire	Gamma	128 621.6	4.4160

Fig. 4.5. The input summary and decision made on distributions for each line of business.

Source: Created by the author.

The simulation results and required capital by applying the sample data presented in this section, are shown in Table 4.5. The reserve in the economic balance sheet is in line with the results presented in Table 4.2. *VaR* with a 99.5 % confidence level is in line with the modelling results by applying a copula model. Solvency capital requirement is calculated using two copula-based approaches, namely normal copula and *t*-copula. The model with normal copula cannot be rejected based on the hypothesis testing (see Table 4.6). The capital for reserve risk with a normal copula is EUR 8.38 million. However, the capital for reserve risk with *t*-copula is EUR 8.78 million.

Table 4.5

Results of case study on capital amount – capital requirement for combined reserve risk for insurance company regarding MTPL, property, GTPL and C&S insurance lines of business (in million EUR)

Approach	*VaR* 99.5 %	Reserve in economic balance sheet	Capital for reserve risk
Option A: Internal model using normal copula	21.38	12.97	8.39
Option B: Internal model using *t*-copula (degree of freedoms is 4)	21.76	12.97	8.78

Source: Calculated by the author.

Table 4.6

Goodness-of-fit results for various copula models

Approach	Statistic, *p*-values Parametric Bootstrap	Cross validation criterion test values	Conclusions
R package functions	*gofcopula()*	*xvcopula()*	
Option A: Normal copula	0.9985	2.81	cannot be rejected, plausible
Option B: *t*-copula (degree of freedoms is 4)	0.0005	–11521.14	reject H_0

Source: Calculated by the author.

The case study without C&S shows the required capital for the reserve risk when there are no tails, no skewed data. The simulation results and the required capital when using the sample data presented in this section are shown in Table 4.7. The capital for the reserve risk with a normal copula is EUR 3.12 million. And the capital for the reserve risk with a *t*-copula is 3.17 EUR million.

Table 4.7

Case study with no tails and no skewed data – capital requirement for aggregated reserve risk for insurance company regarding MTPL, property and GTPL (in EUR million)

Approach	*VaR* 99.5 %	Reserve in economic balance sheet	Capital for reserve risk
Option A: Internal model using normal copula	14.92	11.81	3.12
Option B: Internal model using *t*-copula (4 degrees of freedom)	14.97	11.81	3.17

Source: Calculated by the author.

The settlement period for these specific lines of business is long, and insurance loss distributions are skewed. Therefore, a tail correlation occurs. *t*-copula could be more appropriate during adding other line of business and taking into account the fact that a tail correlation can also occur for these specific lines of business. The tail correlation for a normal copula is 0. The financial crisis of 2007–2008 transpired because the tail correlations were ignored (Balla *et al.*, 2014).

The author's proposed alternative capital management method can be adjusted by adding claim distributions such as skew-*t* and clayton copula and by calculating reserve in economic balance sheet by other method. All these changes of methods would not alter the algorithm of the author's proposed alternative capital management method. Various case studies are described in the next sections.

Comparison of calculated required capital with an internal model and standard method

A standard required capital method is considered to compare capital costs and the capital management plan with a standard approach and the proposed alternative approach. In addition, the difference of capital costs can be calculated between capital setting with a standard capital management method (or standard formula) and the author's proposed alternative capital management method. Capital by a standard model under the Solvency II regime is calculated as the multiplication of reserve in the economic balance sheet and three standard deviations that represent the parametric *VaR* with a 99.5 % confidence level for log-normal distribution with a given correlation matrix. More detailed descriptions are provided in previous sections of the Doctoral Thesis. Capital (in million EUR) with standard approach can be derived, taking into account the reserve in Table 4.1, using the correlation matrix and the measures of volatility as of Table 2.2 and algorithm as presented in Eqs. (2.7) and (2.8).

$$\text{Capital}_{total} = 3 \cdot \sigma_{\text{total}} \cdot \text{BE}_{\text{total}} = 3 \times (8.35 + 0.57 + 2.88 + 1.18) \times 0.082 = 3.18. \quad (4.2.)$$

The Baltic data show different Spearman's rank correlation matrices and volatilities. Finally, if the Baltic non-life insurance Spearman's rank correlation matrix (see Table 4.2) and the Baltic volatilities measures (Appendix 5) are applied, then the required capital amount (in million EUR) is derived as follows:

$$\text{Capital}_{total} = 3 \cdot \sigma_{\text{total}} \cdot \text{BE}_{\text{total}} = 3 \times (8.35 + 0.57 + 2.88 + 1.18) \times 0.203 = 7.89. \quad (4.3)$$

The author concludes that even if a standard formula is applied and no risk re-assessment is performed, the risk level of the portfolio is higher than the EU average and there is a strong correlation, this may lead to an underestimated level of capital (see Table 4.8) with a capital shortfall of 6.33 % for Option A and 11.28 % for Option B. Potential insolvencies could also occur in the event of one large loss event (e.g., hail), multiple major loss events or growing long-term inflationary pressures. Capital shifts are calculated as difference between alternative and standard. However, if there are no tails, skewed data, then capital gains are reached with the proposed internal model.

Table 4.8

Overall summary of capital to cover reserve risk (in EUR million)

Approach	Standard	Option A: Normal copula	Option B: *t*-copula
Skewed data in portfolio, 4 products			
Capital	7.89	8.39	8.78
Capital shifts		+0.5 (+6.33 %)	+0.89 (+11.28%)
No tails, skewed data in portfolio, 3 products, without C&S			
Approach	Standard	Option A: Normal copula	Option B: *t*-copula
Capital	3.26	3.12	3.17
Capital shifts		–0.14 (–4.54 %)	–0.09 (–2.95 %)

Source: Calculated by the author.

