RIGA TECHNICAL UNIVERSITY

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

Doctoral Thesis

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RIGA TECHNICAL UNIVERSITY
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Doctoral Thesis

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ANOTĀCIJA

Promocijas darbs “Kapitāla pārvaldības alternatīvo metožu izmantošanas iespējas un risinājumi apdrošināšanas sabiedrībās” ir uzrakstīts angļu valodā, un tas ietver ievadu, četras daļas, secinājumus un priekšlikumus, bibliogrāfisko sarakstu un pielikumus. Promocijas darbs ir veltīts kapitāla un riska pārvaldībai nedzīvības apdrošināšanas tirgū, lai nodrošinātu finansiālo stabilitāti un efektīvu kapitāla pārvaldību. Tas tiek sasniegts, ja nepieciešamais kapitāls ir aprēķināts tiek pietiekams, lai nodrošinātu apdrošināšanas sabiedrības ilgtspējīgu izaugsmi. Darba mērķis ir izstrādāt alternatīvas kapitāla pārvaldības metodes un piedāvāt iekšējā modeļa algoritmu, ņemot vērā vienas apdrošināšanas sabiedrības, kura darbojas Baltijas nedzīvības apdrošināšanas tirgū, datu īpašības un zaudējumu sadalījuma funkcijas. Tas, kā darbojas izstrādātais iekšējais modelis, kas aprēķina nepieciešamo kapitālu nedzīvības atlīdzību rezerves riska segšanai Maksātspējas II režīmā, parādīts, izmantojot vienas konkrētas Baltijas nedzīvības apdrošināšanas sabiedrības datus.

Promocijas darba pirmajā daļā tiek pētīts un analizēts Baltijas nedzīvības apdrošināšanas tirgus, kurā ietilpst promocijas darba objekts – apdrošināšanas sabiedrība. Daļā ir analizēts Baltijas nedzīvības apdrošināšanas sabiedrību tirgus riska profils, maksātspējas stāvoklis, kapitāla struktūra un galvenie finanšu darbības rādītāji. Ir izstrādāts finanšu stabilitātes novērtējums ar matricas sintēzi un parādīts, kā izmērīt digitalizācijas ietekmi atlīdzību izmaksāšanas ātrumam un tā izmaiņas digitalizācijas rezultātā Baltijas nedzīvības apdrošināšanas tirgū. Noslēgumā tiek piedāvāts modelis, kā prognozēt tirgus izaugsmi un nepieciešamā kapitāla pieaugumu.

Otrajā daļā tiek pētīti teorētiskie aspekti standarta un alternatīvās kapitāla pārvaldības metodēm. Daļa ietver vispārīgus jēdzienus, pētnieku identificētos trūkumus un to iespējamos risinājumus standarta kapitāla pārvaldības metodēs saskaņā ar Maksātspējas II režīmu. Ir iekļautas visbiežāk izmantotās aprēķina metodes par atlīdzību rezervēm, rezerves risku un risku agregāciju.

Trešajā daļā ir aprakstītas un piedāvātas divas alternatīvas kapitāla pārvaldības metodes: iekšējais modelis, kas veidots ar kopulu izmantošanu, un digitalizācija. Ir aprakstīts iekšējā modeļa teorētiskais pamatojums un testi, kurus var pielietot kopulu atbilstības pārbaudei. Tiek veikta arī gadījuma analīze, kā digitalizācija ietekmē rezerves riskam nepieciešamo kapitālu.

Ceturtajā daļā ir iekšējā modeļa aprobācija un darbības pārbaude, izmantojot vienas konkrētas sabiedrības datus, jo modeļa īstenošanai ir nepieciešami sensitīvi dati. Ir salīdzinātas aprēķinātās kapitāla prasības nedzīvības atlīdzību rezerves riska segšanai Maksātspējas II režīma ietvaros ar iekšējo modeli un standarta pieeju dažādu scenāriju gadījumā.

Promocijas darbs ir uzrakstīts angļu valodā. Darba apjoms ir 170 lapas, ieskaitot pielikumus. Darbā ir 68 attēli, 28 tabulas, 10 pielikumi. Tajā ir ievads, četras daļas, secinājumi un priekšlikumi, deviņi pielikumi un bibliogrāfiskais saraksts ar 194 literatūras avotiem.

Atslēgvārdi: kapitāla pārvaldība, finanšu stabilitāte, nedzīvības apdrošināšana, atlīdzību rezerve, rezerves risks, kapitāla pārvaldības alternatīvā metode, digitalizācija, iekšējais kapitāla modelis, kopula.

ANNOTATION

The Doctoral Thesis “Possibilities and solutions for the application of capital management alternative methods in insurance companies” is written in English and consists of an introduction, four parts, conclusions and proposals, a bibliography and appendices. Thesis is dedicated to the field of capital and risk management in non-life insurance that ensure financial stability and efficient capital management. When the necessary capital is determined to be sufficient to ensure the insurance company's sustainable expansion, this is achieved. The aim of this 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. The internal model developed to determine the amount of capital required to cover non-life claim reserve risk under the Solvency II framework is demonstrated using data from a Baltic non-life insurance company.

Part 1 examines and analyses the Baltic non-life insurance market where the object insurance company of the Thesis is a part of. 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 proposes two alternative capital management methods: an internal model using copulas and digitalisation. There is theoretical basis for internal model and described formulas used for copula fitting tests. 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, nine 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.

LIST OF MAIN ABBREVIATIONS

EIOPA	European Insurance and Occupational Pensions Authority which is part of European System of Financial Supervision
Baltic	Represents Latvia, Lithuania and Estonia countries
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	The 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 (LoB), 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

CONTENT

INTRODUCTION

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, 2014b). 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 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 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 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. It should be noted that the Baltic non-life insurance companies are considered small and medium-sized enterprises in the EU context.

The author of this Doctoral Thesis provides development of alternative capital management methods and proposes an algorithm of internal model that takes into account the data specifics and loss distribution functions of a company that is 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 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 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 cover reserve risk and a reduction in the cost of capital in Baltic non-life insurance companies is possible.

The aim of this 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 to 116, 120 to 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. The software R and its packages of published papers are used for the choice of copula by performing available goodness-of-fit tests.
7. In the fourth part, 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 first part 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 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 Baltic countries researchers: *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.

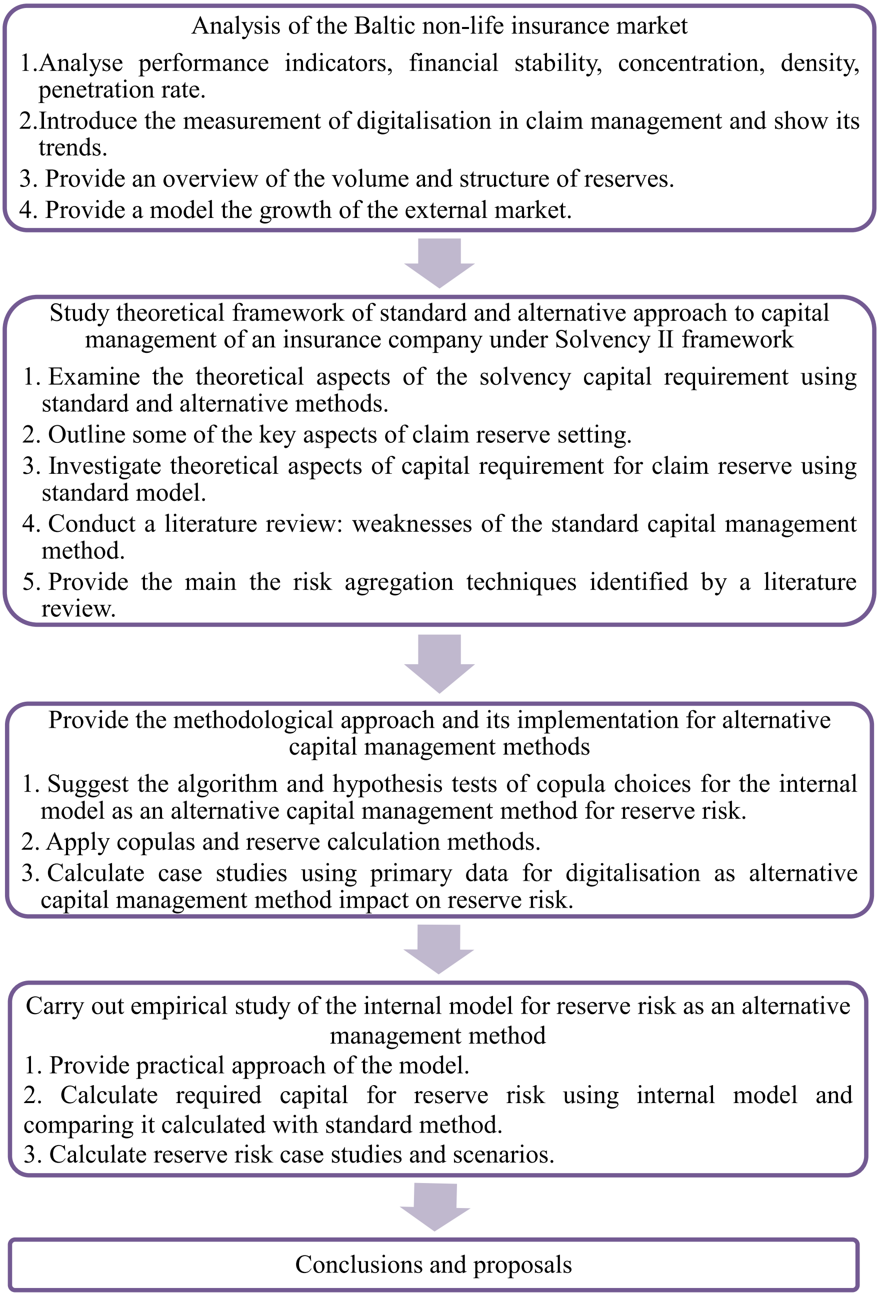


Fig. 1. Research design.

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 measure 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 measure 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 a copulas that takes 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 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 Publication

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, 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. No: *International Scientific Conference „Contemporary Issues in Business, Management and Education"*, Lithuania, Vilnius, 9th-10th 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. No: 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, 29th -30th 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. Paper: Improved Insurer's Capital Adequacy of reserve risk using copula approach and hypothesis tests. 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 "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 within the study course RTU FEEM "Entrepreneurship

and Business Planning” and programme in RTU, “Financial Engeneering”, programme in Vilnius University, “Financial and Actuarial Mathematics”, programme in the University of Tartu, “Actuarial and Financial Engineering” and in the guest lectures on entrepreneurship organized by RTU FEEM in various universities. Also, Thesis can be used in lectures by European national actuaries association.

The volume and content of Doctoral Thesis

The Thesis consists of an introduction, four parts, conclusions and proposals, a bibliographic list and nine appendices.

Part 1 examines and analyses the Baltic non-life insurance market where the object insurance company of the Thesis is a part of. 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, 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, nine appendices and 194 references have been used.

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

1.1. Analysis of Baltic non-life insurance market development

In 2020, the market shares of the life insurance business and the 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 population for the analysis up to 2019 includes 13 non-life insurance companies in Estonia, Latvia and Lithuania (12 in 2020). In 2020, five companies are registered in Estonia, four in Latvia and three in Lithuania. The Baltic insurance companies are also owned by foreign insurance markets outside the Baltic, such as the Polish, German, Finnish, Norwegian, Swedish and Austrian markets. More than half of the companies (seven out of 12) require capital to also operate through branches in Latvia, Lithuania and Estonia. Therefore, the development of the Baltic non-life insurance market is examined. The development of the Baltic non-life insurance market has been investigated since the implementation of the Solvency II framework in 2016 in the EU. A risk-based capital framework has been in force for more than six years. Companies around the world have invested significant human resources in this framework, but the preparatory work was done several years earlier. In the Thesis, data and other relevant information from public reports (i.e., solvency and financial condition reports and financial annual reports) are gathered to calculate and compare the different ratios and aspects of Baltic and European Union (EU) companies. Secondary data and used abbreviations of companies' legal names can be found in Appendix 1. Moreover, 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).

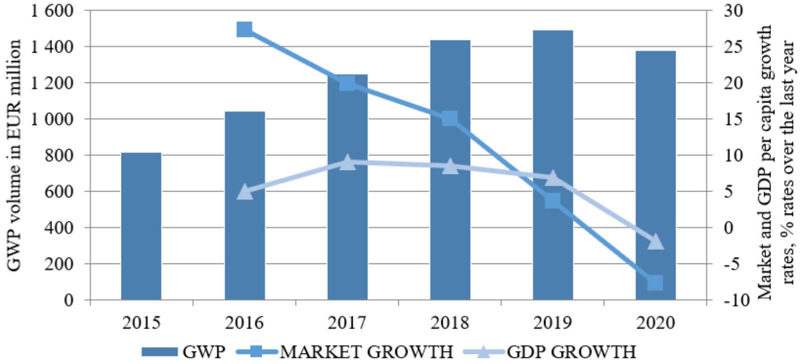


Fig. 1.1. Baltic non-life insurance market volume of business (in EUR million), market and economic growth rates (% rates over the previous year) in 2016-2020.

Source: Calculations by the author based on 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 Baltic GDP of 5%. In the pandemic year 2020, a decrease in demand and a potential decrease in the average premium can be observed. 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. The analysis of merger and acquisition (M&A) transactions and restructurings shows that the Baltic insurance market is also interesting for foreign direct investors. Four M&A transactions have taken place since 2016. Fig. 1.2 shows a comparison of density in the Baltics, including Poland, with some advanced market countries such as Austria, Germany and Sweden. These advanced insurance market countries were selected because the majority of non-life insurance companies belong to large insurance groups registered in these countries. The insurance density in the Baltic shows the level of non-life insurance premiums per inhabitant spent in the advanced market countries in the 1990s (CEA & COMITÉ EUROPÉEN DES ASSURANCES, 2001).The average total premium per inhabitant has increased by more than 10% annually in the Baltic. Insurance density in Estonia remains the highest in the Baltic. Low insurance density means low average premium and less advanced insurance coverage.

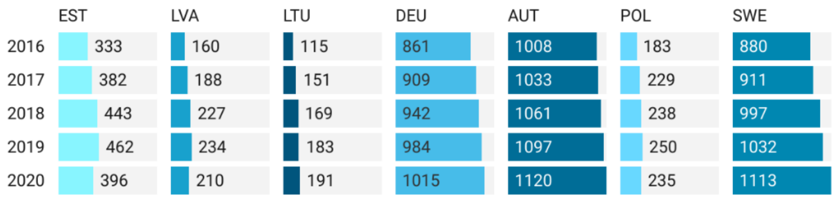


Fig. 1.2. Non-life insurance density rates in the Baltic and in the most foreign-owned countries in 2016-2020 (in EUR).

Source: Author's calculation based on premium volume EIOPA Statistics (2021), and population OECD Global Insurance Statistics (2020).

A summary of all gross premiums written in the Baltic market indicates a high degree of concentration in the market, on an equal market which is assessed by the Gini coefficient of concentration (see Fig.1.3). The Gini coefficient was proposed by Gini (1912). Half of the Baltic non-life market participants had a total market share of more than 80% of total gross premiums. The total market share per company in the market varies from 0.4% to 18.4%, while 8.3% indicates perfect equality in the market. The dissimilarity index is the most commonly used measure of segregation, defined by Duncan & Duncan (1955). It has been stable over the period 2016-2020 (see Fig. 1.3). The low volatility of the index is due to mergers and acquisitions (i.e. splitting off one company, splitting into two companies, merging two companies into one twice). The index is expected to remain stable. Overall, both measures of segregation and inequality signal low premiums and strong competition between market leaders. This trend is particularly evident in 2020, when the decline in the premium due to intense competition and the pandemic is higher than the decline in GDP at market prices (see Fig. 1.3).

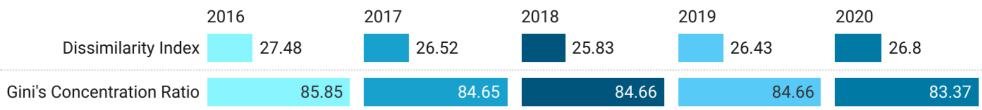


Fig. 1.3. Baltic non-life insurance market competition trends with dissimilarity and Gini indices in 2016-2020.

Source: Author's calculation based on data from SFCR and annual financial reports, 2016–2020: (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).

The penetration rate indicates the level of development of the insurance sector in a country and reflects the economic prosperity of the country. Insurance penetration refers to the total volume of premiums in relation to GDP per capita. Countries with the largest foreign investors and shareholders are also included in the comparison. In mature, advanced insurance markets such as Sweden, Germany and Austria, rates continue to rise. In Estonia, Latvia and Poland, on the other hand, rates have fallen and in Lithuania they have risen slightly (see Fig. 1.4). The Lithuanian non-life insurance market has the greatest growth potential, as uninsured rural areas and the urban poor could be included in insurance coverage. It also has GDP growth factors that differ from those in Latvia and Estonia.

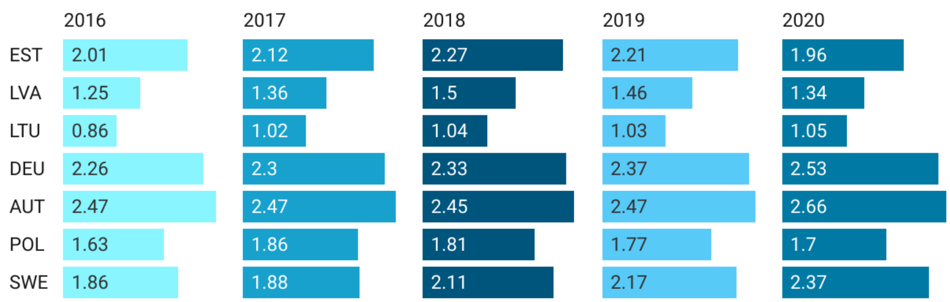


Fig. 1.4. Insurance penetration rates (i.e., the premiums as a ratio of the gross domestic product per capita) in the Baltic and in top foreign shareholders' countries in 2016-2020.

Source: Author's calculation based on data from EIOPA 2016–2020 (EIOPA, 2020b), and GDP at market prices from Eurostat, 2016–2020 prices (EUROSTAT, 2021).

The Baltic non-life insurance market was profitable during 2016-2020 with an average combined ratio of 93%. Performance indicator results have improved significantly over the last four years, which can be explained by the average increase in premiums rather than the cost of labour and services. Key performance indicators show improvements and more profitable business portfolios, as shown in Fig. 1.5. Losses and costs due to claims in relation to earned premiums - also known as the combined ratio - have decreased over the last four years. The positive increase in 2020 is due to the pandemic COVID -19 and the low claims frequency as well as low claims inflation. In addition, business interruption claims have not affected the market very much. The development of the expense ratio in Fig. 1.5 shows that the Baltic non-life insurance market has also improved its efficiency in terms of costs. Costs have increased less than business growth. This leads to a higher level of production and profitable growth of the market, as well as precautionary measures to reduce or stabilise the average level of the insurance premium.

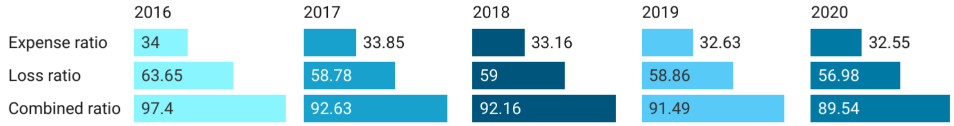


Fig. 1.5. Baltic non-life insurance market's key performance ratios (%) for in 2016-2020.

Source: Calculations carried out by the author based on EIOPA non-life insurance statistics by countries, and companies' annual reports 2016-2020 (EIOPA Statistics, 2021).

Some commercial property insurance policies in the EU include coverage for business interruption losses, which covers part of the losses incurred by the pandemic COVID -19 when businesses had to close. The Organisation for Economic Cooperation and Development (OECD) and the Financial Times have estimated large losses in Germany, France and Italy (OECD, 2021) and a new wave of litigation related to the COVID -19 pandemic (Financial Times, 2022). However, such coverage is excluded in the Baltics and the combined ratio has improved due to lower expenditure on travel, fewer accidents on the road and insurance specifics where insurance income is recorded as a pro rata amount of premiums paid in advance (earned premium). The key performance indicators (loss, cost, combined ratio) of the Baltic non-life insurance market by country are shown in Fig. 1.6. As shown in Fig. 1.6, the loss ratio is subject to only minor fluctuations during the reporting period. Therefore, the main fluctuations for the financial results are also due to the low combined ratios of the companies registered in Estonia.

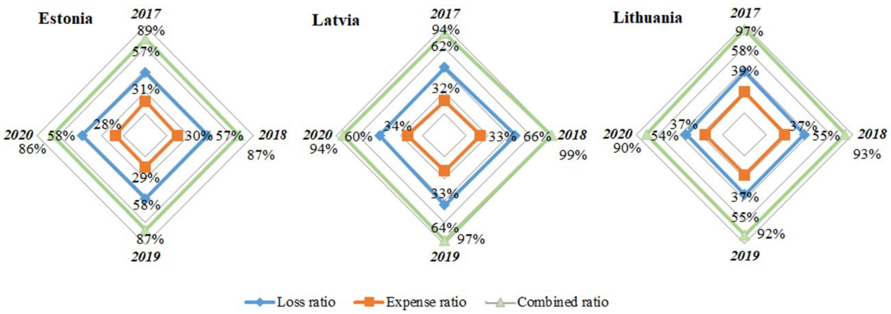


Fig. 1.6. Key performance indicators of the Baltic non-life insurance market in 2017-2020.

Source: Created by the author based on EIOPA Statistics (2021).

Estonia has the highest fluctuation of cost ratio, but the lowest cost ratio in the Baltic region. Lithuania has the highest cost ratio but the lowest loss ratio. Estonia has the best overall performance and the lowest combined ratio. The Estonian market is the most stable in the period under review.

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

The calculation of insurance liabilities under Solvency II, the so-called technical provisions, occupy the largest position in the economic balance sheet of Baltic insurers (both life and non-life), accounting for 90-91% of total liabilities, while the other items account for 9%-10% of total liabilities (see Fig. 1.7). The secondary data used in the analysis of the reserves can be found in Appendix 2. 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 calculation methods must comply with the requirements of Solvency II and there are no deviating local regulations.

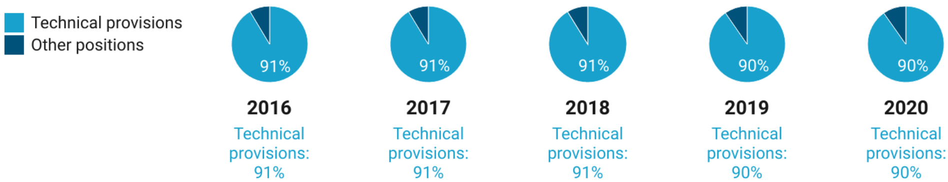


Fig. 1.7. Importance of technical provisions in Solvency II economic balance sheet for the Baltic life and non-life insurers in 2016-2020 (in % technical provisions from total liabilities).

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

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 general requirements for reserves under Solvency II are briefly explained in Appendix 3. In addition, the technical provisions also include a risk margin, which indicates the total cost of capital for the remaining required capital if the company ceases insurance business and only processes claims and settles the remaining liabilities to customers. The amount of the risk margin is also determined by duration of the liabilities. The risk margin is not analysed further and two groups of reserves are analysed: premium reserve and the claim reserve. The technical provisions under Solvency II are valued with a market-consistent approach using the full cash flow method with risk-free interest rates at the valuation date. The risk underlying the actuarial reserve is the premium risk, which covers all future risks, future claims and expenses for claims that have not occurred. The premium risk is covered by the actuarial reserve, i.e. the provision for unearned premiums and unexpired risks. The underlying risk for the claim reserve in non-life insurance is the reserve risk. The alternative management method proposed in this 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. The technical provisions for non-life insurers are covered by the life risk under Solvency II, which includes sub-risks such as longevity risk, mortality risk and revision risk. Life claim reserve are set up by non-life insurers when a serious personal injury has occurred and payments will be made to the victim for at least several years. It is necessary to settle all claims, whether reported or not, for which there is an obligation at a given balance sheet date, including non-life and life claims reserves, which are unpaid claims payments to customers.

Claim reserves are important for a variety of reasons, including having enough money to pay claims, accurately assessing financial strength and underwriting results, meeting regulatory requirements, medium-term capital and business planning, tax purposes and stable dividend distributions. The overall structure of the reserves is shown in Fig. 1.8. More than half of the reserves (55%-60%) are, on average, non-life claims reserves, 9%-15% are long-term life claims reserves (i.e. annuities from non-life products, most commonly from motor liability) and 26%-31% are premium reserves. Overall, an increasing trend for the share of life insurance claims reserves in total reserves and a decreasing trend for the share of premium reserves in total reserves can be observed in the period 2016-2020.

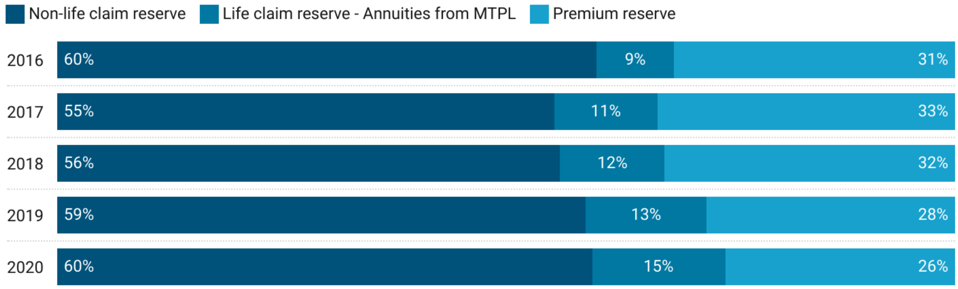


Fig. 1.8. Reserve structure in economic balance sheet of the Baltic non-life insurance market in 2016 – 2020 (as % from total premium and claim reserve).

Source: Created by author based on SFCR reports 2016–2020 (AB Lietuvos draudimas, 2020; BALTA, 2020; BTA, 2020; COMPENSA, 2020; ERGO, 2020; GJENSIDIGE, 2020; IF, 2020; SWEDBANK, 2020).

It is crucial to understand the impact of digital transformation on reserve patterns and their developments. The importance of sustainability risk to the insurance industry is increasing and there is a possibility that it will impact all departments of the business and risks, including reserve risk. Sustainability risk will impact the Baltic non-life insurance market's claim reserves, mainly through property insurance products (e.g. increasing frequency and average loss severity of storms and hail) and business interruption products. The emerging increase in sustainability risk affecting claim reserves will be reflected on both the asset side (reinsurance share of reserves) and the liability side (gross reserves) of the economic balance sheet. It is necessary to check whether the current reinsurance contracts are effective and help to ensure that capital is used optimally and that profitability remains stable more often. Models for natural catastrophe risks also need to be calibrated for the calculation of property insurance premiums. Currently, there is no high-quality, freely accessible database and clustering of cresta zones, sufficient data for each hazard in the Baltic. The European Insurance and Occupational Pensions Authority (EIOPA) is also planning to change the reporting for Solvency II (EIOPA, 2019). The sample of the total reserve structure (both premium and claims reserves) by line of business is shown in Fig. 1.9. More than half of the reserves (56%-60%) are for motor liability and long-term liabilities (i.e., annuities from the motor third-party liability line of business), 13%-17% are for fire and property damage and 10%-15% are for other motor (i.e. CASCO for cars and rolling stock). Other line of business has almost 5% reserve in the structure, medical expenses insurance has 3%. More than 20% of the total reserve for fire and property damage in property insurance and other motor insurance (Motor own damage) has a direct impact of sustainability risk or is related to climate change risk. The author has not conducted a quantitative study of how sustainability risk affects or will affect the total reserve for either premiums or claims in Baltic non-life insurance.

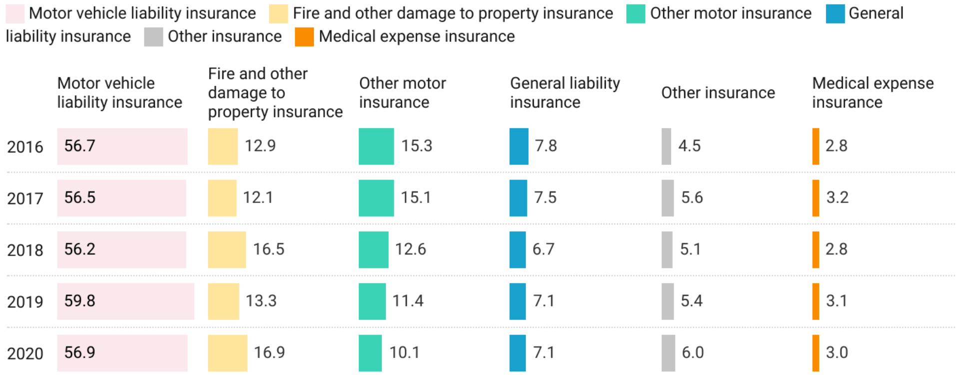


Fig. 1.9. Total reserve structure by line of business in economic balance sheet of the Baltic non-life insurance market in 2016-2020 (as % from total premium and claim reserve).

Source: Created by author based on SFCR reports 2016–2020 (AB Lietuvos draudimas, 2020; BALTA, 2020; BTA, 2020; COMPENSA, 2020; ERGO, 2020; GJENSIDIGE, 2020; IF, 2020; SWEDBANK, 2020).

It should be noted that while climate change could certainly be the most important aspect for the liability side of the Baltic non-life insurers' economic balance sheet, other sustainability aspects, such as social issues related to the ageing population in Latvia, Lithuania and Estonia, also play a role in motor liability and health and accident insurance products. An ageing population would mean that recovery from car accidents would be slower and the severity and frequency of medical and rehabilitation costs would increase, leading to lower profitability and an increase in claims reserves.

In order to assess the sustainability risks on the liability side for the gross provision, medium scenario analyses can be carried out, as is the case for scenarios with high or low climate change. This looks at annual loss rates and projections for the next 3-5 years, also taking into account risk mitigation measures (e.g. reinsurance) and reviewing product coverage and reinsurance retentions. This process is documented in the annual own risk solvency assessment. In the long term, conditions in the Baltic non-life insurance market and new reinsurance costs will have an impact on premiums and thus on the affordability and availability of property insurance cover against losses from hazard risks. Finally, it should be noted that given the uncertainty and lack of data - there is no freely accessible database for each peril - a quantitative assessment of climate-related risks on the liability side for loss reserves and the value of preventive measures and agreements covering climate risk is a major challenge. Gatzert *et al.* (2020) recommends numerous factors that insurers should consider for managing sustainability risks and opportunities in general. Gatzert *et al.* (2020)also point to a number of important barriers, including a lack of information, standards and statistics, which further undermines comparability and openness among companies, especially in light of the upcoming EU reporting requirements.

Fig. 1.10 shows an overall increasing trend for all reserve groups in absolute amounts. It is due to the overall rapid business growth. The reserves for life insurance claims have increased by more than EUR 90 million and tripled over the period 2016-2020. This increase could be due to the increase in average income and is not due to the economic environment or interest rates, as the yields on the 10-year government bonds of Lithuania, Latvia and Estonia were stable and less than 2 percentage points.

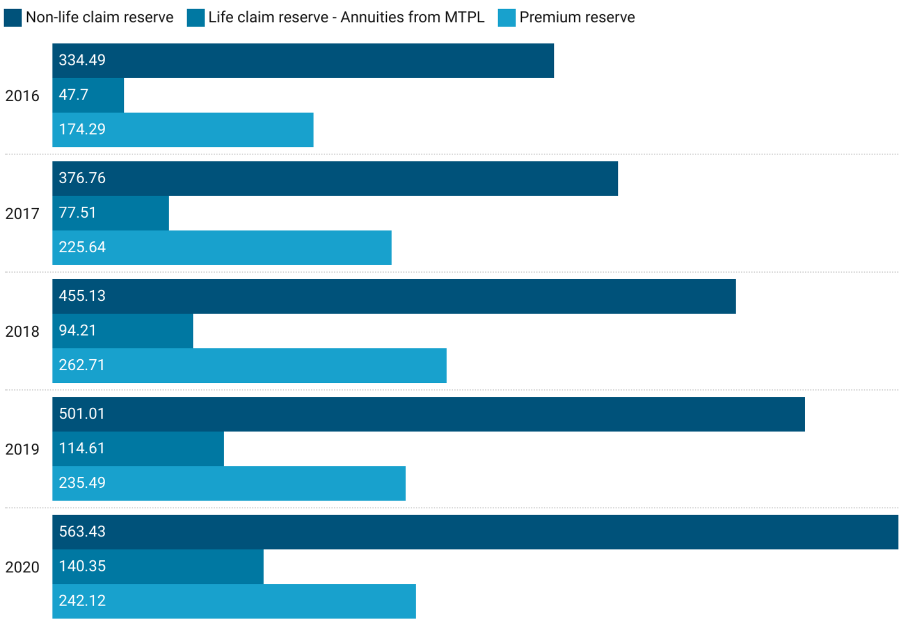


Fig. 1.10. Reserve by each group of the Baltic non-life insurance market in 2016-2020 (in EUR million).

Source: Created by author based on SFCR reports 2016–2020 (AB Lietuvos draudimas, 2020; BALTA, 2020; BTA, 2020; COMPENSA, 2020; ERGO, 2020; GJENSIDIGE, 2020; IF, 2020; SWEDBANK, 2020).

The total volume of claim reserves for non-life insurers increased from EUR 382 million to EUR 704 million. 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).

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 structure of the estimated claim reserve is shown in Fig. 1.11. 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%.

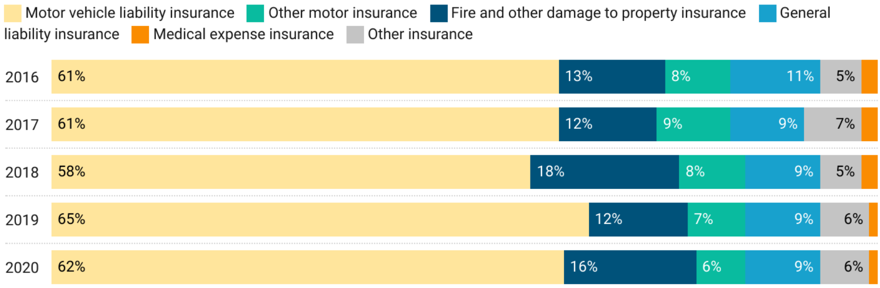


Fig. 1.11. Claim reserves structure by line of business in 2016-2020 (as % from total claim reserve).

Source: Created by author based on SFCR reports 2016–2020 (AB Lietuvos draudimas, 2020; BALTA, 2020; BTA, 2020; COMPENSA, 2020; ERGO, 2020; GJENSIDIGE, 2020; IF, 2020; SWEDBANK, 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, e.g. whether they have high sums insured, domestic or foreign customers. International Financial Reporting Standards (IFRS) claim reserve levels are analysed to identify long-term trends among leading companies. IFRS claim reserves have a direct impact on profit. The level of claims reserves under IFRS and the level of claims reserves under Solvency II are similar. The differences are small, with the exception of Swedbank, which has a difference of 5 percentage points in 2020 (see Table 1.1).

Table 1.1

Ratio of IFRS and Solvency II claim reserve over gross written premium in Baltic non-life insurance market in 2020 (in %)

Insurer:	IFRS	Solvency II	Difference in percentage points
Lietuvos draudimas	49	50	-1
ERGO	56	56	0
BTA	67	66	1
IF	86	88	-1
GJENSIDIGE	46	46	0
SWEDBANK	27	22	5

Source: Created by author based on SFCR 2016–2020 (BTA (2020), ERGO (2020), GJENSIDIGE (2020), AB Lietuvos draudimas (2020), SWEDBANK (2020), IF (2020)).

Fig. 1.12 box plot marker illustrates the high deviation of reserving ratio and reserving policy in the non-life insurance market between insurers. The claim reserve level of Solvency II is not included in Fig.1.12 as the period is too short. The reserve risk is assumed to be significant due to the widely divergent ratios calculated from year to year (see Fig.1.12). 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. However, it should be noted that differences in product structure and conditions could be the main reason.

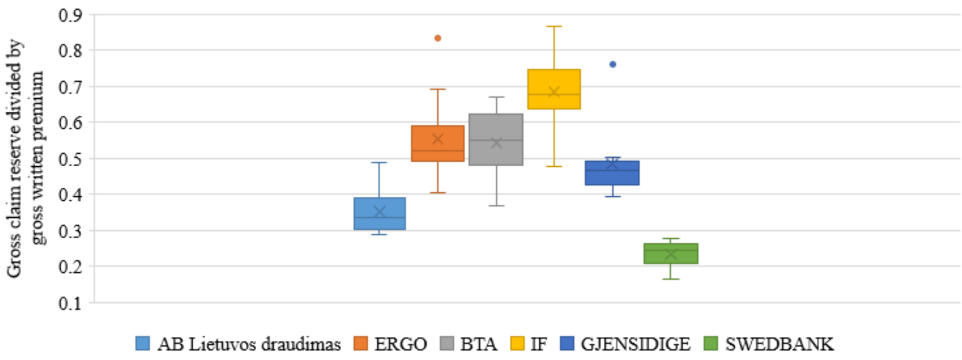


Fig. 1.12. IFRS Claim reserving ratio development for Baltic non-life insurance market as maximum - minimum, interquartile distribution in 2011-2020.

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

Available literature indicates that inadequate pricing and inadequate reserves were the main causes of insurer insolvency in the Canadian insurance market during the period 1960-2005 (Kleffner, Lee, 2009; Leadbetter & Stodolak, 2009). The published working paper by (Massey *et al.*, 2001) summarises the main causes of insolvency for 214 insurers in the United States of America (USA). The main cause is under-reserving in 34% of the defaults. In 20% of insolvencies it is rapid growth, in 10% of insolvencies it is alleged fraudulent claims and in 9% of insolvencies it is investment failure (Buckham *et al.*, 2011; Massey *et al.*, 2001). For the insurance sector in Canada and the US, the main risk that has caused insurer insolvency in the past is the risk of too rapid and uncontrolled reserves and growth. The Baltic non-life insurance market is also characterised by these two features: a high volume of reserves and rapid growth.

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

Development of solvency positions and the capital structure

Solvency and other aspects of financial stability of Baltic non-life insurers have not yet been extensively studied in the Solvency II framework II. Linartas (2012) has studied the financial stability of insurance companies in Lithuania in the context of Solvency I framework. Since 2005, EIOPA has published the Financial Stability Report for the whole EU market every two years. EIOPA has a Financial Stability Committee, which includes experts from national supervisory authorities who monitor and assess risks and vulnerabilities in the insurance sector.

Under Solvency II, new monitoring tools and frameworks have been developed for the insurance sector. This trend is evident when comparing the 2005 reports with the latest versions and methodologies. Lietuvos Bankas (Lithuania), FKTK (Latvia) and Finantsinspektsioon (Estonia) currently supervise and monitor the Baltic insurance market.

Several researchers have developed key elements of financial stability or solved individual problems of financial stability. Campagne (1961)produced the first solvency assessment for non-life insurance companies. Massey *et al.*, (2001) introduced insurance default analysis; and Cummins& Phillips (2005) analysed the cost of equity in the non-life insurance market.

A common definition of stability for the insurance sector and a prevailing analytical framework for assessing the stability of financial systems do not exist. Moreover, the financial sector and the non-financial sector (or the banking and insurance sectors) define financial stability differently. For the insurance sector, the definition of financial stability should include the nature of its business and insurance risks such as biometric risks, lapse and longevity. Among other experts and organisations, Ferguson, (2002), Chant *et al.*, (2003), Large, (2003) and the Board of Governors of the U.S. Federal Reserve System have defined financial stability using the opposite term, instability or systemic risk. In assessing financial stability, EIOPA has included several elements in its Financial Stability Report (2017-2021), namely key developments in market risk and other threats (external risk), changes in own funds, profitability (ROE, ROI, ROA), solvency, future legislative changes (external risk) and risk assessment through SCRs, investments and EU-wide stress test results. These core elements are in line with the findings of Linartas (2012) and the findings of the Geneva Association Systemic Risk Working Group (The Geneva Association Systemic Risk Working Group, 2010).

The International Association of Insurance Supervisors (IAIS) has defined four main approaches to measuring financial stability: simple factor-based, risk factor-based, scenario based and principle-based. The Solvency I structure of capital requirements was based on a simple factor measurement approach and was easy to apply. Market risks were excluded from this structure. Therefore, companies could make risky investments without being directly burdened with capital costs. Doff (2015) collected data and pointed out that when many companies went bankrupt in the early 2000s, some large EU companies also used alternative models such as the cash flow-based Swiss Solvency Test model. Under the Solvency I framework, these companies were overcapitalised, but the alternative models helped to provide a much more accurate risk assessment. In 2005, the capital positions of some large European companies were 326% (Munich Re), 329% (Swiss Re) or 307% (Allianz) Doff (2015).

A summary of indicators based on solvency and financial stability in the Baltic non-life insurance market provides an understanding of key insurance performance measures, the role of the risk management function in implementing internal models and capital management. Internal financial stability factors such as solvency and efficiency ratios (ROA, ROE, ROI) are examined. As shown in Fig. 1.13, the results of the analysis indicate that there is no significant relationship between solvency ratios and market share in the period 2016-2020.

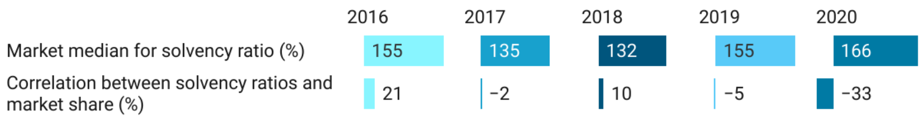


Fig. 1.13. Non-life Baltic insurance market median solvency ratios and their relationship with market share.

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

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). 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.