4.2. Scenario and sensitivity analysis with proposed internal model

The scenario and sensitivity analysis shown in this section is based on the proposed algorithm. The analysis also intends to show the sensitivity of capital requirement if different risk aggregation, correlation methods, and correlation coefficients are used and to reveal the importance of the analysis of companies' individual reserve underlying distribution assumptions for lines of business; otherwise, there is a significant capital reserve risk for each line of business. The aim is to show the potential capital requirement shifts using an alternative capital requirement model or a standard model for the Baltic non-life insurance; surplus can decrease and capital costs can be increased even in a one-year period.

The author has calculated the capital requirement using a standard formula and an internal model based on the copula approach and reserve in the economic balance sheet from the Baltic non-life market over a period of 10 years. The reserve and insurance products applied in the simulation are the same as the ones in Table 4.2. All the input data parameters used in the aggregated loss distribution are presented in Table 4.9.

Table 4.9

Input parameters for scenario analysis (Scenario 1 and Scenario 2)

	MTPL	**GTPL**	**C&S**	**Property**
Underlying distribution for reserve	Log-normal			
Mean	15.93	14.86	13.96	13.25
Standard deviation used in internal model and standard model	0.09	0.11	0.17	0.1
Claim reserve, best estimate *VaR* 50 % (in million EUR)	8.35	2.88	1.18	0.57

Source: Calculated by the author.

The sensitivity of the required capital can be assessed by applying correlation matrix with strong correlation coefficients, next, by applying correlation matrix with weak correlation coefficients. The same correlation matrix is applied for standard and alternative approaches. The algorithm of calculation does not differ from the ones described in previous sections. The correlation between all the lines of business is positive, that is, 0.25 and 0.90 (Table 4.10). The scenario with a high correlation for all the products could occur in case of a high inflation rate resulting in reserve insufficiency that coincides with the reserve risk definition. The scenario could affect the Baltic non-life insurance market and the overall financial stability, taking into account the announced annual moving rate in 2021 – 16.9 % in Latvia – by the Central Statistical Bureau of Latvia (2022).

Table 4.10

Linear correlation matrix used for standard and alternative model approach

	Scenario 1 and Scenario 3					Scenario 2			
	MTPL	GTPL	C&S	Property		MTPL	GTPL	C&S	Property
MTPL	1	0.25	0.25	0.25	MTPL	1	0.9	0.9	0.9
GTPL	0.25	1	0.25	0.25	GTPL	0.9	1	0.9	0.9
C&S	0.25	0.25	1	0.25	C&S	0.9	0.9	1	0.9
Property	0.25	0.25	0.25	1	Property	0.9	0.9	0.9	1

Source: Created by the author.

The simulation results of capital shifts are shown in Table 4.11. All the input parameters that are provided in Fig. 4.5 are included in code, namely mean, standard deviation, and correlation between the lines of business.

Table 4.11

Simulation results of the scenario analysis – capital requirement for combined reserve risk for MTPL, property, GTPL, and C&S insurance line of business (in million EUR)

Approach	***VaR* 99.5 %**	**Reserve in economic balance sheet**	**Capital for reserve risk**	**Capital gain or loss versus standard,%**
Scenario 1 – low volatility measure and low correlation				
Option A: *normal copula*	15.81	12.97	2.84	+4.70
Option B: *t*-copula	15.96		2.99	–0.33
Standard approach	15.95		2.98	
Scenario 2 – low volatility measure and high correlation				
Option A: *normal copula*	16.73		3.74	+3.11
Option B: *t*-copula	16.75	12.97	3.76	+2.59
Standard approach	15.85		3.86	
Scenario 3 – high volatility measure and low correlation (assumptions in line with Section 4.1, correlation matrix in Table 4.8)				
Option A: *normal copula*	20.25		7.28	–0.39
Option B: *t*-copula	20.48	12.97	7.51	–0.62
Standard approach	19.86		6.89	
Scenario 4 – high volatility measure and high correlation: case study with primary data with input parameters in Section 4.1.				
Option A: *normal copula*	21.38		8.39	–6.07
Option B: *t*-copula	21.76	12.97	8.78	–11.00
Standard approach	20.88		7.91	
Scenario 5 – less products, low volatility measure, low correlation (no C&S, refer to Scenario 1, 3 products, no skewed data)				
Option A: *normal copula*	14.36		2.55	+5.90
Option B: *t*-copula	14.57	11.81	2.76	–1.84
Standard approach	14.52		2.71	
Scenario 6 – less products, low volatility measure, high correlation (no C&S, refer to Scenario 2, 3 products, no skewed data)				
Option A: *normal copula*	14.90		3.09	+6.36
Option B: *t*-copula	14.97	11.81	3.16	+4.24
Standard approach	15.10		3.30	

Source: Simulations performed by the author.

The simulation results of capital shifts are shown in Table 4.11. All the input parameters that are provided in Fig. 4.5 are included in code, namely mean, standard deviation, and correlation between the lines of business.

Applications have shown that the multivariate *t*-copula has been successfully used in practice because of its tail dependence property. Therefore, *t*-copula can be used as an alternative method for risk assessment under the Solvency II framework for insurance internal models. The author has focused on the properties of the introduced multivariate tail dependence coefficient for *t*-copula and examined it using the simulation technique. Finally, the author has used R version 3.5.1 and package copula by Hofert *et al*. (2018), as well as package gofCopula by Okhrin *et al*. (2021).

Copula models have large data sets. Calculation tests have the advantage of being easy to implement with R but the disadvantage of being computationally time consuming. This example shows that the most basic copula – normal copula – cannot be used as a solution to reduce the capital requirement and obtain an improved capital adequacy ratio. There is need for more complicated models for the main business lines, products – motor third-party liability insurance for private persons, commercial property insurance against fire and natural catastrophes, professional third-party liability insurance.