A wide range of solvency ratios between providers can be seen. This ratio is shown in Fig. 1.14. Two thirds of the Baltic non-life insurers show a positive, increasing trend in solvency position.

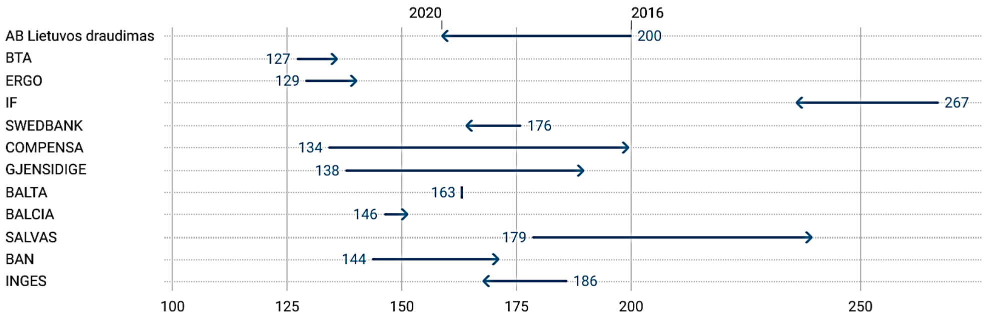


Fig. 1.14. Development of the solvency ratio (in %) for the Baltic non-life insurance market since the enforcement of the Solvency II framework II from 2016 (start of arrow) to 2020 (end of arrow).

Source: Calculations performed by the author based on Baltic non-life insurance companies' SFCR (AB Lietuvos draudimas, 2020; BALCIA, 2020; BALTA, 2020; BTA, 2020; COMPENSA, 2020; ERGO, 2020; GJENSIDIGE, 2020; IF, 2020; INGES, 2020; SALVA, 2020; SWEDBANK, 2020).

Baltic non-life insurance companies use only a standard formula by summarising the Solvency and Financial Condition Reports (SFCRs) in 2016-2020, without employing alternative capital management methods (internal or partial models). The standard formula is utilised in the entire Baltic market to calculate the capital requirement.

A median risk profile using the standard formula for the Baltic non-life insurance companies is shown in Fig. 1.15. 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%). The risk profile remains stable over the period 2016-2020, with market risk tending to increase.

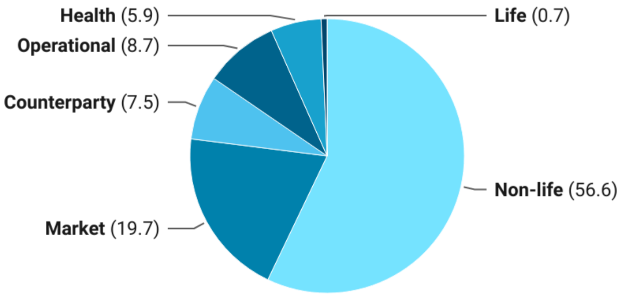


Fig. 1.15. Median risk profile of the market in 2020 (in % from total SCR).

Source: Calculations by the author based on Baltic non-life insurance companies' SFCR reports, 2020 (AB Lietuvos draudimas, 2020; BALCIA, 2020; BALTA, 2020; BTA, 2020; COMPENSA, 2020; ERGO, 2020; GJENSIDIGE, 2020; IF, 2020; INGES, 2020; SALVA, 2020; SWEDBANK, 2020).

For underwriting in the Baltic , with an average market share of over 8% and a premium volume of EUR 117 million, the capital requirement is over EUR 45 million. Market risk has the highest standard deviation and non-life risk the highest share of the risk profile in absolute values, as shown in Table 1.2. The Baltic non-life risk profile is very broad compared to other companies, with an interquartile range of 6.4% (EUR 22.2 million) for underwriting non-life risk. The highest deviation in the risk profile in relative values has the market risk with an interquartile range of 13.7% (EUR 13.4 million). The risk profile of the peer companies shows a high degree of dispersion. The highest coefficient of variation applies to the life risk.

Table 1.2

Capital requirements for each risk (in EUR million), structure of the risk profile (% of the total sum of all SCR risks) and its degree of variability in the Baltic non-life insurance market in 2020

POSITION:	Capital requirement for the whole business and by specific underlying risk, EUR million						
	SCR	Non-life	Market	Counterparty	Operational	Health	Life
Average	46.5	34.6	12.3	5.2	4.9	4.1	0.8
Stdev	17.7	13.4	8.3	2.1	1.5	2.3	0.8
Median	45.6	30.6	11.2	6.3	4.5	3.6	0.4
Variation coefficient	38.1	38.6	68.0	39.3	31.3	48.0	103.2
Interquartile range	29.8	22.2	13.4	3.3	2.1	1.9	1.0
Risk profile structure (in % of all SCRs per peers)							
Average		56.5	18.2	8.9	8.3	6.8	1.4
Stdev		7.9	8.4	3.9	1.5	3.0	1.5
Median		56.6	19.7	7.5	8.7	5.9	0.70
Variation coefficient		13.4	47.5	42.7	16.3	57.6	105.4
Interquartile range		6.4	13.7	4.3	1.3	3.4	1.4

Source: Calculations performed by the author based on Baltic non-life insurance companies' SFCR reports, 2020, represents more than 90% of market share (AB Lietuvos draudimas, 2020; BALTA, 2020; BTA, 2020; COMPENSA, 2020; ERGO, 2020; GJENSIDIGE, 2020; IF, 2020; SWEDBANK, 2020).

All market participants use the standard formula to calculate solvency capital requirements. The standard formula includes diversification between risks. The diversification effect can be calculated as the difference between the sum of all risks minus the final SCR after diversification. Diversification is usually not hedgeable and cannot be influenced and mitigated after an event has occurred. At the end of 2020, the average impact of SCR diversification in the Baltic non-life insurance market was 32.42% (minimum 17% for ERGO, maximum 36% for Swedbank). In the European market, the average diversification impact for SCR was 16% (Christy *et al.*, 2019). Diversification is crucial for the calculation of capital. This is even more true for the Baltic insurance market. This suggests that companies in the Baltics have diversified exposure to market risks as well as health, life and non-life risks compared to the average European market. A risk profile shows the importance of risk aggregation, especially for non-life underwriting risks.

Reserves are invested in real assets set aside to pay obligations to customers and other liabilities of insurers. The investments generate investment income and should be managed using asset-liability management techniques. Asset allocation and modified duration are critical for insurers. Asset allocation should take into account the duration of liabilities. The liabilities held by insurers tend to have a longer duration than their assets. It is critical for insurers to have assets with a duration that exceeds the duration of the liabilities and to have sufficient cash on hand to satisfy all claims, both in normal times and in stress situations. Without access to internal insurance company data, calculating liquidity positions is challenging. Fig. 1.16. shows the ratio of liquid assets as the sum of cash, deposits, corporate and government bonds and shares to claims and premium reserves. On average, the ratio has increased from 1.54 in 2016 to 1.6 in 2020. The ratio varies greatly from company to company.

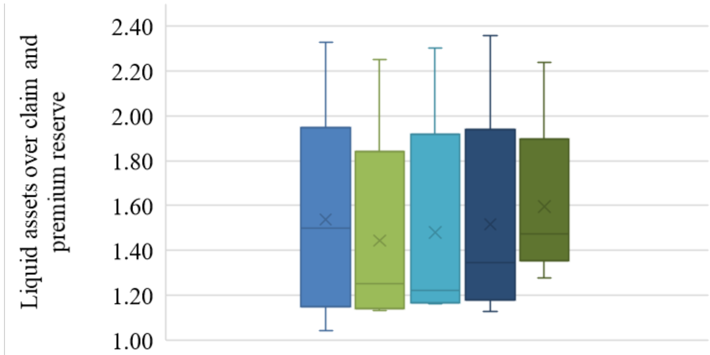


Fig. 1.16. Ratio liquid assets over claim and premium reserve for Baltic non-life insurance market in 2016 – 2020.

Source: Calculations by the author based on Baltic non-life insurance companies' SFCR reports, 2020 (AB Lietuvos draudimas, 2020; BTA, 2020; ERGO, 2020; GJENSIDIGE, 2020; IF, 2020).

The overview of the economic balance implies that the investment structure of the Baltic market is more conservative than that of the EU market. The entire Baltic insurance market is taken into account in the calculations. Fig. 1.17 shows that the investment structure in the Baltic market is more dependent on cash, deposits and bonds than the EU market.

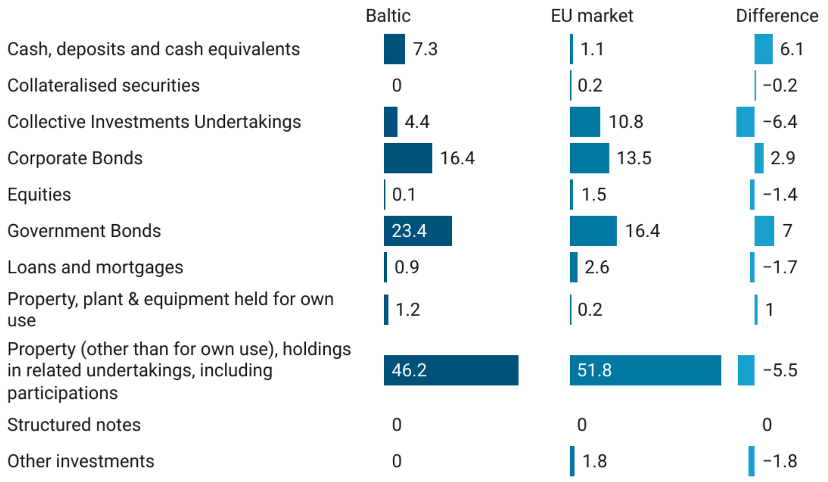


Fig. 1.17. Structure of investment assets and differences in the Baltic and the EU in 2020 (in % of total fixed assets).

Source: Calculations performed by the author based on EIOPA Statistics (2021).

The discrepancy between assets and liabilities should be optimal and should be controlled by the insurer's risk management departments. Claim reserve from motor liability insurance has the longest duration. The claim can be paid for the injured party until the end of his life. As can be seen in Fig. 1.6, the claims reserves from motor third party liability insurance have increased by EUR 92.65 million (194%) from 2016 to 2020. Therefore, the modified duration of the assets should also be increased. If the difference is too large, a sudden change in interest rates could lead to significant fluctuations in the solvency ratio. The standard model for market risk considers a shock of about 70 basis points as a scenario. The impact of the scenario on own funds is the required capital for interest rate risk.

Table 1.3 shows that such a structure of fixed assets tends to be stable over a five-year horizon. However, companies tend to seek higher yields in a low market by increasing their share of corporate bonds. Low yields and low swap rates contribute to the low profitability of the market, with a median ROI of -0.2 to 1.24 per cent over the 2016-2020 period, with asset returns below inflation over this period. Such a return also indicates that the remaining maturity of fixed income assets is short.

Analysis of the market SCR and its division into risk-sensitive assets shows that companies pursue different investment strategies. Insurers act as investors supporting the Baltic governments with investments of more than EUR 1 417 million. Overall, the Baltic non-life insurance market is less vulnerable to interest rate and spread risks than the EU market due to the lower exposure and share of fixed income assets.

Less capital is required for government bonds than for corporate bonds under Solvency II.

Table 1.3. shows that the SCR market is well optimised by a higher share of EU government bonds, which are considered risk-free assets with solid ratings and future prospects.

Table 1.3

Investment asset structure in the Baltic and EU in 2016–2020 (in % of total investment assets) and median ratio of ROI (in % as profit from investment over total investment volume)

	Baltic					EU				
Asset position	2016	2017	2018	2019	2020	2016	2017	2018	2019	2020
Property, plant & equipment held for own use	1	1	1	1	1	0	0	0	0	0
Investments (other than assets held for linked contracts)	47	47	46	46	46	53	52	52	52	52
Equities	0	0	0	0	0	2	2	1	2	2
Government Bonds	24	25	25	24	23	17	16	17	16	16
Corporate Bonds	14	14	14	15	16	16	15	15	14	14
Structured notes	0	0	0	0	0	1	1	1	1	1
Collateralised securities	0	0	0	0	0	0	0	0	0	0
Collective Investments Undertakings	5	5	5	5	4	7	10	10	11	11
Derivatives	0	0	0	0	0	0	1	0	1	1
Deposits	3	2	1	1	1	0	0	0	0	0
Other investments	0	0	0	0	0	0	0	0	0	0
Loans and mortgages	0	0	0	1	1	2	2	3	3	3
Cash and cash equivalents	6	6	8	6	6	1	1	1	1	1
Total	100	100	100	100	100	100	100	100	100	100
Median ROI (ratio in %)	0.6	1.2	-0.2	0.7	0.8					

Source: Calculations performed by the author based on EIOPA Statistics (2021).

The capital efficiency ratios in the Baltic non-life insurance market, which accounts for almost 70% of the market share, are summarised in Fig. 1.18. 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. ROE 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).

Tier 1 capital refers to an insurer's equity, ordinary shares and reserves such as retained earnings. The quality of the capital and the overall capital adequacy can be assessed by the share of Tier 1 capital in eligible own funds. The share shows an increasing trend, with shifts in 2018 compared to 2017 due to capital measures in Tier 2 as subordinated loans. The main reason for this is likely to be the expected future business growth in line with the companies' business plans and thus the expected increase in required capital. The Solvency II Directive states that the eligible amount of Tier 1 positions must be at least half of SCR.

In the period 2016-2020, the median ratio for Ter 1 via SCR is over 120%, well above the statutory minimum, as Figure 1.18 shows. This means that the Baltic non-life insurance market has the highest quality capital at a level that can cover SCR events and that Tier 2 and Tier 3 capital would not be consumed.

As shown in Fig. 1.18, the return on SCR has decreased in 2020 compared to 2019 and 2018, which could indicate higher risk and less profitable business requiring higher capital.

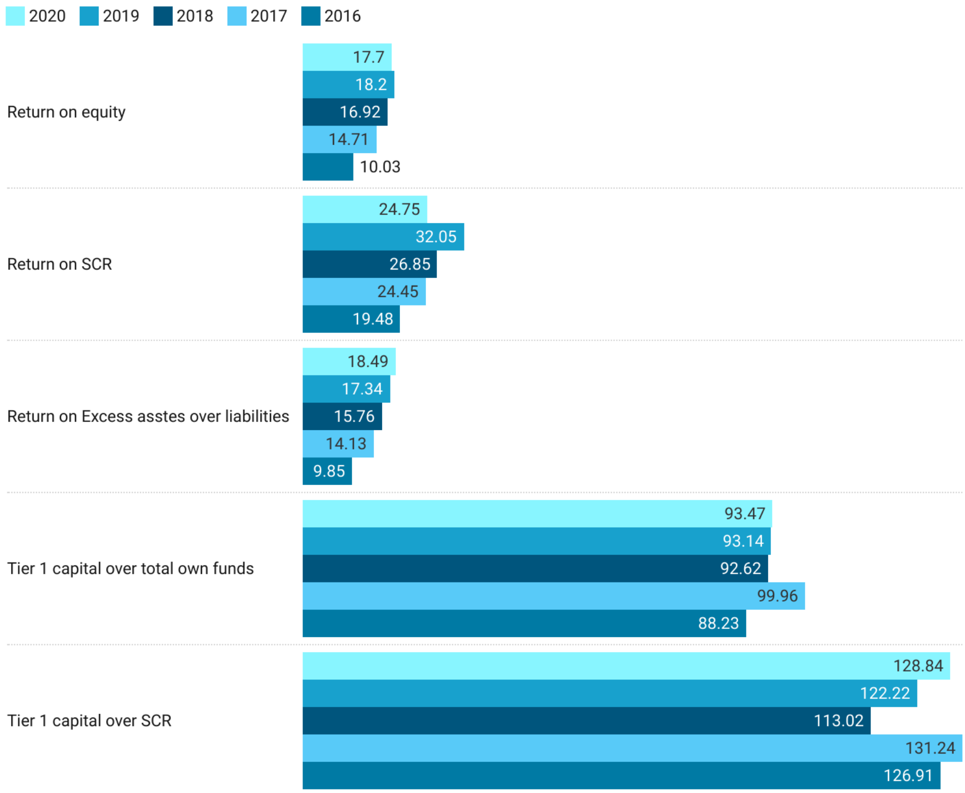


Fig. 1.18. Measures ratios of capital efficiency (in %) for Baltic non-life insurance market in 2016-2020.

Source: Calculations by the author based on AB Lietuvos draudimas (2020), BTA (2020), ERGO, (2020), IF (2020), SWEDBANK (2020).

For the period of the pandemic, the author is unable to identify any significant fluctuations in the solvency ratios of the market leaders. However, the data show that SCRs have increased faster than eligible capital, as shown in Fig. 1.19. Furthermore, despite the decline in business growth, the capital required to cover SCR events has continued to increase. The structure of assets has not changed, so the increase in SCR is not due to riskier assets.

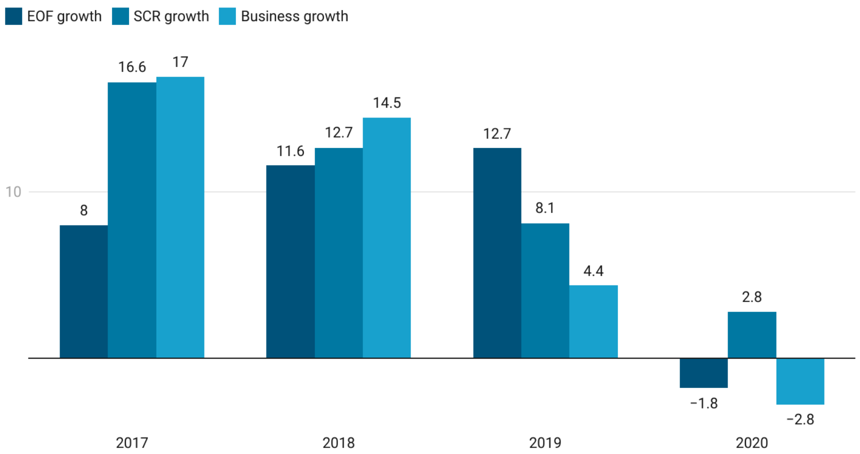


Fig. 1.19. Baltic non-life insurance market EOF, SCR and business volume (GWP) growth 2017-2020 (% rates over the last year).
Source: Calculations by the author based on AB Lietuvos draudimas (, BTA (2020); ERGO (2020); IF (2020), SWEDBANK (2020).

The increase in growth can be explained by a standard formula. If the premium volume shows higher growth, then more capital is needed, and this is not directly related to future expected or current profitability.

Financial stability assessment via matrix synthesis

For the study of the financial stability of the Baltic non-life insurance market, the insurance industry financial strategy matrix is used, which is based on the well-known matrix of Franchon & Romanet (Franchon & Romanet, 1985), adopted by Dell'Atti *et al.* (2020) for insurers in the Italian market. In this study, the method is applied with indices based on the Solvency II framework: Own funds and other economic balance sheet items. The statement of comprehensive income of insurance companies consists of two components: the technical result or pure insurance result and the non-technical result or investment result, which also includes capital costs. The indices used for the insurance business (IB) and the financial business (FB) are defined as follows:

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

and

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

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, a negative or a balanced result (see Fig. 1.20).

Insurance business results = *IB*	Financial business activities = *FB* <0	Financial business activities = *FB* 0	Financial business activities = *FB* >0
>0	1 *IB*+*FB*=0	4 *IB*+*FB*>0	6 *IB*+*FB* significantly above 0
0	7 *IB*+*FB*<0	2 *IB*+*FB*=0	5 *IB*+*FB*>0
<0	9 *IB*+*FB* significantly below 0	8 *IB*+*FB*<0	3 *IB*+*FB*=0

Insurance business results = *IB*	Financial business activities = *FB* <0	Financial business activities = *FB* =0	Financial business activities = *FB* >0
>0	1. Profitable insurance portfolio & gap in financial opportunities	4. Limited financial stability in the long run & Portfolio does not generate profit, expense issue	6.TARGET: Strong capitalised, capital for further growth
=0	7. Improvements in non-technical result & capital measure e.g. reinsurance strategy review	2. Improvements in undewriting&investment strategy, no capital for growth	5. Limited financial liability & well established underwriting policy
<0	9. Insolvency	8. Capital measure and restructure of investment portfolio	3. Burning equity with unprofitable underwriting strategy

Fig. 1.20. Synthesis of the matrix evaluation.

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

From the regulators' and clients' perspective, the aim, in the long run, would be to avoid underwriting in a loss-making business and to have own funds for future growth, as well as to cover shocks from financial market volatility (see square 6 in Fig. 1.20). The stages described in squares 7, 8 and 9 are critical; moreover, companies that fall under stages 1, 2 and 3 in the long run will attract the attention of regulators and shareholders due to solvency risks. Stages 4 and 5 signal the need to change the underwriting business model. The input data used to calculate the indices for the Baltic non-life insurance market defined in formulas (1.1) and (1.2) are shown in Table 1.4.

Table 1.4

Input for matrix synthesis results (in EUR thousand)

Indicator	Period 2016	2017	2018	2019	2020
Gross written premium	1 087 690	1 300 990	1 497 190	1 563 150	1 441 260
Net paid insurance claims	604 739	659 040	755 030	800 030	739 470
Net acquisition costs	168 921	199 120	232 650	232 220	210 490
Reinsurance written premium	79 860	113 230	165 820	164 170	145 900
Eligible own funds	535 983	571 711	638 369	721 902	725 443
Best estimate	748 104	869 533	1 030 635	1 080 470	1 090 359
Total costs	323 034	379 530	424 400	443 500	422 440
Equity, own capital Tier 1	165 146	177 755	179 355	189 685	189 685

Source: Collected by the author based on (AB Lietuvos draudimas, 2020; BALCIA, 2020; BALTA, 2020; BTA, 2020; COMPENSA, 2020; ERGO, 2020; GJENSIDIGE, 2020; IF, 2020; INGES, 2020; SALVA, 2020; SWEDBANK, 2020).

The Baltic insurance market remained at the target stage (stage 6) during 2017-2020 (see Fig. 1.21 and Table 1.5). The current stage represents both a profitable insurance business and a capital surplus that can be used for future growth. These results are also supported by the key performance indicators in Fig. 1.5 and by the solvency ratios in Fig. 1.13.

Table 1.5

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

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
IB+FB	**56**	**19**	**19**	**3**
Financial development potential	8 717	30 560	26 625	118 134

Source: Calculated by the author.

Setting aside capital with a high confidence level is required under Solvency II framework; therefore, the author believes that the entire EU insurance sector would fall under this stage: well-capitalised and profitable insurance portfolio (see Fig. 1.21).

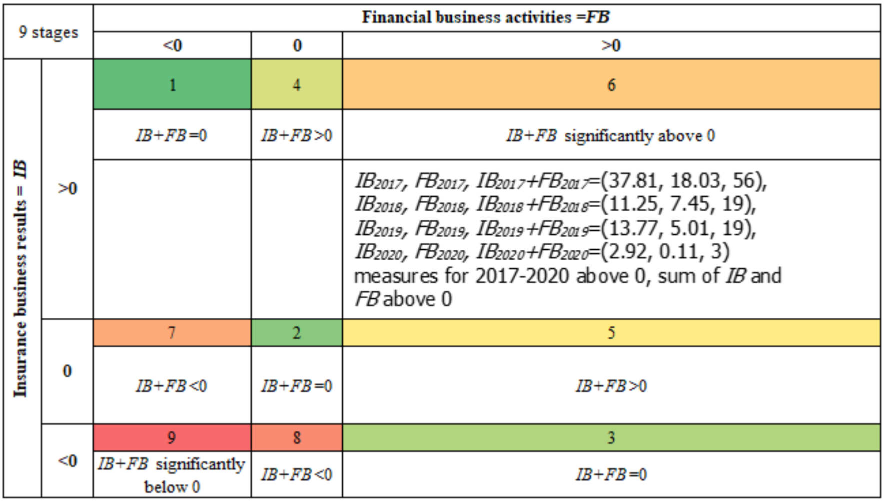


Fig. 1.21. Stages in the matrix for *IB*, *FB* and the sum of *IB* and *FB* in 2017–2020.

Source: Calculations by the author.

Projection of market growth for inclusion in capital allocation

Financial stability is determined not only by internal indicators but also by macroeconomic indicators. Insurers should plan the growth of capital requirements at a level at least in line with the growth of the overall market in order to ensure medium-term financial stability, which is important for society, regulators and investors.

Insurance demand depends on many factors: how economy matures (Enz, 2000), whether the insurance market is considered as advanced or emerging, information frictions (Handel & Kolstad, 2015), biased risk perceptions (Abaluck & Gruber, 2011), household welfare and heterogeneity aspects (Spinnewijn, 2017). In addition to income, political, regulatory, legal and socio-cultural factors such as financial knowledge and risk awareness related to recent disaster experiences could also influence the demand for property insurance (Brainard, 2008; Feyen *et al.*, 2011; Hussels *et al.*, 2005; Swiss Re, 2004; USAID, 2006). Econometric estimates yield the so-called *S-curve*, which is used in many cases to project demand. The *S-curve* is the most popular model for projecting demand for insurance products and can explain changes in insurance premiums (Enz, 2000). The yield curve, which is a logistic function, allows income elasticity to vary as the economy matures, and any variations allow factors other than penetration rates and GDP to be identified as determining insurance demand. In the last 20 years, demand for insurance products in the Baltic has increased due to growing risk awareness. However, premiums as a percentage of GDP (i.e. penetration rate) and GDP have not shown a common clear trend since 2020 (see Fig. 1.22). Secondary data are from Swiss Re (2021) databases, which present data in USD.

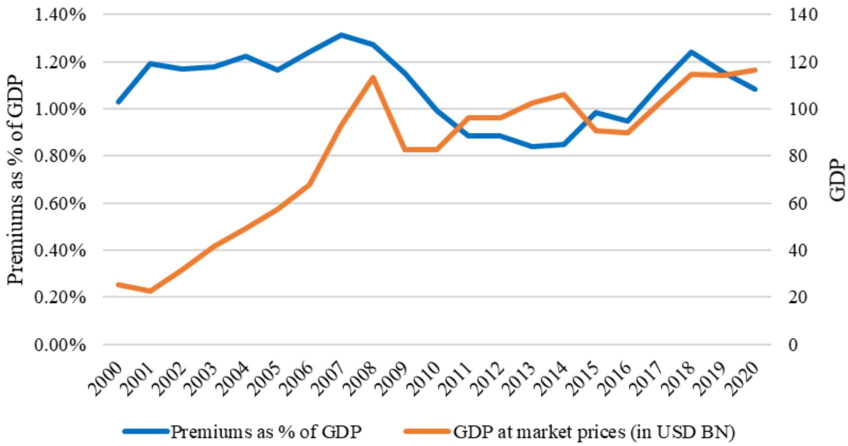


Fig. 1.22. Development of Baltic non-life insurance market GDP (in USD billion) and penetration rate (in % as GWP over GDP) in 2000–2020.

Source: Collected by the author from Swiss Re (2021) data basis in USD.

The development of the penetration rate and GDP over the last 20 years suggests that the drivers of GDP growth are different and that economies have evolved more than the risk awareness and financial literacy of residents over the last 20 years. The reason for this could also be the small or marginal increase in average premium, coverage for non-life insurance products with fewer policies for voluntary products (e.g. property and motor own damage insurance products). There are also differences in drivers between Lithuania and Latvia and Estonia (see Fig. 1.2). Overall, however, simple measures such as growth in premiums written and GDP for the Baltic non-life insurance market show a common clear trend since 2020 (see Fig. 23). Secondary data used is from Swiss Re (2021), which presents data in USD.

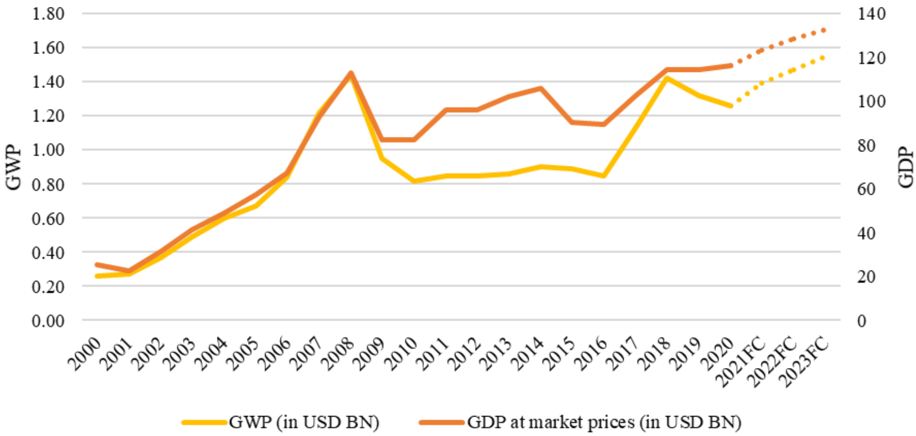


Fig. 1.23. Development of Baltic GDP (in USD billion) in the period of 2000 – 2023FC and Baltic non-life insurance market GWP (in USD billion) during 2000–2020.

Source: Collected by the author using statistics (EUROSTAT, 2021; Swiss Re, 2021).

Based on visual evidence of similarities between premiums and GDP, the forecast of market growth is projected by testing whether a simple linear regression can be used instead of a logistic regression with *S-curves*. The forecast could also be used to project medium-term capital requirements. Next, SCR could be forecast in line with premium growth in the business plan and additionally by external general market growth. However, each insurer should consider its own risk profile and whether GWP can also be used as a driver for the SCR projection for the coming years. The strong correlation between SCR growth and GWP growth is noted for similar market participants: Lietuvos draudimas (0.9), BTA (0.7), Ergo (0.9), Gjensidige (0.8), Balta (0.8). No correlation is found for IF (0.02), which is due to the highest proportion of the risk profile for market risk, the large capital surplus (see Appendix 1).

The dependent variable premium forecast in period is subsequently calculated using linear regression:

$$Y_i = \alpha \cdot X_i + \beta + \varepsilon_i, \tag{1.3}$$

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.

GDP is used as an explanatory variable in the proposed linear regression models used to project insurance demand and market growth. Two different time periods are used in the regression model for forecast. The first model has GDP as the explanatory variable for projecting market growth (gross written premiums) from 2000 to 2020, while the second model has GDP as the explanatory variable for projecting market growth (gross written premiums) and uses data from 2010 to 2020. Both models have a low *p*-value (see Tables 1.5 and 1.6).

Table 1.6

The proposed model parameters with GDP as an explanatory variable for market growth projection results in capital management medium-term plan

	Model 1:	Model 2:
Observations	21 (Based on 2000-2020)	11 (Based on 2010-2020)
Parameters of linear regression		
Coefficients Intercept	0.0328	-0.6856
Coefficients GDP at market prices	0.0104	0.01683
Statistical parameters		
Multiple R	0.9192	0.8406
Significance F, *p*-value ($\alpha=0.05$)	0.0000	0.0012

Source: Calculated by the author.

One proposal is that insurers should in future set aside capital and equity in line with market growth of at least 3%-5% per annum over the period 2021-2023 and include these growth rates as the default minimum assumption for business growth. Such an approach would help maintain financial stability at the same level. Table 1.6 and 1.7. show a regression analysis and the predicted growth rates and penetration rates. The models include different time horizons and different numbers of observations. The first model has 21 observations, i.e. 21 years of experience. The second model, on the other hand, has 11 observations, i.e. 11 years of experience. The first model, which assumes a market growth of 3.51 per cent in 2023, has a lower p-value than the second model. In addition, the first model forecasts a more conservative growth rate for the Baltic non-life insurance market. The author advises using the rates of the second model, as the cost of capital planning should include a safety margin. The use of econometric estimates yielding an *S-curve* is not necessary for the Baltic market due to the statistically significant *p*-value with GDP as the explanatory variable in the proposed linear regression model.

Table 1.7

Market growth and penetration rate projection results with GDP as an explanatory variable

	Model 1	Model 2
2021FC Market growth	4.14%	10.39%
2022FC Market growth	3.91%	5.99%
2023FC Market growth	3.51%	5.26%
2021FC Penetration rate	1.06%	1.127%
2022FC Penetration rate	1.06%	1.148%
2023FC Penetration rate	1.06%	1.167%

Source: Calculated by the author.

Macroeconomic and purely internal indicators should be considered when assessing financial stability, which is important for regulators and investors. Only a factorial regression model can be used to predict premium growth as a percentage of GDP. Goodness-of-fit tests are passed when GDP is used as an explanatory variable. Annual growth of 3%-5% is projected for the years 2021-2023. An insurer should consider the same percentage increase when planning solvency capital requirements in a medium-term capital management plan. The matrix synthesis shows that the Baltic non-life insurance market is at a stage that represents both a profitable insurance business and a capital surplus that can be used for future business growth. The current financial stability and capital surplus should be used by Baltic non-life insurers to absorb today's shocks, such as inflationary pressures on claims costs and the uncertainty of interest rate developments.

Digitalisation impact analysis on claim management

The impact and evaluation methods of digital transformation on the non-life insurance sector for claims management and claim reserves are examined using data from non-life insurance companies in the Baltic countries. Research on the effectiveness or progress of digitalisation in the Baltic and Northern European countries or among non-listed insurance companies was not found (Dörner & Edelman, 2015). "Innovations" and "digitalisation" were mentioned in the business strategy and recognised as a priority for insurers by several Baltic non-life insurers.

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. Enterprise risk management (ERM) frameworks for companies are considered in the rating process of external credit rating agencies, e.g. A.M. Best., (2018), Moody's (2019) and Standard and Poor‘s (2013). External credit agencies have an increased focus on ERM (Lundqvist & Vilhelmsson, 2018). The majority of Baltic non-life insurers belong to insurance and banking groups as subsidiaries. These insurance groups have a "financial strength rating" assigned by international rating agencies; therefore, Baltic insurers must also meet these requirements.

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). Increasing competition and innovations from insurtech start-ups are two reasons why insurance companies need to continue to improve and develop their services to ultimately ensure the continuity of their business. Lemonade, a company active in the fintech sector, has announced its intention to expand further in Europe (insurance is available in Germany, France and the Netherlands) by using a business model that is completely different from a traditional model

(Insurance Journal, 2020; Lemonade, 2018). In addition, Friendsurance and Policygenius have made large investments and developed business models that are different from traditional ones (OECD, 2017). In the current study, insurtech companies are assumed to increase customer satisfaction. However, companies with traditional insurance models, such as those in the Baltic market, can quickly learn from them and adopt these new start-ups.

The companies on the Baltic market can also develop new ideas much faster due to the high surplus of capital. The ongoing digital transformation in the insurance industry will shorten the time horizon for personalising products with premium risk tariffs by avoiding overpricing and individual capital modelling based on companies' individual risk profiles.

Fig. 1.24. illustrates an insurance-specific value chain distinguishing the required primary and supporting activities for the provision of insurance products. Both primary and supporting activities should include excellent customer service. Customer service is central to all primary activities. For example, IT should provide secure and easy online tools for the end consumer. The part of claims management that comes from primary sources is analysed. The faster processing of claims and the resulting lower claims reserve will also directly influence and reduce capital requirements. A positive customer experience after the insurance claim can be the main reason for policy renewals and the overall growth of the Baltic insurance market.

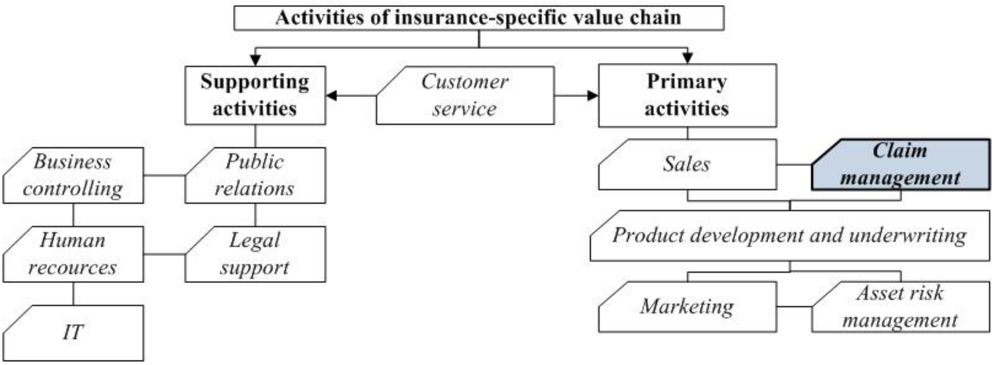


Fig. 1.24. Insurance-specific value chain's activities.

Source: Created by the author based on Carsten & Ulrich (2007), Eling & Lehmann (2018), Porter (1985).

No quantitative analysis of digitalisation is conducted for the Baltic non-life insurance market. Baranauskas & Raišienė (2021) conducted a qualitative assessment of digitalisation by conducting an expert-based review of online services available in the Baltic non-life insurance industry. According to the results of the assessment of digitalisation (Baranauskas, Raišienė, 2021), the level of readiness of service providers for digital solutions in the Baltic non-life insurance market ranges from "satisfied" to "rather good". However, it lags behind the actual needs of end consumers.

The results show that standardisation prevails among the Baltic online platforms for non-life insurance. In Baranauskas& Raišienė (2021)'s assessment of the digitalisation of the insurance industry, Latvia scores best on average. The impact of digitalisation on an insurer's value chain in relation to this research area, main activities and claims management is shown in Table 1.8.

Table 1.8

Impact of digitalisation on the value chain process: claim management

Tasks	Technology	Impact on the value chain
Investigation of fraud	Artificial intelligence and big data	• prevention of fraud through data analytics, • automated calculation and pay-out of the amount of damage.
Claim handling	Blockchain	• storage of the information for the automated pay-out, • mobile devices with mobile applications: customers file their claims via smartphones.

Source: Created by the author based on Eling & Lehmann (2018).

The line of business most affected by digitalisation so far is health insurance worldwide and in the Baltic. Even reporting a claim is not necessary, as medical services are paid for via electronic insurance cards (pay-as-you-live) in mobile phones, which is partly due to the low number of fraud cases, the high frequency and the mostly low severity.

In a research, Yamamoto (2016) describes a conflict of interest in Japan between the public interest and privacy protection arising from the use of health insurance claims databases. In the EU, there are no such concerns due to the General Data Protection Regulation. Leppert *et al.* (2018) summarise the weaknesses and strengths of the digital health economy in Germany. The biggest weakness is the lack of business models and the willingness of private users to pay for digital services is low.

The author has not identified any published quantitative research showing whether claims payment behaviour, speed of claims processing and overall reserving structure, capital requirements are changing as a result of digital transformation for the Baltic insurance market. The main benefits are fewer human errors (reduction of operational risk) and consistent processing of claims across the organisation (KPMG, 2017). McKinsey (2015) has analysed that the cost of automating claims management can be reduced by 40% on IT. Disruptive technology change enables savings of up to 10% in premium costs and 8% in claims expenses (BCG, 2018). Bohnert *et al.* (2019) examine 41 listed European insurance companies that express a digital agenda in their annual reports (2007-2017) and find a positive correlation between the cost of implemented digital tools and the company's profitability level. The combined ratio would decrease rapidly and this trend would also cover the Baltic market.

This chapter therefore addresses the following research questions to quantitatively evaluate the measurement of digitalisation as an alternative method of capital management: how can the impact of digital transformation in the insurance sector be measured for claims management; what is the relationship between the speed of claims processing (digitisation measure), the volume of claims paid out (business growth) and GDP in the Baltic countries; does the structure of companies' product and claims reserves affect the effectiveness of digitalisation.

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 Baltic countries.

It is important to bear in mind that the required capital for the reserve risk can be influenced by the speed of claims payments and digitalisation. The required capital for reserve risk decreases when liabilities decrease. Digitalisation in claims settlement also requires more advanced fraud systems and could lead to more resources in the claims settlement units. There is no data on how many claims are reported via call centres, mobile apps and direct online sites in the Baltic insurance market.

One of the most important steps to assess the impact of digitalisation on claims management is the analysis of paid claims triangles. A claims triangle represents the volume of claims paid in an accident year and a given financial year. It indicates how much of the total amount of claims paid in a financial year comes from the same accident year, previous accident years, etc. The more claims paid in the same financial year in which an event occurred, the more effective the transformation process to digitalise claims processing. The percentage of total claims paid (including claims not yet reported) can be calculated using the well-known Chain Ladder actuarial reserving method.

The Chain Ladder method is a simple and distribution-free approach (Mack, 1994). Section 2.2. describes the details of triangulation and the Chain Ladder method. A simple triangle example is shown in Table 1.9.

First, it is important to note that the annual triangle is used. Claims are usually settled within one month of their due date and terms for most business lines. Secondly, automatic claims payments will also be introduced in the near future. Therefore, the author suggests using monthly daily triangle data as well. Thirdly, separate analyses of attritional claims and large catastrophic claims should be carried out to assess the impact of the digitisation strategy as an alternative capital management method that reduces capital requirements for reserve risk.

The digitalisation strategy also leads to a reduction in the cost of capital and an improvement in capital efficiency. Finally, the calculation frequency for required capital and risk assessment in the digital age needs to be revised to immediately assess these risks (e.g. reserve risk) and dynamically adjust risk limits.