Conclusions on the development of a new capital alternative model and its application to non-life risk

In the scenarios used, the normal copula model is more plausible than the *t*-copula when the degrees of freedom are 4 and the standard approach for insurance companies. The required capital can be higher with the copula than with the standard approach, which leads to an insufficiency of the required capital. This situation could result in losses not being paid to customers. The case studies and scenario analysis have shown that the capital saving can be up to 6 % and insufficiency up to 11 % if an appropriate risk aggregation is used. The case studies (i.e., the scenario analysis in the authors' previous papers Zariņa *et al*., 2022; 2021) have shown that the capital saving for the Baltic non-life insurance market can reach 11–12 % if an appropriate risk aggregation is used (if the volatility measure is the EU average).

If reserve distributions are not skewed (case of GTP, property, MTPL) then capital saving for a company can be reached with proposed internal model using normal copula. The following conclusion could be valid also for non-life insurers in the Baltic non-life insurance market. The normal copula as a risk aggregation method can be used if the loss distributions are not skewed. The author did not find skewed distributions with very long tails in the primary data used in the empirical study, so the normal copula model cannot be rejected. Hypothesis testing for the skewed *t*-copula is recommended when long tails are found.

The model can be extended with other copula families and their goodness-of-fit tests. The R packages for of skew *t*-copula do not include goodness-of-fit tests when the multivariate dimension is high. This is computationally difficult, and output with new extended R packages is advisable for further research. The results of the hypothesis tests are crucial for the approval process of the internal model.

An inappropriate approach to risk aggregation and product allocation may lead to incorrect business decisions by stopping underwriting for a particular product.

The model can be extended to other products and dimensions. Then calculate the exact cost of capital for each product and its profitability. Suggested topics for further research include identifying an appropriate type of copula insurance sector reserve risk modelling when reserve risk is distributed with a narrower or broader size distribution, calculating the correlation between lines of business when claim inflation exclusion is considered and its sensitivity.

The proposed model could help achieve a sustainable solvency ratio for the Baltic non-life insurance market. Moreover, its application can improve the discipline of dividend distribution by achieving a reliable solvency ratio.

CONCLUSIONS AND PROPOSALS

In the development of this Doctoral Thesis, the author provided possibilities and solutions of an alternative management methods for non-life insurers. The author presents two alternative capital management methods for **non-life claim reserve risk** under the Solvency II framework:

1. The alternative capital method as the **proposed internal model** solves problems that have been discussed in research papers, including insufficient capital due to risk aggregation and simple deterministic approaches. The author addressed the research gap using a copula approach, stochastic reserving and hypothetical testing to determine the appropriate model for the company in the Baltic non-life insurance market. The author's proposed methodology based on a copula approach can avoid this problem and unproductive or insufficient capital.
2. Alternatively, the required capital for reserve risk can be improved by an alternative capital management method – **digitalisation**. Investing in the digitalisation of claims management has an impact on the capital required and reduces the capital requirement and cost of capital based on a case study.

The analysis of the Baltic non-life insurance market, theoretical and practical framework of an alternative and standard methods for capital management to cover non-life claim reserve risk and its implementations was examined. The theoretical findings of the basis of the papers where the Thesis was utilized and the results of the empirical results justify that the aim of the Thesis has been achieved and the stated hypothesis has been proven.

The **hypothesis** stating that "with the application of an alternative capital management methods, a more accurate assessment of capital requirement that covers reserve risk and a reduction in the cost of capital in the Baltic non-life insurance companies is possible" was tested sequentially

1) as a result of the empirical study with data obtained in insurance company, and
2) by confirming the research results with the developed alternative capital methods (internal model and digitalisation) in scientific conferences and seminars.

The author of the paper has summarised the results of the research conducted and formulated **the main conclusions** resulting from it:

1. The author conducted a market analysis, concluding that the Baltic non-life insurance market has been growing rapidly and the average growth in gross written premiums from 2015 to 2020 is 11 %, which is higher than the average growth in Baltic GDP of 5 %. The market has huge growth potential (based on the analysis of average premiums and in comparison to other EU countries) and is classified as an emerging market. A summary of all gross written premiums in the Baltic market shows a high degree of concentration in the market (i.e., an unequal market), as assessed by the Gini concentration ratio. Half of the Baltic non-life market participants had a market share of more than 80 % of total gross premiums. The market was profitable in 2016–2020, with a stable average combined ratio of 93 %. The positive gains evident in 2020 are due to the COVID-19 pandemic and the low claims frequency. Market concentration is high, and the investment portfolio is more

conservative than in the EU.

2. The results obtained from the market analysis demonstrate that the market is well and strongly capitalised in the five-year horizon. The median solvency ratios in 2016 and 2020 are 155 % and 166 %, respectively. However, the Baltic solvency ratio is lower than the median in the EU.
3. The market analysis conducted by the author reveals that the main risk and required capital for the Baltic non-life insurance market is the underwriting non-life risk. If the required capital is divided according to the underlying risk, the non-life risk has the highest capital requirement, and the highest share is 57 % in 2020.
4. The Baltic non-life insurance market overview of the reserve volume in market proves that claims reserve occupies a major position in the economic balance sheet of non-life insurers with the most important line of business being motor third-party liability. Therefore, they are the key governing subject for the public sector, including the regulator, in protecting the Baltic policyholders in the unlikely event or multiple events that their insurer becomes insolvent. The high divergence of reserving ratios and policies in the non-life insurance market is evident. This finding suggests that greater attention is needed for capital assessment in covering reserve risk. Also historically, in the insurance sector in Canada and the United States, reserve risk and too rapid and uncontrolled growth have been the main risks for insurer insolvency. These characteristics of significant reserve volume and rapid growth can also be observed in the Baltic insurance market.
5. The analysis of the market proved that companies in the Baltic non-life insurance market do not use alternative capital management valuation method as an internal capital model. The Baltic market does not even use it for the most important risk identified by the author: the premium and reserve risk.
6. The matrix synthesis of financial stability shows that the Baltic non-life insurance market in 2017–2020 is at a stage that represents both a profitable insurance business and a capital surplus, which can be used for future business growth. The regression analysis confirms that an insurer should consider the same percentage increase in GDP when planning solvency capital requirements in a medium-term capital management plan. The current financial stability and capital surplus should be used by the Baltic non-life insurers to absorb current shocks, such as inflationary pressures on claims costs and uncertainty in interest rate developments.
7. The assessment and provision of an adequate amount of capital and the ability to absorb losses even in a volatile business environment are important for financial stability management for the society and shareholders. To achieve such results, insurers should carry out a risk assessment for the required capital that is compliant with the legal requirements, i.e., the Solvency II framework in the EU.
8. The precise assessment of the risk profile is the basis of the long-term capital management plan within the Solvency II framework. The quantitative results of the proposed alternative capital management method as internal model show that capital release, additional dividend distribution and reduced cost of insurance coverage for Baltic residents can be achieved.
9. Achieving solvency and financial stability requires establishing a collaboration with

decision-making and background model operations.

10. Implementing an internal capital model that is part of an alternative capital management approach provides the opportunity of allocating capital more accurately and helps to achieve long-term capital-cost efficiency.
11. A standard capital management approach using the standard formula for non-life underwriting risk under the Solvency II framework is neither appropriate nor sufficient for the Baltic non-life insurance data for the main business lines.
12. If the solvency capital requirement is set by applying alternative capital management, the capital structure and capital tiering could be changed.
13. To evaluate an internal capital model with a copula technique, cross-validation tests (AIC principle) and Parametric Bootstrap tests (method-of-moments estimation principle) can be used for goodness-of-fit. Both tests are easy to apply in R software, but the calculations for a large set of insurance data are computationally time-consuming.
14. The basic copula family –normal – can be used for the non-life insurance market if the underlying assumptions hold and for a given data sample, unless strong correlation and volatility measures are not obtained. An improper risk aggregation approach and split by-products may lead to incorrect business decisions by stopping the underwriting for a particular product and inappropriate capital planning during the business planning process.
15. Digitalisation can be used as an alternative method of capital management. Investing in the digitalisation of claims management has an impact on capital requirements and leads to a reduction in capital requirements and the cost of capital. The author has selected a company and a product in the Baltic non-life insurance market that offers several digitalisation tools. The results show that the reserves in the economic balance sheet decreased by 45 %, and the required capital for the property product decreased by 60 % in the period of 2011 to 2020. The same procedure can be applied to other products in assessing the effectiveness of the digitalisation tools.
16. If internal model is used as an alternative capital management method, then the required capital may also be higher with the copula than with the standard approach, resulting in insufficient required capital. This situation could result in losses that are not paid to customers. The case studies and scenario analysis have shown that the capital saving can be up to 6 % and insufficiency up to 11 % when using an appropriate risk aggregation comparing with standard formula. The case studies (in the authors' previous research papers) have shown that the capital savings can reach 11–12 % (if the volatility measure is the EU average) for the Baltic non-life insurance market when using an appropriate risk aggregation.
17. The main aim of insurance company management is to increase shareholder value and enforce a strategy that promotes the sustainable growth of a company. The recognised realisable measures for insurers include share price, economic value, market capitalisation, combined ratio and solvency ratio. These measures consist of efficient capital management and its cost, which can be an important cost position depending on the risk appetite and the amount of capital required for it. Optimising capital is crucial due to the rise in the cost of capital, the low rate of return and low interest rates in the EU until 2021.

18. Efficient capital management can be carried out through SCR revaluation, which is also known as internal modelling and is a method of alternative capital management. In the Thesis, the significant role of the claim reserve is explored and its contribution to the economic balance sheet is examined. The importance of calculating the required capital for the reserve risk with an appropriate risk assessment and a more in-depth sensitivity analysis of the impact on their own funds is also explored. The Thesis, therefore, underlines the importance of calculating the required capital for the reserve risk with an appropriate risk assessment and a more in-depth sensitivity analysis of the impact on their own funds. Alternative capital management tools (e.g., internal models) are currently used in several risk-based capital systems, such as Basel III for the banking sector in the EU, Solvency II for the insurance sector in the EU, the NAIC standard in the United States and SST in Switzerland.
19. Based on literature review any internal model under Solvency II must contain five features and provide specific options. First, the model, which uses market-consistent valuation approaches and applies *VaR* with a confidence level of 99.5 % on a one-year horizon, adheres to the fundamentals of the Solvency II framework's standard regulatory formula. Secondly, reserves and capital are properly set aside and allocated to individual business lines to allow the observation of the pure risk profiles of all portfolios. Third, accurate capital allocation should maintain a good reputation. Fourth, a balance between accuracy and simplicity should be achieved, and the process should be neither too costly nor time-consuming. Finally, the model should avoid all the issues that have been intensively discussed in academic journals.
20. Risk aggregation and interdependency problems between reserve risk for different insurance products are the most frequently mentioned factors based on the empirical research of other authors. The results of the literature review suggest that the internal modelling technique should use stochastic approaches to solve the dependency problem. Copula is used by the Baltic researchers mainly in the mathematics or science fields (70 %), 28 % in economics and entrepreneurship and 2 % in linguistics and literary studies (branches of science grouped as in Latvia). Copula-case studies for modelling non-life claim reserve risk in the Baltic non-life insurance have not been investigated. There are no research papers published by the Baltic authors in internal capital modelling for reserve risk.
21. Testing the reserve risk underlying distribution should be the initial step for internal model. The standard-formula approach, which uses a linear correlation matrix, cannot solve insurance sector-specific problems.
22. According to published research papers, the standard formula only fits large companies under normal market conditions. In this study, the Baltic non-life insurance companies are assumed to be small and medium-sized enterprises in the EU context. The density of the Baltic non-life insurance market from 2016 to 2020 shows that the insurance coverage spending per inhabitant is at least three times lower than in advanced insurance markets such as Germany, Austria and Sweden. Insurance density in the Baltic shows the level of non-life insurance premium per inhabitant spent in the advanced market countries in the 1990s.