Table 1.9

Baltic non-life insurance market aggregated claims paid (non-cumulative) triangle (in EUR million)

		DEVELOPMENT YEAR												
	YEAR	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
CLAIM ACCIDENT YEAR	**2008**				3.9	3.0	4.4	1.8	1.4	0.6	0.5	0.0	0.0	0.0
	2009			6.1	6.5	1.9	2.3	1.0	1.1	1.0	0.0	0.0	0.0	
	2010		51.2	4.5	4.6	4.2	1.0	-0.1	1.0	0.0	0.0	0.0		
	2011	183.3	58.8	7.0	5.3	2.5	0.9	0.5	0.6	0.0	0.1			
	2012	219.0	60.6	6.8	2.7	0.9	0.7	0.8	0.8	1.0				
	2013	238.0	64.0	6.5	3.0	2.6	3.1	1.1	0.3					
	2014	269.7	81.3	12.9	3.8	2.2	0.9	0.9						
	2015	321.0	86.6	7.5	3.2	3.2	1.1							
	2016	377.4	90.9	12.5	4.8	3.0								
	2017	399.5	96.4	10.1	4.8									
	2018	430.7	169.7	12.3										
	2019	475.3	126.8											
	2020	469.7												

Source: Calculations performed by the author based on SFCR (AB Lietuvos draudimas, 2020; BALTA, 2020; BTA, 2020; ERGO, 2020; GJENSIDIGE, 2020; IF, 2020; SWEDBANK, 2020).

To justify the relationship between the speed of claims settlement and the structure of the claim reserve portfolio, a Pearson correlation technique is used. This analysis helped to understand that despite digitalisation, there may still be a line of business that takes more time for various reasons (e.g. court proceedings, legal requirements and complicated processes to determine the cause of risks). The test procedure is explained below.

- First, the claims reserve was divided into two parts: fast and slow settlement. In the fast settlement group, the reserves for medical expenses, income protection insurance, other motor insurance, fire and other property damage, legal expenses insurance, assistance, marine, aviation and transport insurance, credit and surety insurance and the reserves for other financial losses were classified. The claims reserves for motor third party liability insurance, general liability insurance and annuities claims reserves were classified in the slow settlement group. Their data was not considered for this analysis.
- The quick-pay claims ratio is calculated using an aggregated triangle of cumulative paid claims for each individual company. The ratio shows how much of the total claim amount is paid in the first year. In this study, the fast paid claims ratio is assumed to be a measure of digitalisation in claims management.

Calculating how much of the total claims are paid out in a one-year period is possible using the Chain Ladder method, where the data are presented as a triangle (see Table 1.9). The quick pay out ratio in 2020 is 76% or 76% of the total claims paid out in 2020 are paid out for new business, accidents in 2020 (see formula 1.4). Example of the calculation of the quick pay ratio using the triangle from Table 1.10.

$$Quick\ paid\ ratio_{2020} = \frac{469.7}{469.7+126.8+12.3+4.8+3+1.1+0.9+0.3+1+0.1} = 0.76 \qquad (1.4)$$

Comparing the results from year to year shows the impact of digitalisation for each company and the overall market. The correlation between the speed of claims processing and the volume of claims reserves for the group of fast adjusters is significant at a significance level of 0.05 for 2017 (i.e. a *p*-value of 0.04) (see Fig. 1.25). Therefore, RQ1 cannot be rejected for 2017. And RQ1 is rejected for 2016, 2018, 2019 and 2020.

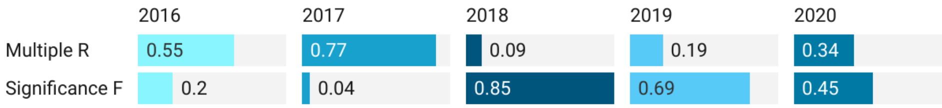


Fig. 1.25. Baltic non-life insurance market correlation and significance level coefficients for claims handling speed and claim reserve volume for the fast regulation group in 2016-2020.

Source: Calculations performed by the author based on SFCR reports 2016–2020 (AB Lietuvos draudimas, 2020; BALTA, 2020; BTA, 2020; ERGO, 2020; GJENSIDIGE, 2020; IF, 2020; SWEDBANK, 2020).

This analysis shows that late reported claims, late developed claims and lower claim frequency were observed during the pandemic period. Also, the overall claim speed for short settlement products cannot be analysed using the available annual triangles since 2017, and the digitalisation effect reached the Baltic non-life insurance market in 2017 (see Fig. 1.26). However, the same proposed procedure can be applied using monthly, quarterly and even daily triangles. The analysis presented in Fig. 1.26 shows that if the insurer offers less advanced products with lower liability risks in potential courts, the overall speed of claims payouts in the company is also lower. The impact of digitalisation on claims management depends on the underwriting business model.

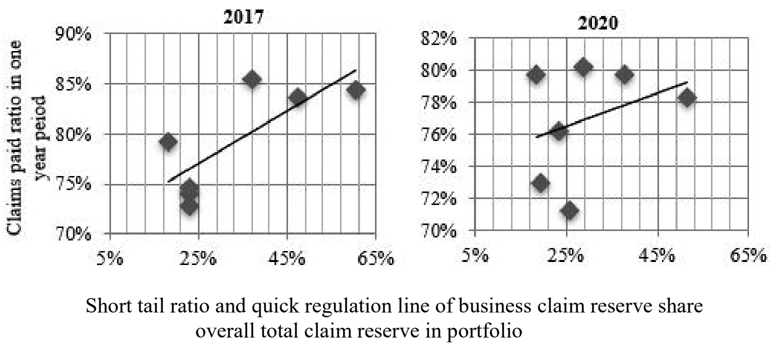


Fig. 1.26. Strong positive relationship in 2017,weak in 2020 between the companies for the speed of claims regulation (in % from total claim paid) and quick regulation reserve (in % from total claim reserve).

Source: Calculations performed by the author based on SFCR reports 2016–2020 (AB Lietuvos draudimas, 2020; BALTA, 2020; BTA, 2020; ERGO, 2020; GJENSIDIGE, 2020; IF, 2020; SWEDBANK, 2020).

To rationalise the relationship between the speed of claims settlement and the increase in business volume (claims paid), a Pearson correlation technique is used. This calculates the correlation between the total number of claims paid and the claims paid in a one-year period divided by the total volume of claims. This analysis helps to understand that despite business growth, the increase in claims paid out and the speed of claims settlement are also increasing.

The testing procedure involved two steps. First, for each year, the amount of claims paid in the accident year, one year after the accident year, two years after the accident year, etc. is calculated using the market aggregate claims triangle (see Fig. 1.27.). Secondly, the quick paid ratio is then calculated.

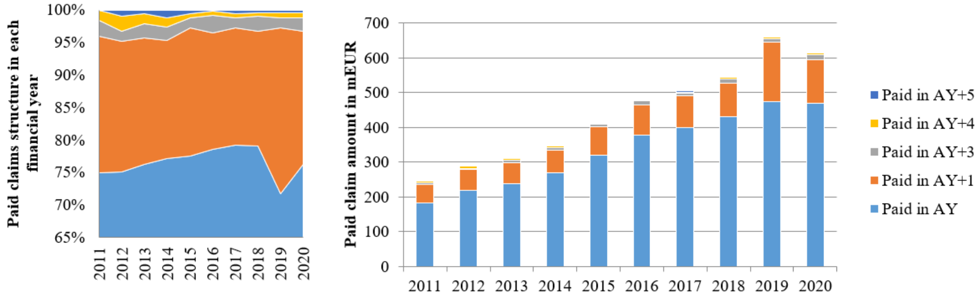


Fig. 1.27. Payment pattern (in % from total) and paid claims in financial year 2011 - 2020 for each accident year, EUR million.

Source: Calculations performed by the author based on AB Lietuvos draudimas (2020), BALTA (2020), BTA (2020), ERGO (2020), IF (2020), SWEDBANK (2020).

There is a strong positive correlation between the total amount of claims paid out and the claims paid out in a one-year period divided by the total amount of claims - 98%. The result of the correlation is significant at a significance level of 0.05 (i.e. a p-value of 0.0000, an R-squared value of 96.31%) and the result generated is below the study's significance level of 0.05. The market data clearly shows that the speed of claims processing and the impact of digitalisation are increasing year by year. In 2011, 74% of the total claims were paid in one year, in 2017 it was - 79%. Consequently, RQ2 cannot be rejected for the period 2011-2017. For the period 2011-2020, a very weak negative correlation between total claims paid and claims paid in one year divided by total claims volume of 7% is observed. The correlation result is significant at a significance level of 0.05 (i.e. a p-value of 0.8440, R-squared value of 5.14%) and the generated result is larger than the significance level of 0.05 in the study (see Fig. 1.28).

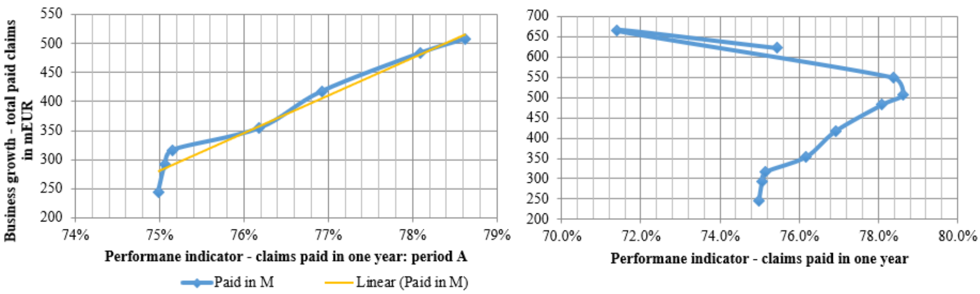


Fig. 1.28. Total paid claims (in EUR million) and claims paid in one year period (in % from total paid claims).

Source: Calculations performed by the author based on AB Lietuvos draudimas (2020), BALTA (2020), BTA (2020), ERGO (2020), IF (2020), SWEDBANK (2020).

Market data shows that the speed of claims processing and the impact of digitalisation are not increasing year by year. In 2011, 74% of total claims were paid in one year, in 2020 it was - 75%. Therefore, RQ2 was rejected for the period 2011-2020. Impact of digitisation in 2011-2017 (period A) and no further trend justified 2018 - 2020 (see Fig. 1.28).

A ratio regression analysis is performed to justify the relationship between GDP and fast paid claims. The analysis test of the third research question shows a strong positive relationship between the ratio of fast paid claims (in a one-year period) and GDP per capita of the Baltic countries from 2011 to 2017.

For the period 2011-2017, a strong positive correlation is found between the GDP per capita of the Baltic and the digitisation measure (speed of claims processing in a one-year period in relation to the total number of claims paid) - 94%. However, no strong positive correlation is found for the period 2018-2020 and the hypothesis of research question RQ2 must be rejected for the whole period 2011-2020 (see Fig. 1.29). The author believes that this is due to large claims and that a detailed breakdown of payments is needed.

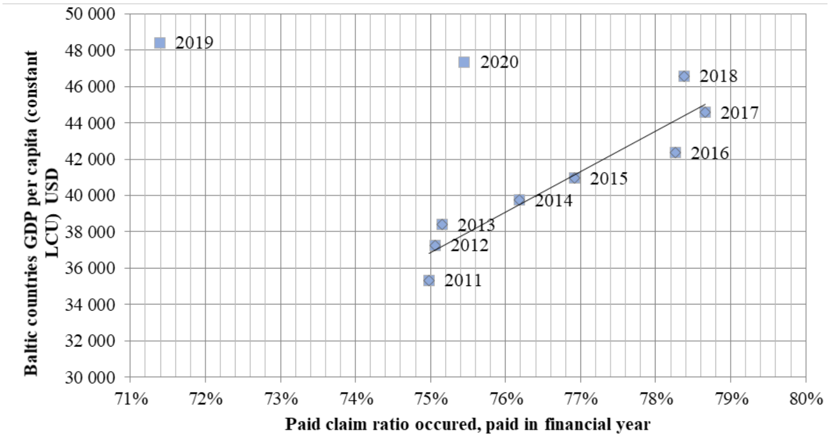


Fig. 1.29. Baltic non-life insurance market quick paid claims ratio (in % paid in one year over total paid claims) and the GDP per capita in USD million of Baltic.

Source: Calculations performed by the author based on AB Lietuvos draudimas (2020), BALTA (2020), BTA (2020), ERGO (2020), IF (2020), SWEDBANK (2020) and GDP per capita (World Bank, 2018).

Given the presence of correlation, the result is significant at 0.05 level of significance (i.e., the p-value of 0.0000) and the generated result is less than the 0.05 significance level in the defined research question RQ_3. The regression analyses show a good fit for period 2011-2018 (R-squared value is high, that is, 87.75%; F critical < F). Thus, RQ_3 cannot be rejected for period 2011-2018 (see Table 1.10).

The regression analyses show a poor fit (R-squared value is low, that is, 93.78%; F critical < F) and RQ_3 can be rejected for period 2011-2020. Table 1.10. shows the results of the regression analysis for the relationship between Baltic GDP and the rate of fast paid claims. The rate of quickly paid claims refers to claims where the year of occurrence and the year of payment are identical compared to the total paid claims.

The author advises to conduct the same investigation but with more detailed data per month and per quarter. The publicly available annual triangular data per company does not reveal the speed of claims settlement in a line of business such as health insurance, where claims are paid within one day. Furthermore, the increase in large claims and court claims could also lead to misleading quantitative results. Legal practise and the digitalisation of other state institutions in the Baltic States could also lead to misleading results. It is important to also take into account the different claims inflation between companies resulting from the different coverage and customer profile (e.g. fewer small and medium-sized companies).

Table 1.10

Regression analysis results 2011- 2020

Period: 2011-2018

Regression Statistics	
Multiple R	**93.78%**
R Square	**87.95%**
Adjusted R Square	0.8594
Standard Error	0.0059
Observations	8

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.6075	0.0242	25.0951	**0.0000**
GDP per capita	0.0000	0.0000	6.6161	**0.0006**

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1.00	0.0015	0.0015	**43.7724**	**0.0006**

Period: 2011-2020

Regression Statistics	
Multiple R	**1.20%**
R Square	**0.01%**
Adjusted R Square	-12.48%
Standard Error	2.31%
Observations	10

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.7629	0.0723	10.5468	**0.0000**
GDP per capita	0.0000	0.0000	-0.0340	0.9737

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1.00	0.0000	0.0000	**0.0012**	**0.9737**

Source: Calculations performed by the author based on AB Lietuvos draudimas (2020), BALTA (2020), BTA (2020), ERGO (2020), IF (2020), SWEDBANK (2020).

All three hypothetical research questions are accepted using regression analysis and the correlation analysis method with a 0.05 significance level for period 2011-2017 or 2011-2018. However, all research questions are rejected for full period 2011-2020.

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

The Baltic non-life insurance market has grown rapidly. The average growth of gross premiums during 2015-2020 is 11%, which is higher than the average growth of Baltic GDP of 5%. The market has huge growth potential (based on the analysis of average premiums and a comparison with other EU countries) and is classified as an emerging market. A summary of all gross written premiums in the Baltic market indicates a high degree of concentration in the market, an unequal market 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%. Estonia has the best overall performance and the lowest combined ratio. The positive profits in 2020 are due to the pandemic COVID -19 and low claims frequency. However, business interruption claims did not affect the market very much.

Claims reserves occupy the most important position in the economic balance sheet of non-life insurers with motor liability as their main line of business motor third-party liability.

Therefore, it is also the key governing subject for the public sector, including the regulator, to protect Baltic policyholders in the unlikely event, or multiple events, that their insurer becomes insolvent. The high deviation of reserving ratio and policies in the non-life insurance market is evident. The Baltic non-life insurance market has not used an alternative capital management method as an internal model during the period 2016-2021. In fact, the Baltic market does not even use it for the significant risk premium and reserve risk identified by the author.

The market is well and strongly capitalised over a five-year period. The median solvency ratios for 2016 and 2020 are 155% and 166%, respectively. However, the Baltic solvency ratio is lower than the median in the EU. The companies in the Baltic non-life insurance market do not use alternative methods for assessing capital management or internal capital models. The solvency framework II provides for greater harmonisation; since 2016 it has made it easier for companies to analyse and compare capital margin data. Market concentration is high and the investment portfolio is more conservative than in the EU. If the required capital is divided according to the underlying risk, then non-life risk has the highest capital requirement and the highest share is 57%. An overview of the economic balance implies that the investment structure of the Baltic market is more conservative than the EU market, resulting in a low median ROI of -0.2% to 1.24% over the period 2016-2020. Compared to 2016, ROE has increased from 10.03% to 17.7% in 2020 due to overall higher profitability, higher underwriting profits and business growth with a stable combined ratio. ROE is higher on an aggregate level than in advanced markets.

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 that can be used for future business growth. The regression analysis confirms that an insurer should consider the same percentage increase in GDP when planning the solvency capital requirement in a medium-term capital management plan for alternative and standard capital management methods. The current financial stability and capital surplus should be used by Baltic non-life insurers to absorb today's shocks such as inflationary pressures on claims costs and uncertainty in interest rate developments.

This chapter has analysed the relationship between the impact of digitalisation on insurers' claims management and the structure of claims reserves, total volume of claims paid out and GDP per capita in the Baltic countries. The analysis also helps to develop and improve other alternative methods of capital management, such as an internal capital model. All three research questions are rejected using regression analysis and the correlation analysis method with a significance level of 0.05 for the whole period 2011-2020. However, for the leading market participants, all three research questions are accepted for at least one year or at least part of the period (e.g. 2011-2017). The analysis confirms that the speed of claims processing depends on a portfolio, and the structure of the best estimate of claims only in 2017.

Legal frameworks and large claims may reduce the effectiveness of digitalisation in claims processing. Therefore, human intervention is still necessary. Furthermore, the analysis confirms that despite business growth and the increase in paid claims, the speed of claims processing is also increasing. The analysis also shows a strong positive correlation. The speed of claims processing and first-year payment behaviour increased by 4% between 2011 and 2017.

However, no increasing trend can be seen from 2018 to 2020. The speed of claims processing has increased by 1% over the period 2011-2020, which could be due to different pandemic trends and customer behaviour. Furthermore, the analysis shows that the insurance sector has started to use more digitalisation tools as the economy in the Baltic has grown. Furthermore, the results of this study show positive signs for digitalisation in claims management. Financial annual reports show the effect of faster claims settlement and reporting through mobile apps in the Baltic countries.

There are no quantitative studies quantifying the impact of digitalisation on claims management in the Baltic non-life insurance market. Digitisation of online services has been studied by other researchers through qualitative studies, expert-based developments and surveys. The author advises to work on the same research questions but with more granular data per month and per quarter. The publicly available annual triangular data per company does not give an indication of the speed of claims settlement in a line of business such as health insurance, where a claim is paid within one day. Furthermore, the increase in large claims and court actions could also lead to misleading quantitative results. Legal practise and the digitalisation of other state institutions in the Baltic States could also lead to misleading results. It is also important to take into account the different claims inflation between companies resulting from the different coverage and customer profile (e.g. fewer small and medium-sized companies.

2. THEORETICAL ASPECTS TO CAPITAL MANAGEMENT OF AN INSURANCE COMPANY

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.

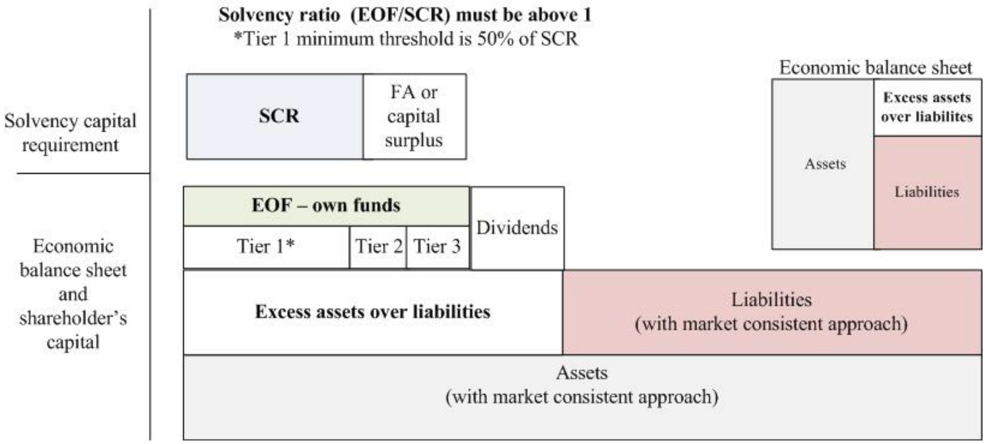


Fig. 2.1. Solvency ratio, free assets or surplus simplified calculation principle.

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' 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%).

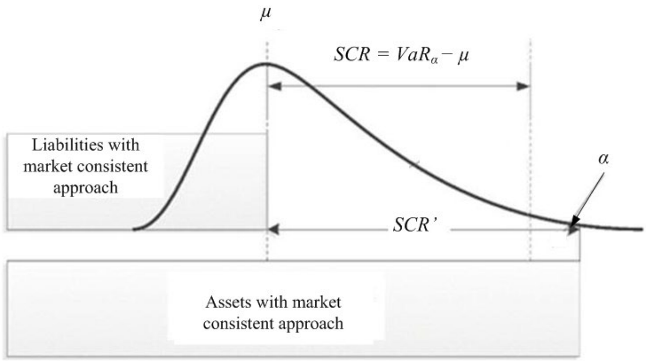


Fig. 2.2. The general concept of modelling capital requirements.

Source: Author's adjustments using Sandström (2011) and Valecký (2017).

Risk-based capital covers risks (sub-module risks): market risk (interest rate, equity, property, spread, currency, concentration); health underwriting risks (SLT health, catastrophic risks, non-SLT health); counterparty 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. Structure of SCR is illustrated in Fig. 2.3.