23. Hypothesis testing (i.e., how to select the most appropriate type of copula for non-life insurance risk for different lines of business) is not examined in the context of market for the object of this Thesis (i.e., the Baltic non-life insurance market).
24. In modern risk management, the use of the internal model is the best approach, as the necessary tools and methods are readily available in R software.
25. In the scenarios used, the normal copula model is more plausible than the *t*-copula when the there are 4 degrees of freedom and the standard approach for insurance company.
26. The normal copula as a risk aggregation method can be used if the loss distributions are not skewed. The author did not find skewed distributions with very long tails in the primary data used in the empirical study, so the normal copula model cannot be rejected. The use of the skew *t*-copula is recommended when long tails are identified.
27. The model can be extended with other copula families and their goodness-of-fit tests. R packages for the skew *t*-copula do not include goodness-of-fit tests when the multivariate dimension is high. It is computationally difficult, and this issue with the new extended R packages is advisable for further research. The results of the hypothesis tests are crucial in the approval process of the internal model.
28. A value-maximising Baltic non-life insurance market can be achieved by applying both standard and alternative capital optimisation methods..Capital management methods must take into account the dynamic economy and real data. This is not possible when applying the standard approach to capital requirements in the Baltic and EU markets.
29. Lower capital costs and more efficient capital management by also using internal model could give the insurer competitive advantages in the changing market landscape, as average premiums are lower. This case is particularly critical in developed countries where insurance has reached an advanced market stage and the industry has matured, with no rapid growth expected, whereas Baltic non-life insurance market has not yet reached this stage and is classified as an emerging market.
30. At the moment, the regulators of the Baltic insurance market do not restrict the use of an internal model. However, there could be changes in regulatory requirements, decisions or restrictions in the future. Baltic governments may raise different levels of corporate tax revenue if the internal model is widely used in the Baltic.

Based on the aforementioned conclusions, the author has formulated **several recommendations** to be implemented in practice.

To non-life ***insurance industry experts*** *(risk managers, actuaries, risk analysts, pricing analysts, directors leading innovation****) and management*** *of the Baltic non-life insurance companies in Latvia, Lithuania and Estonia are set out below:*

1. Invest in digitisation to reduce capital to cover reserve risk, which does not require regulatory approval. Set the digitalisation in claims management as a top priority by making the insurance company customer-oriented, applying digitalisation tools management.
2. Replace the application of the standard formula with internal models using copulas that lead to sufficient required capital. Apply a normal copula for the reserve risk, only if the correlation between the products is low and the reserve distributions are not skewed. Copula

theory is in the development stage, so it is important to follow new papers and set up appropriate warnings.
3. Perform standard formula adequacy tests for key risks when the internal model is not applied.
4. Apply the proposed internal capital model using copulas that could help ensure a stable dividend distribution policy and adequate required capital to cover the non-life claims reserve risk and proper capital costs by products. Use capital gains from the application of internal model for future financial growth and further digitalisation.
5. Promote interaction with the human intelligence that creates the model and the decision-making process that is automated when the internal model is applied.

To the ***authorities responsible in supervising the insurance industry*** *in Latvia, Lithuania, Estonia and the European Union:*

1. Approve the proposed internal model to reach optimal capital structure and financial stability for the EU insurers. Capital gains will be high for advanced markets, especially if regional diversification is used and data is less skewed, leading to stronger capitalisation and financial stability.
2. Require the performance of a full quantitative risk assessment for the most important risks (e.g., premium and claim reserve risk) and include the results in the mandatory own risk solvency assessment report. This requirement should be mandatory for insurers experiencing rapid growth and where claim reserves are the most important item on the balance sheet.
3. Obligate the testing of the internal model as an alternative capital management method and the calculation of capital shifts only if a standardised approach is used.
4. Require the description of the disclosure of dividends and the principles of dividend distribution planning and the determination of the sustainable solvency ratio for the insurance undertaking in the public and supervisory reports on solvency and financial condition.
5. Develop calculation methods to determine capital covering non-life underwriting risk taking into account climate change, a dynamic economy, real data and risk aggregation using the copula approach.

Insurance associations and statistical offices *in the Baltic states are recommended to publish market data, such as average claim size, claims frequency trends and paid triangles by product, which could help monitor and improve the adequacy of capital, reserves and premiums.*

BIBLIOGRAPHY

AB Lietuvos draudimas (2020) [online]. *Annual reports (2016-2020) and SFCR report (2016–2020)*. [accessed on 29 August 2022]. Available at: https://www.ld.lt/privatiems-klientams/apie-kompanija/finansiniai-rezultatai

Accenture (2019) [online]. *Securing the digital economy*. [accessed on 29 August 2022]. Available at: https://www.accenture.com/_acnmedia/Thought-Leadership-Assets/PDF/Accenture-Securing-the-Digital-Economy-Reinventing-the-Internet-for-Trust.pdf

ASTIN (2016) [online]. *Non-life Reserving Practices report*. [accessed on 29 August 2022]. Available at: http://www.actuaries.org.astin.dokuments

BALCIA (2020) [online]. *Annual reports (2016–2020) and SFCR report (2016–2020)*. [accessed on 29 August 2022]. Available at: https://www.balcia.com/about-company/financial-reports/

Balla, E., Ergen, I., Migueis, M. (2014). Tail dependence and indicators of systemic risk for large US depositories. *Journal of Financial Stability*, Vol. 15, pp. 195–209.

BALTA (2020) [online]. *Annual reports (2016–2020) and SFCR report (2016–2020)*. [accessed on 29 August 2022]. Available at: http://www.balta.lv/lv/par-mums/darbibas-rezultati

BAN (2020) [online]. *Annual reports (2016–2020) and SFCR report (2016–2020)*. [accessed on 29 August 2022]. Available at: http://www.ban.lv/kompanija/finansu-informacija/

Bank for International Settlements. (2017). *Basel III: Finalising post-crisis reforms*. Available at: https://www.bis.org/bcbs/publ/d424.pdf

Biard, R., Lefèvre, C., Loisel, S. (2008). Impact of correlation crises in risk theory: Asymptotics of finite-time ruin probabilities for heavy-tailed claim amounts when some independence and stationarity assumptions are relaxed. *Insurance: Mathematics and Economics*, Vol. 43, Iss.3, pp. 412–421.

Binder, S. *et al.* (2022)[online]. McKinsey&Company. *Small and medium-size commercial insurance: The big opportunity*. [accessed on 29 August 2022]. Available at: https://www.mckinsey.com/industries/financial-services/our-insights/small-and-medium-size-commercial-insurance-the-big-opportunity

Boumezoued, A. *et al.* (2011). One-year reserve risk including a tail factor: closed formula and bootstrap approaches. *eprint arXiv:1107.0164*, Cornell University, 48 p.

BTA (2020)[online]. *Annual reports (2016-2020) and SFCR report (2016–2020)*. [accessed on 29 August 2022]. Available at: https://www.bta.lv/lv/about/finansu-raditaji#-2016-gads

Buckham, D., Wahl, J., Rose, S. (2011). *Executive's guide to solvency II*. Wiley. 208 p.

Cadoni, P. (2014). *Internal Models and Solvency II*. *England*, Risk Books. 394 p.

Central Statistical Bureau of Latvia (2022) [online]. *Inflācijas kalkulators*. [accessed on 29 August 2022]. Available at: https://tools.csb.gov.lv/cpi_calculator/lv/2021M05-2022M 05/0/100

Chollete, L., de la Peña, V., Lu, C.-C. (2011). International diversification: A copula approach. *Journal of Banking & Finance*, Vol. 35, Iss. 2, pp. 403–417.

CISA. *2021 Trends Show Increased Globalized Threat of Ransomware* (2022) [online].

[accessed on 29 August 2022]. Available at:https://www.cisa.gov/uscert /sites/default/files/publications/AA22-040A_2021_Trends_Show_Increased_Globalized _Threat_of_Ransomware_508.pdf

COMPENSA (2020) [online]. *Annual reports (2016–2020) and SFCR report (2016–2020)*. [accessed on 29 August 2022]. Available at: http://www.compensa.lt/content/ Finansines_ataskaitos.html

CRESTA. *CRESTA has completely revised its worldwide zoning standard* (2013) [online]. [accessed on 29 August 2022]. Available at: https://www.cresta.org/index.php/ news?start=8

Dell'Atti, S., Sylos Labini, S., Nyenno, I. (2020). Matrix forecasting to investigate the capital efficiency of the insurance market: Case of Italy. *Journal of Governance and Regulation*, Vol. 9 Iss. 3, pp. 72–83.

Deloitte. *The influence of IFRS17 on reward KPIs – volatility of pay parameters and new opportunities* (2017) [online]. [accessed on 29 August 2022]. Available at: https://www2. deloitte.com/ content/ dam/ Deloitte/de /Documents/financial-services/ FSI_Influence-of-IFRS-POV.pdf

Demarta, S., McNeil, A. J. (2007). The t Copula and Related Copulas. *International Statistical Review*, Vol. 73, Iss. 1, pp. 111–129.

Diers, D. (2008). Stochastic re-reserving in multi-year internal models – An approach based on simulations. In *ASTIN Colloquium in Helsinki*. [accessed on 29 August 2022]. Available at: https://www.actuaries.org.uk/system/files/field/document/S4_11_Diers. pdf

Duncan, O. D., Duncan, B. (1955). A Methodological Analysis of Segregation Indexes. *American Sociological Review*, Vol. 20, Iss. 2, pp. 210–217.

Dutang, C., Goulet, V., Pigeon, M. (2008). actuar: An R Package for Actuarial Science. *Journal of Statistical Software*, Vol. 25*,* Iss*.*7, pp. 1–37.

Efron, B., Tibshirani, R. J. (1993). *An Introduction to the Bootstrap*. Springer US. 456 p.

EIOPA: European Parliament, & Council of the European Union. U. *Regulation 2015/35/EC of the European Parliament and of the Council of 10 October 2014 supplementing Directive 2009/138/EC of the European Parliament and of the Council on the taking-up and pursuit of the business of Insurance and Reinsurance (Solvency II)*. (2014) [online]. [accessed on 29 August 2022]. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri= CELEX%3 A32015R0035

EIOPA. *Financial Stability Report 2016* (2016) [online]. [accessed on 29 August 2022]. Available at: https://eiopa.europa.eu/Publications/Reports/Financial_Stability_Report _December 2016.pdf

EIOPA. *Financial Stability Report 2020* (2020a) [online]. [accessed on 29 August 2022]. Available at: https://www.eiopa.europa.eu/document-library/financial-stability-report/ eiopa-financial-stability-report-july-2020_en

EIOPA. *Insurance statistics (2020b)* [online]. [accessed on 29 August 2022]. Available at: https://eiopa.europa.eu/pages/financial-stability-and-crisis-prevention/insurance-statistics.aspx

EIOPA. *What is internal model* [online] (2022) [online]. [accessed on 29 August 2022]. Available at: https://www.eiopa.europa.eu/browse/supervisory-convergence/internal-models_en#Whatareinternalmodels?