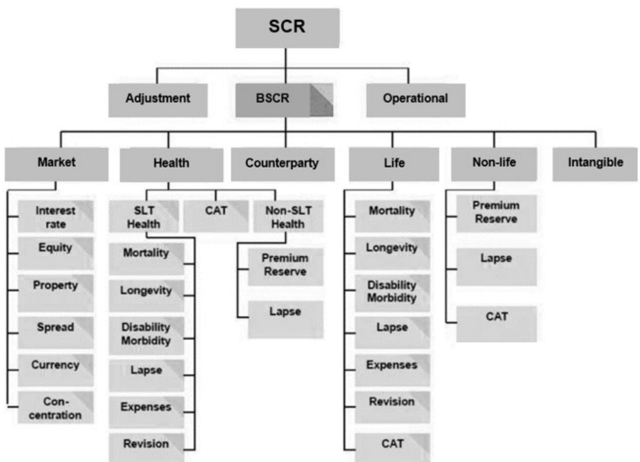


Fig. 2.3. Sub-module risks of SCR.

Source: Based on EIOPA (2014b).

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. 2.4 and formula (2.1).

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

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. 2.4**.** Standard formula correlation matrix.

Source: Based on European Parliament & Council of the European Union (2014).

The Solvency II framework is a risk-based model consisting of three pillars. Pillar one relates to the calculation of capital requirements. Pillar two covers risk management. Pillar two requires a solvency assessment of own risk (ORSA) and the assessment of the standard formula. Signs that the implementation of the internal model may be creating a greater own risk profile and indications of significant changes may already be observed during the ORSA process. If such is the case, then the internal model should be developed. Moreover, a financial supervisory body can also require this internal model.

The internal model is approved by a local regulator. These problems may affect both the stand-alone economic capital model of a single entity that is a member of a group as well as the economic capital model of the entire group as a whole. Regulators have to regularly approve a re-submitted internal model in the EU, while the company should continually analyse the sensitivity of the internal model to the input parameters. Local regulator has approved for NewRe, a Zurich-based subsidiary of Munich Re Group, and the main reason was a fully different risk profile compared to the group (NewRe, 2019). Pillar 3 is related to public disclosure management and supervision reporting.

A company's risk appetite reflects its overall risk appetite and the expectations of its stakeholders, including shareholders and policyholders. A company's overall risk appetite determines the amount of risk it is willing to bear. Risk tolerance represents the amount of capital an insurance or reinsurance company is willing to put at risk by converting the value of risk appetite from qualitative to quantitative terms. A company's risk tolerance is a critical factor in determining the level and structure of its capital structure.

Heuristically, a company with a very low capitalisation immediately leads to bankruptcy, while too high a capitalisation makes the company unprofitable, as it would not be able to generate the return on capital that shareholders are hoping for. Between these two extremes there is the so-called "capital trade-off", the ideal capitalisation.

As shown in Fig. 2.5, the only link between capital management and the enterprise risk management (ERM) structure is the risk appetite set by the supervisory board. Thus, the higher the risk appetite set in the business strategy, the more capital is required.

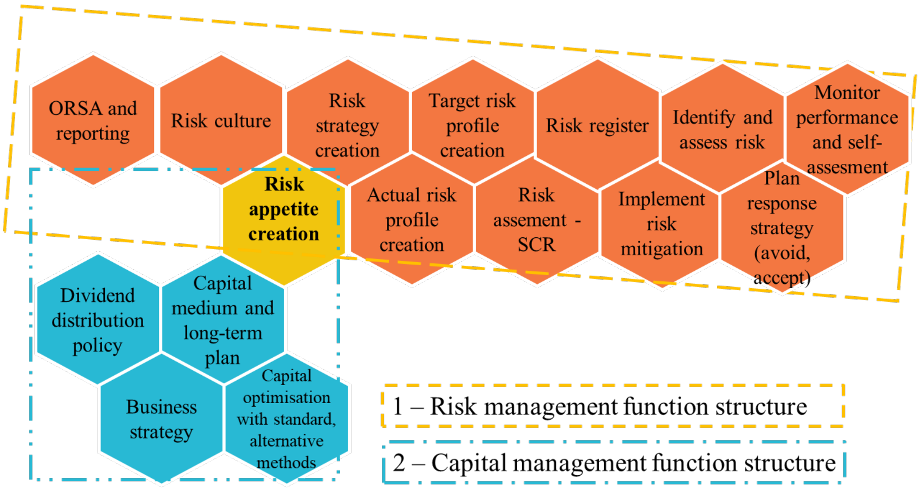


Fig. 2.5. Link between capital management and risk management function, and risk appetite.

Source: Created by the author based on COSO (2019), Kaļiņina & Voronova (2014), Proctor (2013), EIOPA (2014) and Spencer (2014).

Under Solvency II there are three lines of defence. The governance system states that the risk management function includes properly assessing the risk profile, promoting the risk management system and taking responsibility for the ORSA and SCR calculations. The person in charge of the actuarial function (appointed chief actuary) is primarily responsible for coordinating the calculations of technical provisions. The person in charge of the compliance function primarily relates to the evaluation and facilitation of the internal control system. The person responsible for internal audit ensures the independent and objective review of all processes and functions as well as the risk management system. The risk owners and business units are all employers involved in business performance, measurement management, internal control systems and risk management systems. The framework is not stringent throughout in the area of internal modelling. It is based on the idea that an insurer should know more than a national regulator about the most important risks in relation to the company's goals and its own risk profile.

The author's concept for the internal process for assessing capital adequacy according to Basel II with adaptations for the insurance industry is shown in Fig. 2.6. It also shows the link between financial management, capital management and risk management. A higher level of risk provides higher returns and higher capital requirements and capital costs. For many years, banks have used risk-adjusted return on capital (RAROC), a measure of risk-based profitability, as an important criterion for deciding whether to enter into business relationships with companies. EU insurers can use the return on SCR as a measure of risk-based profitability, which can be compared to the RAROC measure for the banking sector.

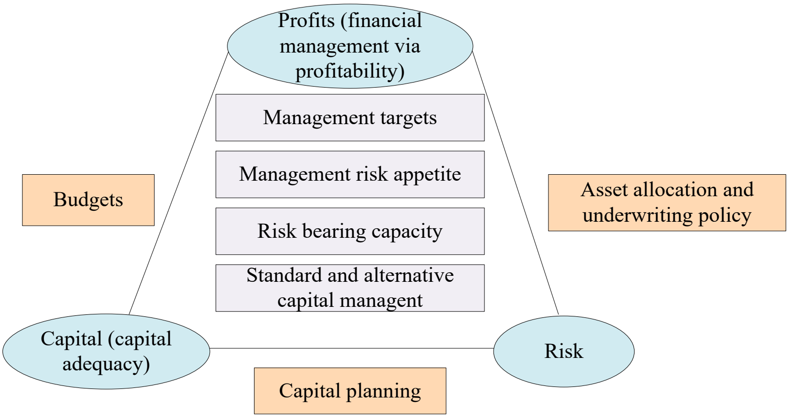


Fig. 2.6. Triangular relationship among profit, capital and risk.

Source: Adjusted by the author based on concept of Basel II and COSO framework (The Norinchukin Bank, (2009) and COSO (2019)).

An appropriate goal for financial management is to maximise the current value of the company (Ross *et al.*, 2016). By maximising the share price, management maximises shareholders' shares, return on equity, return on working capital and shareholder value. Minimising the total cost of the company's projects maximises the value of the company's cash flow. Capital optimisation and performance optimisation are also the main objectives of capital management, which helps to maintain financial stability with desirable financing techniques (Malyon, 2013).

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. 2.7).

When digitalisation tools and technologies are integrated and used, alternative management techniques are applied by reassessing the main risks. For example, automatic claim payments or faster claims settlements lead to a lower claim reserve on the economic balance sheet, reducing the capital required for reserve risk. According to the author, companies should give high priority to customer service through the digitalisation of claims management. Important performance parameters such as the loss ratio (fraud is detected), the cost ratio (lower manual effort, human error) and the solvency capital requirement can be improved as a result (especially for reserve risk).

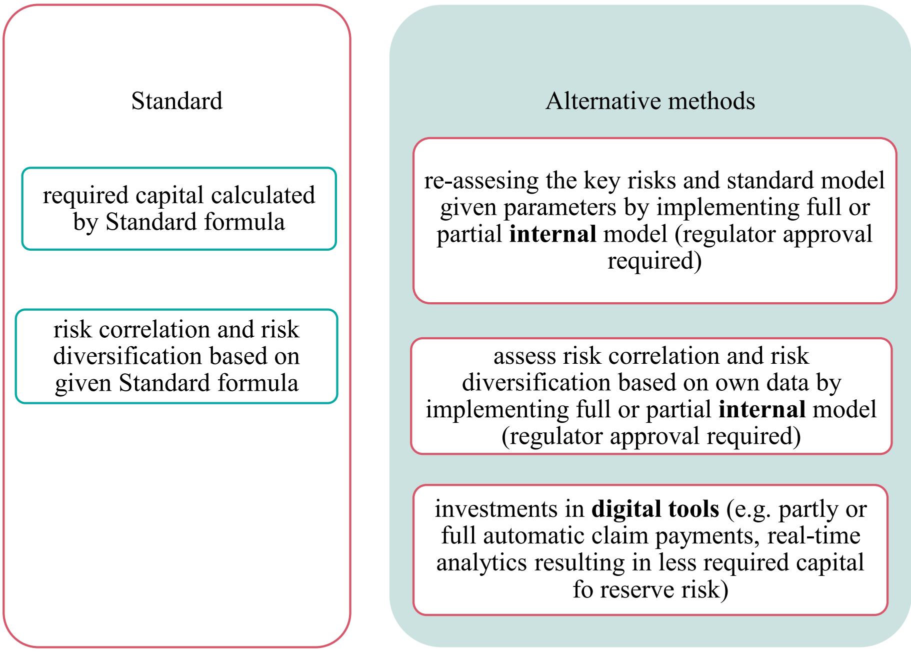


Fig. 2.7. Standard and alternative capital management methods.

Source: Created by the author.

The main optimisation techniques which can be applied for both alternative and standard approaches are decrease of net liabilities with reinsurance or loss portfolio transfer, synchronize the investment structure, tighten cost management, strengthen product pricing and customer relationships. Schwarz *et al.* (2011) describes full potential points how insurers can optimize their capital and risk structure.

In the Thesis, the internal model is used for re-assessing the key risks and capital required and is classified as an alternative capital management method. The internal model may be beneficial for reflecting a true risk situation (Gatzert & Kosub, 2016). It can lead to complex models, but complexity should have limits. Green & Armstrong (2015) compared simple and complex methods and concluded that complexity increased a forecast error by 27% on average in 25 papers with quantitative comparisons. Clients who prefer accuracy should accept forecasts only from simple evidence-based procedures (Green & Armstrong, 2015).

Fig. 2.8 depicts the idea that the more complex the model, the more accurate the risk profile and the higher the running time, development and maintenance costs of the model. The highest costs, running time but the most precise risk profile will be achieved by using an internal model.

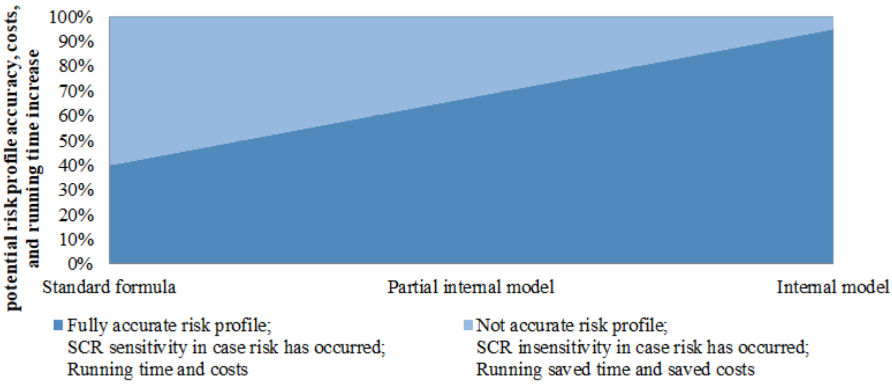


Fig. 2.8. Example of potential risk profile accuracy, costs, and running time based on a model used for risk-based capital calculation.

Source: The author's interpretation is based on PricewaterhouseCoopers (2011).

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. A parent and a subsidiary may be located in different regions, and each standard change may affect many large insurance groups (Gatzert & Kosub, 2016). According to the US regulator NAIC, insurance is more regulated than other business sectors due to the complexity of insurance contracts (NAIC, 2011).

A precise definition of the alternative model was not given in the Solvency II framework in the main regulations delegated by the EU Commission, namely the Solvency II Directive 2009/138/ EC and the Solvency II Regulation 2015/35. The reason for this is that Solvency II is a principles-based regulatory regime. Experts may have different views and levels of understanding of what an internal model means. The CEA and the Groupe Consultatif (CEA & Groupe Consultatif Actuariel Europeen, 2007) use the definition of internal model as a risk management system developed by an insurer to analyse the overall risk position, quantify risks and determine the economic capital required to manage those risks.

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).

Regulators should be updated with new risk assessment methods and continue to improve knowledge. To implement an internal model, regulators should keep in line with requirements in accordance with articles 120 to 125 of the Solvency II Directive 2009 (European Parliament, 2009). The main issue is that a regulator needs to individually test the internal model. Many standards and tasks must not only be included in the documentation but must also be built into the everyday decision-making process and risk governance system.

Every internal model under the Solvency II framework should have following characteristics and provide certain possibilities. First, the model follows the principles of the standard formula of the Solvency II regulation. It consists of market-consistent valuation techniques and uses a *VaR* measure with a 99.5% confidence level in the one-year horizon. The internal model must also have the regulator's previous authorisation. Second, reserves and capital must be properly set aside and allocated to each line of business and all portfolios so that the pure risk profile can be seen. Third, the precise capital allocation must maintain a good reputation. Fourth, a balance between accuracy and simplicity must be achieved, and the process should be neither too costly nor time consuming. Finally, the model must avoid all the intensely discussed issues in academic journals, that is, the potential dependences between risks. The literature review in the subsequent section demonstrates this principle.

Fig. 2.9 shows a scenario of how capital management decisions can be changed in case of own funds is less sensitive, volatile to a certain extreme event, a certain risk than under the standard formula's SCR. And therefore, resulting in capital gains and savings in potential capital costs for shareholders, and supporting to make long-term investments.

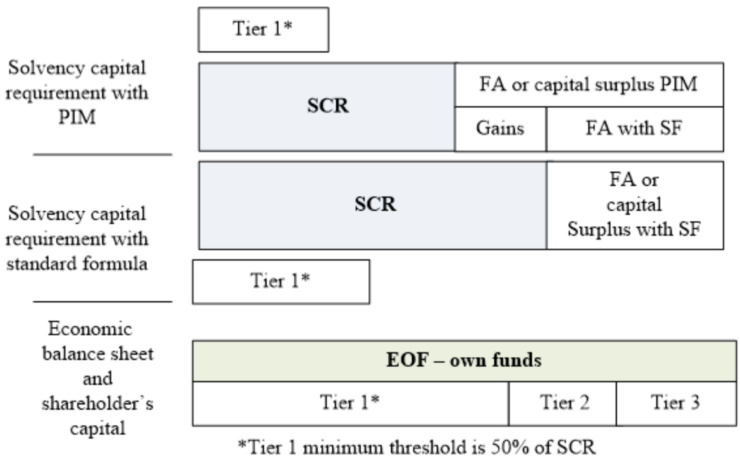


Fig. 2.9. Scenario of capital gain with internal model as alternative capital management method and potential changes in capital tiering.

Source: Created by the author.

Changes to the SCR amount affect how much Tier 1 capital e.g. common equity capital must contain. The example scenario shows that Tier 1 capital can be reduced or the amount of dividends paid can be increased to maintain the same SR. The full description of the minimum and maximum thresholds is shown in Fig. 2.10.

The calculation of the solvency ratio must take into account certain limitations imposed by the European Parliament and the Council of the European Union (2014). If the thresholds are not reached, the capital position is not taken into account in the calculation of eligible own funds.

SCR		
EOF = Tier 1 + Tier 2 + Tier 3		
Tier 1 = unrestricted + restricted	Tier 2	Tier 3
Total Tier 1 must be at least 50% of the SCR. Restricted Tier 1 can be up to 20% of total Tier 1.	Tier 2+Tier 3 capital can be up to 50% of the SCR. Tier 3 capital up to 15% of the SCR.	

Fig. 2.10. Scenario of capital gain with PIM and potential changes in capital tiering.

Source: Created by the author based on European Parliament & Council of the European Union (2014).

Fig. 2.11 provides a description of the main internal model standards that need to be included in the approach and the objectives of each standard. The utilisation test is a key lever to achieve a positive return on investment (Sia Partners, 2011). The internal model methodology includes model components such as model type (e.g., deterministic or stochastic), assumptions (e.g. longevity), interactions (e.g. future management actions, policyholder behaviour), data (e.g. internal or external), IT (e.g. the program used for the calculations) and process (procedure, governance and internal or external audit).

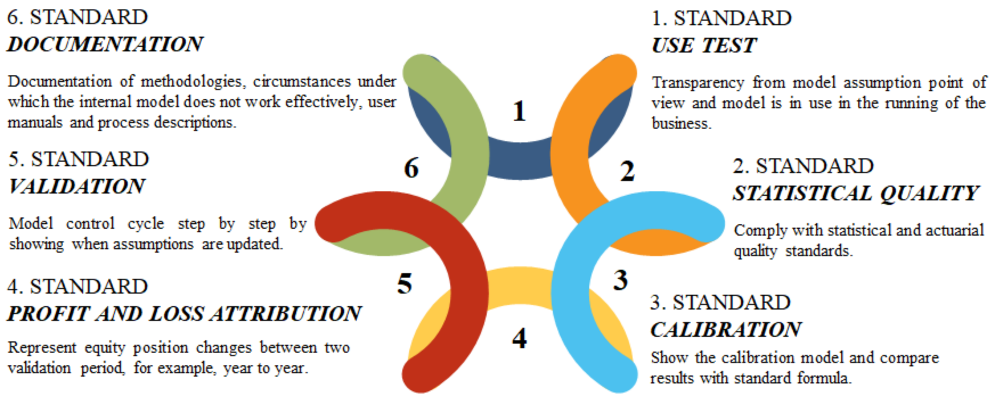


Fig. 2.11. Main standards and their aim for internal model implementation.

Source: The author's interpretation based on EIOPA (2014a).

The standards shown in Fig. 2.11. must be approved by boards as internal policies with underlying procedures.

The first step in maintaining financial stability is to prepare forward-looking capital projections that take into account the uncertainty of the net asset value, the solvency capital requirement, the solvency ratio and the foreseeable dividends. The projections should take into account the potential impact of macroeconomic and uncertainty scenarios. Fig. 2.12 illustrates a possible scenario in the coming years and its impact on SCR, own funds and SR with a possible macro scenario. For example, inflationary pressures would affect premium risk and increase SCR. Second, systematic defaults could lead to an insufficient reserve. Next, an interest rate increase by the central bank affects the volume of assets and own funds. The market value of fixed-income assets decreases after the shock is realised.

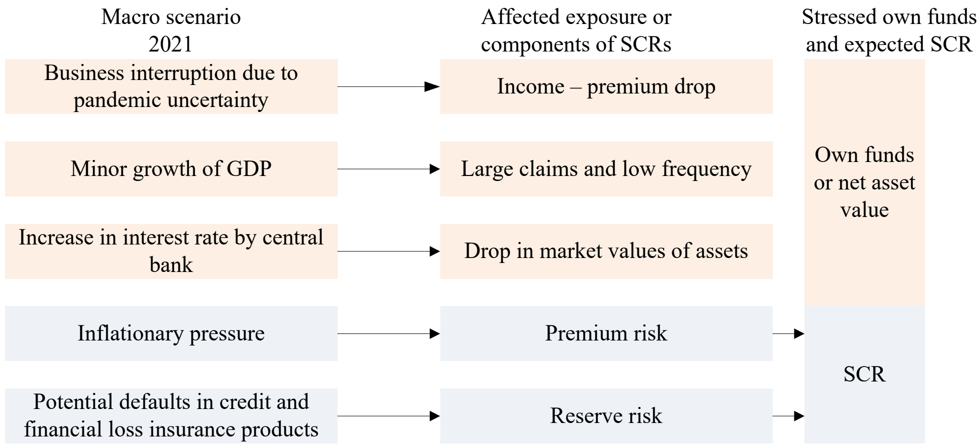


Fig. 2.12. Potential capital projections forecasts with macro scenario.

Source: Created by the author.

A medium- and long-term capital management plan requires forecasting SCR changes over a time horizon longer than one year. Local regulators require a minimum period of three to five years. Fig. 2.13 shows a simplified section of the flow chart of the decision-making process that takes into account which shifts, losses due to potential risks are significant and described in the insurer's local internal control system.