EIOPA Statistics (2021) [online]. *Data 2016-2020*. [accessed on 29 August 2022]. Available at: https://www.eiopa.europa.eu/tools-and-data/insurance-statistics_en

Embrechts, P. (2017). A Darwinian view on internal models. *The Journal of Risk*, Vol. 20, Iss. 1, pp. 1–21.

England, P. D., Verrall, R. J. (2002). Stochastic Claims Reserving in General Insurance. *British Actuarial Journal*, Vol. 8, Iss. 3, pp. 443–518.

Enz, R. (2000). The S-Curve Relation Between Per-Capita Income and Insurance Penetration. *The Geneva Papers on Risk and Insurance - Issues and Practice*, Vol. 25, Iss. 3, pp. 396–406.

ERGO (2020) [online]. *Annual reports (2016–2020) and SFCR report (2016–2020)*. [accessed on 29 August 2022]. Available at: https://www.ergo.ee/ergo/ergo-eestis/finantstulemused

European Parliament & C. of the E. U. *Directive 2009/138/EC of the European Parliament and of the council of 25 November 2009 on the taking-up and pursuit of the business of Insurance and Reinsurance (Solvency II)* (2009) [online]. Directive 2009/138/EC of the European Parliament and of the Council of 25 November 2009 on the Taking-up and Pursuit of the Business of Insurance and Reinsurance (Solvency II). [accessed on 29 August 2022]. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri =CELEX:32009L0138&from =EN

European Parliament & Council of the European Union. (2014). *Regulation 2015/35/EC of the European Parliament and of the Council of 10 October 2014 supplementing Directive 2009/138/EC of the European Parliament and of the Council on the taking-up and pursuit of the business of Insurance and Reinsurance (Solvency II)* (2014) [online]. [accessed on 29 August 2022]. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri= CELEX%3A32015R0035

EUROSTAT. *Gross domestic product at market prices (*2021) [online]. Data Browser. [accessed on 29 August 2022]. Available at: https://ec.europa.eu/eurostat/databrowser/ view/tec00001/default/table?lang=en

Fang, Y., Madsen, L. (2013). Modified Gaussian pseudo-copula: Applications in insurance and finance. *Insurance: Mathematics and Economics*, Vol. 53, Iss. 1, pp. 292–301.

Fermanian, J.-D. (2005). Goodness-of-fit tests for copulas. *Journal of Multivariate Analysis*, Vol. 95, Iss. 1, pp.119–152.

Financial Times. *London lawyers expect new wave of Covid litigation* (2022) [online]. [accessed on 29 August 2022]. Available at: https://www.ft.com/content/1aae1e3e-a431-4549-ab32-5cded3e1cf7e

Frachon, G., Romanet, Y. (1985). *Finance de l'entreprise. Comprendre et maitriser l'evolution financiere de l'entreprise*. CLET. 246 p.

Genest, C., Rémillard, B. (2008). Validity of the Parametric Bootstrap for goodness-of-fit testing in semiparametric models. *Annales de l'Institut Henri Poincaré, Probabilités et Statistiques*, Vol. 44, Iss. 6, pp. 1096–1127.

Gesmann, M. (2015). Claim reserving and IBNR. In: A. Charpentier (Ed.), *Computational Actuarial Science with R* 1st ed., Chapman and Hall/CRC. pp. 543–577.

Gillespie, O. *et al.* (2008). *Benefits and challenges of using an internal model for Solvency II*. London: Milliman, Inc. [accessed on 29 August 2022]. Available at: http://publications.milliman.com/periodicals/st/pdfs/benefits-challenges-using-internal-sol11-01-08.pdf

Gini, C. (1912). Variabilità e Mutabilità. *Contributo Allo Studio Delle Distribuzioni e Delle Relazioni Statistiche*. [accessed on 29 August 2022]. Available at https://www.byterfly.eu/islandora/object/librib:680892#page/6/mode/2up

GJENSIDIGE (2020) [online]. *Annual reports (2016-2020) and SFCR report (2016-2020)*. [accessed on 29 August 2022]. Available at: https://www.gjensidige.lt/apie-mus/finansiniai-rezultatai

Grønneberg, S., Hjort, N. L. (2014). The Copula Information Criteria. *Scandinavian Journal of Statistics*, *41*(2), pp.436–459.

Hindley, D. (2017). *Claims Reserving in General Insurance*. Cambridge University Press. 500 p.

Hofert, M., *et al.* (2018). *Elements of Copula Modeling with R*. Springer International Publishing. 277 p.

IAA. (2010). *Note of the use of internal models for Risk and Capital Management Purposes for Insurers*. Available at: http://www.actuaries.org/cttees_solv/documents/internal_models_en.pdf

IF (2020) [online]. *Annual reports (2016–2020) and SFCR report (2016–2020)*. [accessed on 29 August 2022]. Available at: https://www.if.ee/ifist/meist/finantsandmed

INGES (2020) [online]. *Annual reports (2016–2020) and SFCR report (2016–2020)*. [accessed on 29 August 2022]. Available at: https://www.inges.ee/aruanded/2016-2/

Jordanger, L. A., Tjøstheim, D. (2014). Model selection of copulas: AIC versus a cross validation copula information criterion. *Statistics & Probability Letters*, Vol. 92, pp. 249–255.

Karagrigoriou, A., Claeskens, G., Hjort, N. L. (2011). Model Selection and Model Averaging. Psychometrika, Vol. 76, Iss. 3, pp. 507–509.

Kemaloglu, S. A., Gebizlioglu, O. L. (2009). Risk analysis under progressive type II censoring with binomial claim numbers. *Journal of Computational and Applied Mathematics*, Vol. 233, Iss. 1, pp. 61–72.

Kielholz, W. (2000). The Cost of Capital for Insurance Companies. *The Geneva Papers on Risk and Insurance –- Issues and Practice*, Vol. 25 Iss. 1, pp. 4–24.

Kleffner, A., Lee, R. (2009). An examination of property & casualty insurer solvency in Canada. *Journal of Insurance Issues*, Vol. 31, Iss. 1, pp. 52–77.

Leadbetter, D., Stodolak, P. (2009). *Why insurers fail. Inadequately pricing the promise of insurance* [online]. [accessed on 29 August 2022]. Available at: http://www.pacicc.com /publications/pages/publications/WIF Inadequately Pricing Insurance.pdf

Li, J., Zhu, X. *et al.* (2015). On the aggregation of credit, market and operational risks. *Review of Quantitative Finance and Accounting*, Vol. 44, Iss. 1, pp. 161–189.

Markowitz, H. (1952). Portfolio Selection. *The Journal of Finance*, Vol. 7, Iss. 1, pp. 77–91.

Massey, R. *et al.* (2001). *Insurance Company Failure*. Working Party. 65 p.

McNeil, A. J., Frey, R., Embrechts, P. (2015). *Quantitative risk management: Concepts, techniques and tools*. Princeton, NJ: Princeton University Press. 720 p.

Merz, M., Wuthrich, M. V. (2014). Claims Run-Off Uncertainty: The Full Picture. *SSRN Electronic Journal*. pp. 14–69.

Nelsen, R. B. (2006). *Introduction. In An Introduction to Copulas.* Springer New York. pp. 1–5.

OECD Global Insurance Statistics. (2020) [online]. *OECD Global Insurance Statistics*.

[accessed on 29 August 2022]. Available at: https://www.oecd.org/daf/fin/insurance/ Global-Insurance-Market-Trends-2020.pdf

Okhrin, O., Trimborn, S., Waltz, M. (2021). gofCopula: Goodness-of-Fit Tests for Copulae. *The R Journal*, Vol. 13, Iss. 1, pp. 467–498.

Quessy, J.-F. (2005). *Méthodologie et application des copules: tests d'adéquation, tests d'indépendance, et bornes sur la valeur-à-risque.* Doctor theses. Universite LAVAL, QUEBEC. 239 p.

R Core Team (2018) [online]. R: A Language and Environment for Statistical Computing. *R Foundation for Statistical Computing*. [accessed on 29 August 2022]. Available at: https://www.r-project.org

Rousseau, R., Egghe, L., Guns, R. (2018). *Statistics*. In *Becoming Metric-Wise.* Elsevier. pp. 67–97.

Roy, A. D. (1952). Safety First and the Holding of Assets. *Econometrica*, Vol. 20, Iss. 3, pp. 431–450.

Rüschendorf, L. (2009). On the distributional transform, Sklar's theorem, and the empirical copula process. *Journal of Statistical Planning and Inference*, Vol. 139, Iss.11, pp. 3921–3927.

SALVA (2020) [online]. *Annual reports (2016–2020) and SFCR report (2016–2020)*. [accessed on 29 August 2022]. Available at: https://www.salva.ee/et/salvast/ majandustulemused

Sandström, A. (2011). *Handbook of Solvency for Actuaries and Risk Managers*. Boca Raton: CRC Press. 1113 p.

SEESAM (2019) [online]. *Annual reports (2016–2018) and SFCR report (2016–2018)*. [accessed on 29 August 2022]. Available at: https://www.seesam.ee/en/about-seesam/financial-results/

Single Resolution Board (SRB). *The public interest assessment and bank-insurance contagion*. (2022) [online]. [accessed on 29 August 2022]. Available at: https://www.srb.europa.eu/ en/content/public-interest-assessment-and-bank-insurance-contagion

Sklar, A. (1996). *Random variables, distribution functions, and copulas---a personal look backward and forward.* Vol. 28, pp. 1–14. [accessed on 29 August 2022]. Available at: https://doi.org/10.1214/lnms/1215452606

Spearman, C. (1904). The Proof and Measurement of Association between Two Things. *The American Journal of Psychology*, Vol. 15, Iss. 1, 72 p.

SWEDBANK (2020) [online]. *Annual reports (2016–2020) and SFCR report (2016–2020)*. [accessed on 29 August 2022]. Available at: https://www.swedbank.ee/about/ about/reports/annual/lifeins?language=ENG

Tarbell, T. (1934). Incurred but not reported claim reserves. *Proceedings of the Casualty Actuarial Society*, *20*, pp. 84–89.

Thirumalai, C., Chandhini, S. A., Vaishnavi, M. (2017). Analysing the concrete compressive strength using Pearson and Spearman. *2017 International Conference of Electronics, Communication and Aerospace Technology (ICECA)*, pp. 215–218. [accessed on 29 August 2022]. Available at: https://doi.org/10.1109/ICECA.2017. 8212799

Valecký, J. (2017). Calculation of Solvency Capital Requirements for Non-life Underwriting Risk Using Generalized Linear Models. *Prague Economic Papers*, *26*(4), pp. 450–466.

Venables, W. N., Ripley, B. D. (2004). *Statistical Analysis of Financial Data in S-Plus*. Springer-Verlag. 455 p.

Wilson, T. C. (2015). Corporate Strategy and Capital Allocation. In: *Value and Capital Management: A Handbook for the Finance and Risk Functions of Financial Institutions* John Wiley & Sons Ltd, pp. 263–284.

Wüthrich, M. V., Merz, M., Lysenko, N. (2009). Uncertainty of the claims development result in the chain ladder method. *Scandinavian Actuarial Journal*, *2009*(1), pp. 63–84.

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