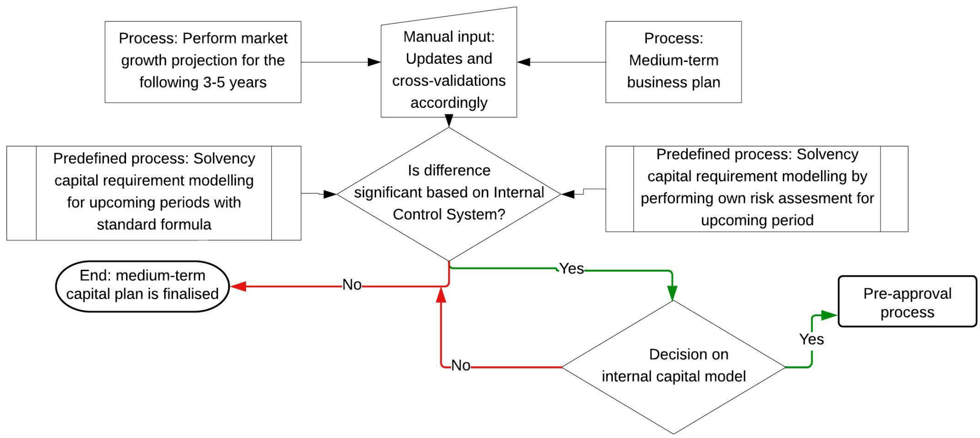


Fig. 2.13. Simplified part of process flow chart for medium-term capital planning.

Source: Created by the author.

The author proposes a procedure for medium-term capital planning and decision-making for Baltic non-life insurers, which refers to using internal models and performing harmonisation between a company and expected market growth in line with GDP growth, as described in section 1.2. If the SCR difference between the standard formula and the own assessment is above the materiality threshold, an internal pre-approval procedure may be initiated.

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. The calculation of the required capital using the internal model is based on the Solvency II framework reserve. The IFRS reserve is required for the profit calculation and its methodology is not in scope of Doctoral Thesis. The alternative capital management method as internal model for the reserve risk has to be built on the basis of the non-life claim reserve in the economic balance sheet with the valuation principles of Solvency II (see Appendix 3). The choice of methods also has an impact on the amount of capital required.

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. In contrast, the risk underlying the premium reserve is premium risk. The author does not provide internal modelling techniques for premium risk and therefore the methods and determination of premium reserves are not concluded in this Thesis. In addition, there is a risk margin within the SII that explains the cost of capital for future capital requirements or SCR run-off in the event of insolvency. If the reserve volume has been increased, the risk margin also follows the same trend.

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. The Non-life Section of the International Actuarial Association Section ASTIN (Actuarial Studies in Non-Life Insurance) has published survey results for non-life reserving practice in the world (ASTIN, 2016). Deterministic approaches, are used for claim reserve calculation, including the widely used technique Chain Ladder, Bornhuetter-Ferguson, Loss ratio, Average cost, Cape Cod, Fisher Lange, Generalised linear model Chain Ladder, Munich Chain Ladder and De Vylder (ASTIN, 2016). Schmidt (2007) provided an extended bibliography on loss reserving. Stochastic approaches, such as Mack (1993) and Bootstrap (Efron, 1979), have been developed using a classical Chain Ladder approach as a base model. These methods help calculate the standard deviation of a reserve from the mean (i.e. the amount on the economic balance sheet). Some countries, including Germany and Finland, clearly prefer Mack, while others, such as Australia and the Netherlands, prefer Bootstrap (ASTIN, 2016). Wütrich and Bühlmann (2009), and Merz and Wütrich (2008) developed classical approaches to assess reserve risk for a one-year time horizon as it was under the Solvency II framework. The Mack Chain Ladder model provides not only the claim best estimate but also the reserve standard deviation. Best estimate is typically highly sensitive in the most recent accident years. Therefore, the Mack model shows reserve risk, capital sensitivity and the idea of whether significant uncertainty exists by using any other method (Mack, 1993). 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 (England & Verrall (2002, p.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 – refers to incremental claims data;

i - the suffix refers to the row indicating accident year;

j - the suffix refers to the column and indicates the delay in years;

n - the suffix refers years, count of columns;

k - the suffix refers to the column for estimates;

D_{ij} - are denoted assumed cumulative claims;

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

$D_{i,n-i+1}$ – are 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. Calculation holder should understand common business sense and the main changes in products.

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

The author has examined that the importance of claim reserve plays a significant role in the economic balance sheet. This leads to the importance of calculating the required capital for reserve risk with proper risk assessment and a broader sensitivity analysis of the impact on own funds. This cannot be done without an appropriate culture of risk and stability management, which includes assessing the risk aggregation of insurance products. Underwriting risk in non-life insurance consists of three sub-modules: premium and reserve risk, lapse risk and catastrophe risk (see Fig. 2.14).

Reserve risk is a sub-component of SCR for non-life underwriting risk.

In this Doctoral Thesis the reserve risk definition is applied as highlighted: **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.**

However, the exact definition of reserve risk is not provided by the Solvency II framework. It considers the distribution of the profit and loss on the estimated reserves over a one-year time horizon. According to Buckham *et al.*, (2011) and England *et al.*, (2019), reserve risk is a risk in which additional technical provisions might have to be raised against previous years' claims. For Diers & Linde, (2013), reserve risk relates to embedding future accident years, leading to an integrated approach for quantifying a multi-year risk arising from the settlement of outstanding claims.

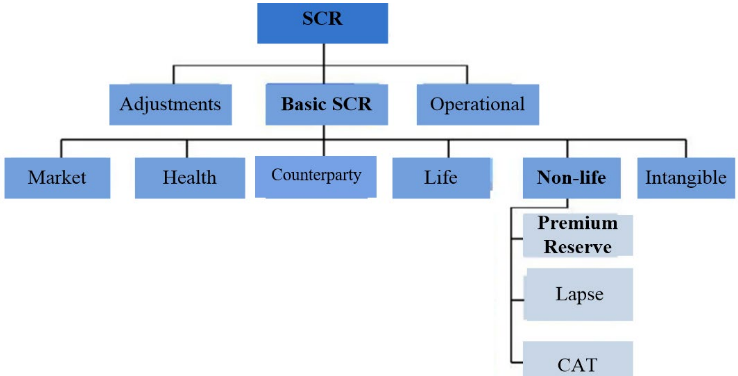


Fig. 2.14. Reserve risk in the classification of SCR in the Solvency II framework.

Source: Adjusted by the author based on EIOPA (2014b).

SCR for reserve risk depends from standard deviation of reserves expressed as fraction from volume (see formula (2.7)). Net reserve is calculated as the difference between gross and reinsurance share, reserve in liabilities minus reserve in assets in the economic balance sheet. Assuming log-normal distribution of reserve risk the standard deviation for each line of business is set by Solvency II framework by EIOPA Article 117(1) (EIOPA: European Parliament, 2014). 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 − volatility measure, standard deviation for e product reserve risk;

CBE_e − 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} - sum of claim reserves best estimate after reinsurance for all the lines of business;

(e, p) - the sum covers all possible combinations of the line of business e to p;

$CorrS_{(e,p)}$ - a correlation coefficient between lines of business e and p set out by the EIOPA (EIOPA: European Parliament, 2014) (see Appendix 4).

The correlation matrix and measures of the volatility of non-life reserve risk for the top line of business in the Baltic non-life insurance market are shown in Table 2.2.

Table 2.2

Correlation matrix and measures of the volatility of non-life reserve risk for the main line of business

	Motor vehicle liability	Other motor	Fire and other damage to property	General liability	Measures the volatility
Motor vehicle liability	1	0.5	0.25	0.5	0.09
Other motor	0.5	1	0.25	0.25	0.08
Fire and other damage to property	0.25	0.25	1	0.25	0.10
General liability	0.25	0.25	0.25	1	0.11

Source: Based on 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 published the way how claim development for one year can be derived using the bootstrap Chain Ladder method (see procedure Appendix 7). Boumezoued *et al.* (2011) and Diers (2008) have summarised the major advantages of the bootstrap methodology. Fig. 2.15. represents the main principle that reserve risk is assessed for next year's payments and outstanding claim reserve. It presents a simplified triangulation method for visualization of next year's payments (called also one-year run-off vector). Probability density function can vary from the presented normal distribution density function.

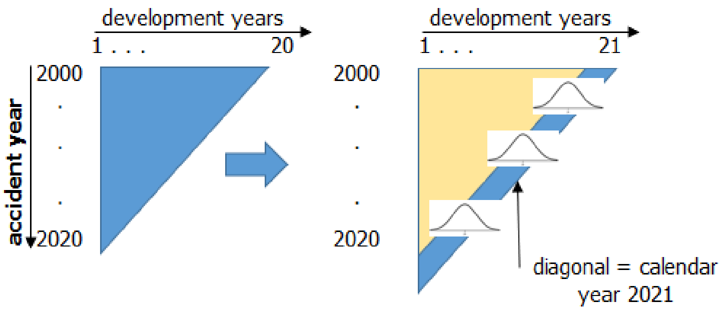


Fig. 2.15. One-year reserve risk in the Solvency II framework.

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

The main mathematical criteria in case of standard formula application are summarised in Fig. 2.16.

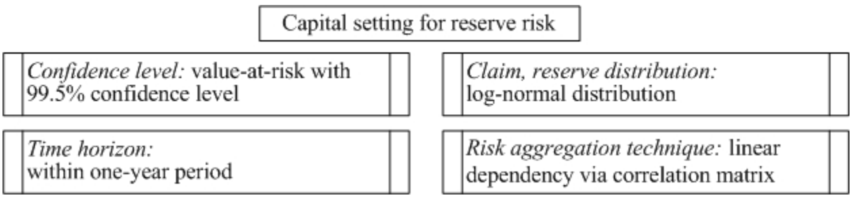


Fig. 2.16. Main mathematical criteria for reserve risk in Solvency II.

Source: Concluded by the author based on EIOPA (2014b).

The main mathematical criteria in case of standard formula application are choice of value at risk with confidence level 99.5%. Next, one-year time horizon and risk aggregation by applying correlation matrix. Finally, assume that reserve risk has log-normal distribution (EIOPA, 2014b). 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 this 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. Application of internal model is method of alternative capital management.

The research question formulated in the Thesis for literature review is as follows: What are the weaknesses of the EIOPA's standard formula for non-life reserve risk under the Solvency II framework? The answer to the research question would help in identifying capital influencing factors based on quantitative case studies and would help to achieve reliability and the accuracy of proposed method for an alternative capital management. Peer-reviewed articles (published between 2006 and 2020) in the Scopus database are used in the search process. The database has been selected because it is the largest abstract and citation database of peer-reviewed (primary) literature. It also has a wide range of literature coverage of enterprise risk management, actuarial science and mathematics. The search starting year of 2006 has been chosen because it was the period when the quantitative impact study of SII was approved for the first time (CEIOPS, 2007). The keywords for the literature review are 'reserve' and 'capital', and 'risk' and 'solvency'. The keywords used are outlined in Fig. 2.17.

Search: TITLE-ABS-KEY("**reserve**" AND "**capital**" AND "**risk**" AND "**solvency**") AND (LIMIT-TO (PUBYEAR,2020) OR (LIMIT-TO (PUBYEAR,2019) OR (LIMIT-TO (PUBYEAR,2018) OR (LIMIT-TO (PUBYEAR,2017) OR LIMIT-TO (PUBYEAR,2016) OR LIMIT-TO (PUBYEAR,2015) OR LIMIT-TO (PUBYEAR,2014) OR LIMIT-TO (PUBYEAR,2013) OR LIMIT-TO (PUBYEAR,2012) OR LIMIT-TO (PUBYEAR,2011) OR LIMIT-TO (PUBYEAR,2010) OR LIMIT-TO (PUBYEAR,2009) OR LIMIT-TO (PUBYEAR,2008) OR (LIMIT-TO (PUBYEAR,2007) OR LIMIT-TO (PUBYEAR,2006))

Fig. 2.17. Keywords.

Source: Created by the author.

Twenty-six papers have been selected after a review of 57 papers. Non-life insurance companies are the object of the selected papers, and the subject is the internal model for reserve risk in the context of SII. Life insurance companies are disregarded because of their different profit and risk drivers such as low-yield environment, biometrical risk, number of healthy life years and life expectancy. Furthermore, legislation from regulators is not considered as a primary source. Papers written in the English language are considered. The weaknesses are classified into the following four groups:

- risk aggregation (factor 1),
- time horizon used for capital setting (factor 2),
- model type, that is, stochastic instead of deterministic (factor 3), and
- profitability (factor 4).

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. Certain keywords or mentions in the analysed materials for the risk aggregation aspect have been identified, namely correlation, dependence, diversification, aggregation and independent. Time horizon can be described as a period during which capital is set in an adequate amount for a one-year horizon but it should be assessed in a longer time horizon. Some keywords or mentions in the analysed materials for the time horizon aspect have been found, namely ‘short time’, ‘one year’ and ‘not a lifetime’. Meanwhile, model type can be defined as capital in which the risk is not even appropriately calculated for each line of business.

The following keywords or mentions in the analysed materials for the model type aspect have been found: distribution, deterministic, parameter, proportionality, greater variance, network approach and stochastic. Finally, profitability can be interpreted as a state in which risk depends on average claim costs, which can vary when comparing different regions. Certain keywords or mentions in the analysed materials for the profitability group have been identified, such as profit, profitability, average premium, exposure, profit and loss, and expected profits.

The process flowchart of paper selection, rejection and classification is illustrated in Fig. 2.18.

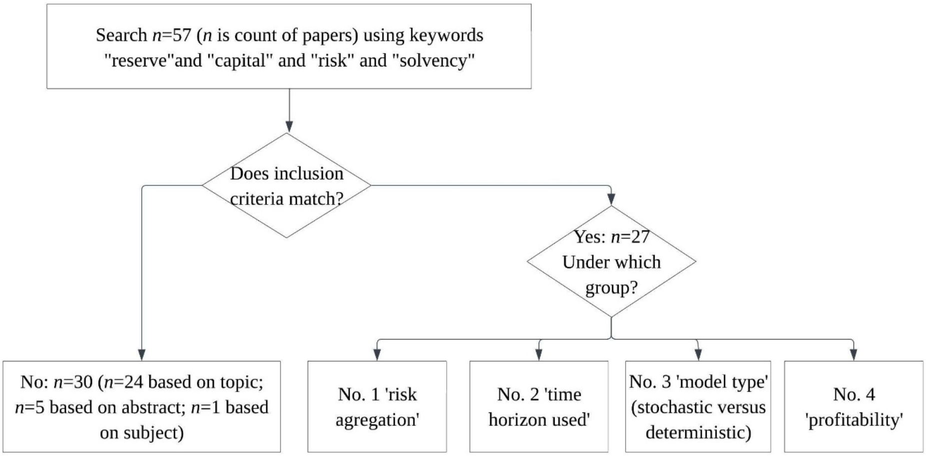


Fig. 2.18. Flowchart diagram of the literature review.

Source: Created by the author.

Table 2.2 presents an overview of the proposed factors for implementation in the internal model methodology and the weaknesses of the EU standard formula for reserve risk discussed in peer-reviewed papers. Table 2.3. presents overview of all papers, researchers that were included in review.

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 (for an extended review, refer to Appendix 5).

Table 2.3

Research papers and weakness discussed by researchers.

		Factor No:	Factor 1	2	3	4
No.	Papers' authors	Reference	Risk aggregation	Time horizon used	Model type	Profitab ility
1	Alm, J.	Alm, (2015)	+			
2	Araichi, S., & Belkacem, L.	Araichi & Belkacem, (2014)	+			
3	Araichi, S., Peretti, C. D., & Belkacem, L.	Araichi *et al.* (2017)	+			
4	Arbenz, P., Hummel, C., & Mainik, G.	Arbenz *et al.* (2012)	+			
5	Bargès, M., Cossette, H., & Marceau, É.	Bargès *et al.* (2009)	+			
6	Bermúdez, L., Ferri, A., & Guillén, M.	Bermúdez *et al.* (2013)	+			+
7	Biard, R., Lefèvre, C.,& Loisel, S.	Biard *et al.* (2008)	+			
8	Bølviken, E.,& Guillen, M.	Bølviken & Guillen (2017)	+			
9	Butaci, C., Dzitac, S., Dzitac, I., & Bologa, G.	Butaci *et al.* (2017)	+			
10	Clemente, G. P., & Savelli, N.	Clemente & Savelli (2017)	+			+
11	Dacorogna, M., Ferriero, A., & Krief, D.	Dacorogna *et al.* (2018)			+	
12	Diers, D., & Linde, M.	Diers & Linde (2013)		+		
13	Diers, D., Eling, M., & Linde, M.	Diers *et al.* (2013)			+	
14	England, P. D., Verrall, R. J., & Wüthrich, M. V.	England *et al.* (2019)		+		
15	Ercole, C. G., & Paolo, C.G.	Ercole & Paolo (2020)			+	
16	Ferriero, A.	Ferriero (2016)	+			
17	Fersini, P., & Melisi, G.	Fersini & Melisi (2016)			+	
18	Forte, S., Ialenti, M., & Pirra, M.	Forte *et al.* (2012)		+	+	
19	Fröhlich, A., & Weng, A.	Fröhlich & Weng (2018)			+	
20	Hejazi, S.A.,& Jackson, K.R.	Hejazi & Jackson (2017)			+	
21	Kemaloglu, S.A.,& Gebizlioglu, O.L.	Kemaloglu & Gebizlioglu (2009)			+	
22	Moro, E. D., & Krvavych, Y.	Moro & Krvavych (2017)	+		+	
23	Munroe, D., Odell, D., Sandler, S., & Zehnwirth, B.	Munroe *et al.* (2015)			+	
24	Ohlsson, E., & Lauzeningks, J.	Ohlsson & Lauzeningks (2009)		+		
25	Savelli, N., & Clemente, G. P.	Savelli & Clemente (2011)	+			+
26	Slim, N., & Mansouri, F.	Slim & Mansouri (2015)	+			
27	Van WouWe, M., Verdonck, T., & Van Rompay, K.	Wouwe *et al.* (2009)			+	
	Total count		**14**	**4**	**11**	**3**

Source: Created by the author (extended review in Appendix 5).

There are papers which are classified under more than one group of weakness. The result would allow for the avoidance of issues for alternative management method as internal model development that have already been discussed in research papers such as. Clemente & Savelli (2017), Savelli & Clemente (2011) and Bermúdez *et al.* (2013) have discussed both profitability and risk aggregation. Forte *et al.* (2012) have discussed both time-horizon and model type weakness and improvements needed. Moro & Krvavych (2017) have discussed both risk aggregation and model type weakness under standard model in Solvency II framework.

Almost all the selected papers are from well-known actuarial science and ERM journals, for example, *Insurance: Mathematics and Economics*, *Scandinavian Actuarial Journal*, *Journal of Computational and Applied Mathematics*, *Journal of Applied Economic Sciences, Risks* and *Journal of Economic Modelling*. Overall, the set of studies is dominated by EU researchers. EU researchers dominate because the Solvency II framework is a risk-based EU framework.

Fourteen of 27 papers have mentioned the dependency problem related to risk aggregation, namely the ones authored by Araichi, Moro, Bølviken, Ferriero, Fersini, Alm, Slim, Bermúdez, Hummel, Savelli, Bargès, Biard, Clemente and Butaci. Non-linear risks mainly exist in the real world, but not in a linear manner. Analysed studies (52%) 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 creating multivariate distribution not normal distribution. Large insurance groups, chief risk officers, chief executive officers and national financial supervisory authorities should consider this issue by creating and approving internal capital models. Otherwise, the consequences would be insolvency, capital insufficiency and a market crisis (for large insurance groups).

Ten of 27 papers indicate that problems occur because insurance companies use only deterministic approaches for outstanding claim reserving. These papers are authored by Dacorogna, Diers, Fersini, Forte, Fröhlich, Hejazi, Kemaloglu, Munroe, Moro, Ercole, Paolo and Wouwe. Claim best estimate (claim reserve) should be set only with a 50% confidence level in accordance with the definition of best estimate. Therefore, companies can change methodologies to increase their SR and decrease the reserve risk. Furthermore, reserve risk depends on reserving policy, behaviour of actuaries, management actions (e.g., reinsurance) and reserving sufficiency. Therefore, the approach of the standard formula is extremely simple. Anyway, both deterministic and stochastic includes some sort of subjectivity and company should provide at least two independent working teams or experts in order to obtain sound and plausible estimates.

Four papers state that the major problem is related to an excessively short time horizon for SCR calculation. The authors of these papers mentioning such excessively short period for capital setting projections are England, Forte, Diers and Ohlsson. According to researchers, the standard formula fits only large companies in the case of normal market conditions. Thus, small and medium-sized companies have the highest possible difference between current capital risk assessment using standard formulas and the appropriate capital risk assessment. In this study, Baltic non-life insurance companies are deemed to fall within the scope of small and medium-sized companies in the European context. Baltic non-life insurance 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 such as Germany, Austria and Sweden. Large claims, which are outliers, also have a significant impact. The standard formula entails holding capital in a one-year horizon for risk assessment. This issue is identified and mentioned in 12% of the analysed papers.

Three of 27 papers have indicated that profitability should be taken into account. Profit margin, risk premium and costs can considerably vary in different European regions. Savelli, Clemente and Bermúde have mentioned loss-making business, profitability aspect for capital setting projections.

The possible solutions and alternative approaches to solve the problems of the EIOPA Solvency II standard formula are then investigated in this study. To solve the dependency problem, 14 papers propose a copula approach. The main copulas that are mentioned include the Gaussian copula (3 papers), the Clayton copula (2 papers), the Farcie–Morgenstern copula (1 paper) and the non-specific copula (8 papers). To resolve the issue of a short time period, ruin theory and geometric Brownian motion are proposed. To address deterministic and time issues, bootstrapping and Monte Carlo methods (7), regression models (3), stochastic reserving methods, including a robust Chain Ladder and Mack Chain Ladder, a generalized cap code, the Frohlich and Weng model, a neural network approach, a credibility approach, a Bayesian model, and a COT method developed by the SCOR insurance group are proposed.

The author of the present study maintains that a neural network approach and machine learning techniques will also be mentioned in the following papers, as big data algorithms are becoming more popular. The credibility approach method is also becoming more popular in non-life insurance as a pricing technique. This method is simple and easy to build within systems. The first step should be to test the reserve risk underlying distribution. There are following papers published in data basis after this specific literature review and which the author would like to highlight: Castellani *et al.* (2018) and Fernandez-Arjona (2021).

These topics in published papers are investigated in this Doctoral Thesis, and parts of these studies are included in the following sections: 'suggestion of an alternative approach for non-life risk using a copula approach' and 'how to choose the most appropriate type of copula for non-life reserve risk for different lines of businesses. 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.

In the last step, the author has determined whether the copula approach is used in research papers by Baltic researchers. A total of 50 papers were published. A total of 19 authors from the Baltic were identified using the keywords "copula" in Scopus and Web of Science (Appendix 6). 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. There are no research papers with the keywords "reserve" and "copula" published by Baltic authors in Scopus and Web of Science.

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. These methods were mentioned in the research papers in the literature review. Although the approaches individually have advantages and disadvantages, researchers have rarely compared them in the same empirical study, especially for the insurance sector. The Pearson correlation method captures a linear correlation, but non-linear risks' dependence mainly exists in the practice.

Natural catastrophes or pandemic events (or both events) 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.

The correlation matrix used is calculated using Spearman's rank correlation (Spearman, 1904). Pearson correlation method cannot be used in copula modelling. The Spearman correlation coefficient is defined as the Pearson correlation coefficient between the ranks (from the largest to the smallest, and vice versa, but this aspect does not matter), using ranks instead of real observations. Ranks in the reserving context are calculated from incurred claims in each accident year for each line of business.

To obtain a multivariate distribution of an aggregate risk level considering all the lines of business, a copula approach is used. Copulas are functions that join or "couple" multivariate distribution functions to their one dimensional marginal distribution functions (Nelsen, 2006). Fig. 2.20. represents 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, markets. Copulas are applied in different fields of science and engineering.

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. Stoliarova (2018) considered the gamma Poisson model of behaviour using copula. Poisson distribution is typically used for modelling the insurance counts of claim frequency. The copula model is widely utilised for valuating collateralised debt obligations and assessing default risk in which the default of one asset can cause the default of another. Romano (2002) and Matvejevs *et al.* (2017) used copula for listed equities and demonstrated its usefulness for extreme event modelling, which is in the interest of risk managers and supervisors.

Insurers should perform extreme event modelling if the risk-based capital confidence level set by regulators is excessively high, that is, *VaR* of 99.5% (European Parliament & Council of the European Union, 2014).

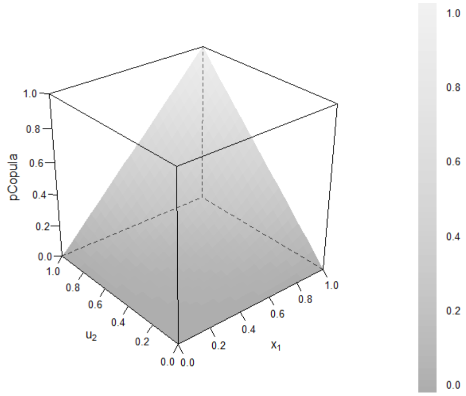


Fig. 2.20. Wireframe plot of copula.

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

In a recently published paper, Pellecchia and Perciaccante (2019) aggregated the main risks (market, counterparty, life, non-life) using copulas and concluded that a standard formula could result in an overestimation of capital requirements. 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

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

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 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*.

Sklar's Theorem (Sklar, 1959). *For any distribution function of a random* d*-vector* H *with univariate margins* $F_1, \dots, F_d$*, there is a* d*-copula* C *such that*

$$H(\boldsymbol{x}) = C\big(F_1(x_1), \dots, F_d(x_d)\big),\ \boldsymbol{x} \in \mathbb{R}^d. \quad (2.10)$$

The copula C *is uniquely defined on* $\prod_{k=1}^{d} ran\, F_k$ *and is given by*

$$C(\boldsymbol{u}) = H\big(F_1^{\leftarrow}(u_1), \dots, F_d^{\leftarrow}(u_d)\big),\ \boldsymbol{u} \in \textstyle\prod_{k=1}^{d} ran\, F_k. \quad (2.11)$$

Conversely, given a d*-copula* C *and univariate distribution functions* $F_1, \dots, F_d$*,* H *defined* *by (2.10) is a distribution function of a random* d*-vector with margins* $F_1, \dots, F_d$ *where* $ran\ F_k$ *denotes the range of the distribution function,* F_k.

In the case study in the fourth part, the creation of a Spearman correlation matrix and assessment of the correlation between various products from a real data, copula modelling is performed.

Conclusion on capital management with an 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, 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. Alternative capital management methods such as digitalisation should also be a top priority in claims management, resulting in a lower claims reserve and a lower capital requirement for reserve risk.

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.

The author maintains that the neural network approach and machine learning techniques will also be mentioned in the following papers as Big Data algorithms become more popular. The credibility approach method is also becoming popular in non-life insurance as a rating technique. This method is simple and can be easily incorporated into systems by using different source data. Copula is used by Baltic researchers mainly in mathematics science field (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 reserve risk in Baltic non-life insurance have not been investigated. There are no research papers published by Baltic authors in Scopus and Web of Science with the both keywords "reserve" and "copula".

Regulators should keep abreast of new risk assessment methodologies and continue to improve their knowledge. In order to implement an internal model, regulators should comply with the requirements set out in Articles 120 to 125 of the Directive Solvency II. The main problem is that a regulator has to validate the internal model individually. Many standards and tasks must not only be included in the documentation, but also integrated into the day-to-day decision-making process and risk management system.

Risk aggregation and dependency 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 indicate that the internal model methodology should solve the dependency problem and use stochastic approaches. The first step should be to test the underlying distribution of the reserve and reserve risk. The standard formula approach, which uses a linear correlation matrix, cannot solve the insurance sector-specific problems. Based on case studies performed by other researchers, the standard formula only fits large companies under normal market conditions. In this study, it is assumed that Baltic non-life insurance companies belong to small and medium-sized companies in the EU context. The density of the Baltic non-life insurance market from 2016 to 2020 shows that the expenditure on insurance cover per inhabitant is at least three times lower than in advanced insurance markets such as Germany, Austria and Sweden. The testing of the hypothesis "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 insurer as part of Baltic non-life insurance market is not examined.

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

3.1. General considerations before developing an alternative capital management method and planning capital

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 – refers to solvency ratio;

C_a – denoted as economic capital or available capital;

C_{rT} – denoted as 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 $Profit_a$ – denoted as 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 part of 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,
- and impacts dividend distribution and its frequency, 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.

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).

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.

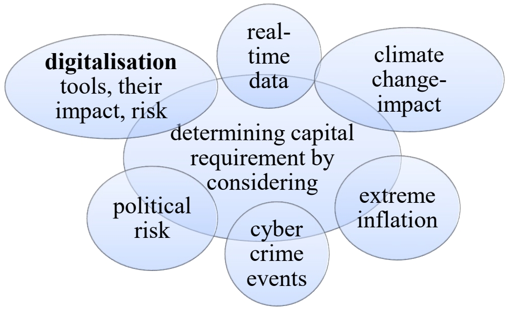


Fig. 3.1. Proposed risks for modelling required capital with an alternative capital management methods.

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 Baltic non-life insurance market.

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

Risk aggregation techniques in internal model

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

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

where $VaR^{e}_{99.5\%}$ – value at risk (VaR) at 99.5% confidence level for line of business e;

CBE_e – 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 applies to the aggregate reserve risk for many business lines, i.e. the difference between the 99.5% value at risk and the mean or best estimate booked in the economic balance sheet. The actuary and reserve risk holder should know the value at risk at certain confidence levels. In order to obtain a multivariate distribution at an aggregate risk level that takes into account all lines of business, a copula approach is used. The diversification effect can be calculated as the difference between the sums of all risks and the aggregated risk from the multivariate distribution.

The results of the literature review conducted by the author show that the risk aggregation technique copula approach would solve the problems of dependence and capital allocation. The previous part provided a definition of copula. The author proposed to use copulas for risk aggregation. The copula has a great impact on the shape of the joint distribution (Li *et al.*, 2015). Therefore, the impact of the required capital and the choice of copula should also be appropriate. Li *et al.* (2015) summarise that identifying the copula that can best model the dependency structure is relatively easy when years of daily data are available and the data offered for capital assessment is always insufficient when aggregating bank risks. The author sees the problem for the insurance industry also for the Baltic non-life insurance market, considering that the required capital has to cover shock 1 over 200 years. However, the Baltic insurance market operates in emerging markets and lacks experience. Fig. 3.2. represents the copula classes. Multivariate distributions that can be used for reserve risk modelling include multivariate normal distribution, *t*-distribution.

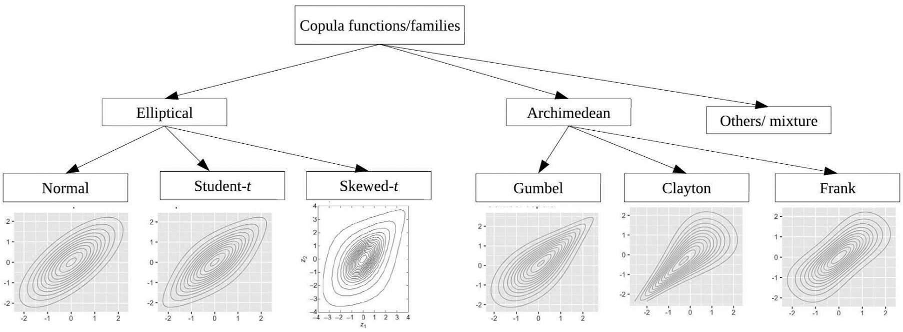


Fig. 3.2. Different copulas and classes (available bivariate and multivariate) for capital to cover non-life claim reserve risk.

Source: Based on author and Li *et al.* (2015).

In the empirical study, two copulas are used: the well-known normal copula and the *t*-copula, which is valid for insurance products with a low frequency of large claims and a high frequency of small claims, a skewed distribution of insurance claims and reserves in the economic balance sheet. The normal copula is by far the most popular copula (Fang & Madsen, 2013). 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.

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_d^n 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

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

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

The t-copula $C^t_{d,v}$ is the distribution function of a random d-vector derived from 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, $C^t_{d,v}(\boldsymbol{u})$ is given, for any $\mathbf{u} \in [0, 1]^d$, by (Hofert *et al.*, 2018)

$$C^t_{d,v}(\boldsymbol{u}) = t_{d,v}\left(t_v{}^{-1}(u_1), \dots, t_v{}^{-1}(u_d)\right) =$$
$$= \int_{-\infty}^{t_v{}^{-1}(u_d)} \dots \int_{-\infty}^{t_v{}^{-1}(u_1)} \frac{\Gamma\left(\frac{v+d}{2}\right)}{\Gamma\left(\frac{v}{2}\right)(\pi v)^{\frac{d}{2}}\sqrt{det\boldsymbol{P}}} \left(1 + \frac{\boldsymbol{x}'\boldsymbol{P}^{-1}\boldsymbol{x}}{v}\right)^{-\frac{v+d}{2}} dx_1 \dots dx_d, \quad (3.6)$$

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

If the hypothesis test shows that the *t*-copula cannot be rejected, the author advises to continue the test with a skew *t*-copula or another multivariate copula. Other copulas, such as the skew *t*-copula, are not used in empirical studies because goodness-of-fit tests are not built into the R software. Testing multivariate copula-based models, which are required due to the existence of many insurance products, is computationally difficult and time-consuming. The algorithm of the new internal model developed by the author takes into account that many copulas can be applied.

Goodness of fit and model selection tests in internal model

The author has used the use of two statistical hypothesis tests for the copula approach, which are available in the R statistical packages and are needed for the validation of different copula models. A simple graphical diagnosis may be sufficient in practise to find an approximation to the risk assessment. However, it is not a sufficient argument for the internal capital model methodology, the documentation package for national regulators and financial market authorities. Formal statistical tests calculating *p*-values that can help in the choice of the hypothetical copula family play an important role. The author formally addresses this question of goodness of fit for appropriate parametric copula families by testing

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

where Ƕ_0 - the choice of the hypothesised copula family $\mathcal{C}$ cannot be rejected;
Ƕ_1 - states that the choice of the hypothesised copula family $\mathcal{C}$ can be rejected.

The first used hypothesis testing is Parametric Bootstrap . As suggested in papers (Fermanian, 2005; Genest & Rémillard, 2008; Quessy, 2005), a natural goodness-of-fit test consists of comparing C_n with an estimate C_{θ_n} of C obtained under the assumption that $\mathrm{C} \in \mathcal{C}$ holds. The estimated margins are used to form the sample

$$\boldsymbol{U}'_{i,n} = \left(F_{n,1}(X_{i1}), \dots, F_{n,d}(X_{id})\right), i \in \{1, \dots, n\}, \quad (3.8)$$

where for any $j \in \{1,\dots,d\}, F_j$ is estimated by using component samples of $\boldsymbol{X}_1, \dots, \boldsymbol{X}_n$

$$F_{n,j(x)} = \frac{1}{n+1} \sum_{i=1}^{n} 1\big(X_{ij} < x\big), x \in \mathbb{R}. \quad (3.9)$$

In the previous statement, $\boldsymbol{\theta_0}$ is an estimate (parameter vector) of $\boldsymbol{\theta}$ computed from the pseudo-observations $U_{1,1}, \dots, U_{n,n}$ such as the maximum pseudo-likelihood estimator.

The author use an approach that appears to perform particularly well according to the large-scale simulations carried out in by Genest *et al.* (2009), where Cramer-von Mises statistic is used for the test fitting:

$$S_n^{gof} = \int_{[0,1]^d} n\left(C_n(\boldsymbol{u}) - C_{\theta_n}(\boldsymbol{u})\right)^2 dC_n(\boldsymbol{u}) = \sum_{i=1}^{n} \left(C_n(U_{i,n}) - C_{\theta_n}(U_{i,n})\right)^2. \quad (3.10)$$

An approximate *p*-value for the test based on S_n^{gof} can be obtained by means of a Parametric Bootstrap whose asymptotic validity is investigated in Genest and Remillard (2008). Advantage of the method is its conceptual simplicity.

Parametric Bootstrap algorithm is summarised by Hofert *et al.* (2018):

1. Compute the pseudo-observations $U_{1,1}, \dots, U_{n,n}$.
2. Compute an estimate $\boldsymbol{\theta_n}$ of $\boldsymbol{\theta}$ from the pseudo-observations $U_{1,1}, \dots, U_{n,n}$.
3. Compute the test statistic S_n^{gof}.
4. For some large integer N, repeat the following steps for every $k \in \{1, \dots, N\}$:

4.1 Generate a pseudo-random sample $U_1^{(k)}, \dots, U_n^{(k)}$ from the fitted copula C_{θ_n} and compute the corresponding pseudo-observations $U_{1,n}^{(k)}, \dots, U_{n,n}^{(k)}$.

4.2 Compute an estimate $\boldsymbol{\theta}_n^{(k)}$ of $\boldsymbol{\theta}$ from the pseudo-observations $U_{1,n}^{(k)}, \dots, U_{n,n}^{(k)}$ using the same (rank-based) estimator as in Step 2.

4.3 Compute the corresponding value $S_n^{gof,(k)}$ of S_n^{gof} as:

$$S_n^{gof,(k)} = \sum_{i=1}^{n} (C_n^{(k)}(\boldsymbol{U}_{i,n}^{(k)}) - C_{\theta_n^k}\left(\boldsymbol{U}_{i,n}^{(k)}\right))^2, \quad (3.11)$$

where

$$C_n^{(k)}(\boldsymbol{u}) = \frac{1}{n} \sum_{i=1}^{n} 1(\boldsymbol{U}_{i,n}^{(k)} \leq \boldsymbol{u}),\ \boldsymbol{u} \epsilon [0,1]^d. \quad (3.12)$$

Under H_0, $S_n^{gof,(k)}$ are approximately independent copies of S_n^{gof}.

5. An approximate *p*-value for the test is given by

$$(\tfrac{1}{2} + \sum_{k=1}^{N} 1(S_n^{gof,(k)} \geq S_n^{gof}))/ (N+1). \quad (3.13)$$

The second used test is model selection with test Cross-validation criterion. There can happen that all candidate parametric copula families are rejected when the sample size is large or none of the families is rejected when the sample size is small. Test uses *Akaike information* *criterion* (AIC). AIC is used also in order to choose the reserve distribution for each line of business and is calculated using formula:

$$AIC = 2(k - ln(L)), \tag{3.14}$$

where k is the number of model parameters;

ln(L) is the log-likelihood of the model.

R package *fitdistrplus* can be used for AIC results provided by Delignette-Muller *et al.* (2015). Cross-validation test for copula selection also uses AIC and performs the selection of the best ranked family can be justified by using formula:

$$AIC_{cross\ validation\ test} = 2(m - l_{n,max}), \tag{3.15}$$

where $l_{n,max}$ is the maximised likelihood function;

m is the total number of marginal and copula parameters.

Grønneberg and Hjort (Grønneberg & Hjort, 2014) have defined cross-validation copula information criterion up to a multiplicative constant, the first-order equivalent of the cross validation criterion:

$$\widehat{xv}_n = \frac{1}{n}\sum_{i=1}^{n} log c_{\boldsymbol{\theta}_{n,-1}}(F_{n,-i}(\boldsymbol{X}_i)), \tag{3.16}$$

where $\boldsymbol{\theta}_{n,-1}$ – the maximum pseudo-likelihood estimate computed from the sample $\boldsymbol{X}_1, \dots, \boldsymbol{X}_{i-1}, \boldsymbol{X}_{i+1}, \dots, \boldsymbol{X}_n$ and

$$F_{n,-i}(\boldsymbol{x}) = \left(F_{n,1,-i}(x_1), \dots, F_{n,d,-i}(x_d)\right), \ \boldsymbol{x} \epsilon \mathbb{R}^d, \tag{3.17}$$

with

$$F_{n,j,-i}(x) = \begin{cases} \dfrac{1}{n\sum_{k=1,k\neq i}^{n} 1(X_{kj} \leq x)}, & if\ x \geq \min X_{kj}, k \in \{1, \dots, n\} \backslash \{i\} \\ \dfrac{1}{n}, & otherwise. \end{cases}$$

This test leaves out and penalises copula families with too many parameters that tend to overfit. Papers (Grønneberg, Hjort, 2014; Jordanger, Tjøstheim, 2014; Karagrigoriou, 2011; McNeil *et al.*, 2015) help to improve the AIC formula approach and historical development in the copula theory in a more detailed way. Cross-validation criterion shows preferred copula family based on ranked first (the highest value) using R package *xvcopula*. The purpose of this test is to rank the candidate copula families, which will ultimately lead to the selection of the family with the highest ranking (Hofert *et al,* 2018). Cross-validation criterion values can be negative and the highest test value belongs to the recommended copula family (Hofert *et al,* 2018). In addition, the criterion of cross-validation is used to check which distribution for is also more suitable in the one-dimensional case. Except that here, instead of the function shown in (3.16), the AIC values shown in formula (3.14) are used. Therefore, the smallest value is the best in this case.

Approaches and algorithm for reserve and reserve risk with internal model

The formula and correlation coefficients established by the EIOPA are not used for proposed alternative capital management method as internal model. Spearman's rank correlations, real reserve distributions and another risk aggregation technique (i.e., copula) are instead applied. The alternative capital requirement for aggregated reserve risk is calculated by using formula as previously mentioned by formula (3.4) which is the difference between *VaR* at a 99.5% confidence level and the mean or the best estimate booked in the economic balance sheet. The types of uncertainty errors in the model that will improve reality should be taken into account. Fig. 3.3. shows a summary of the uncertainty errors, which also includes the importance of using expert judgement during the reserving process. The proposed internal model excludes the expert judgement process because the product design and local legal requirements of each company are different.

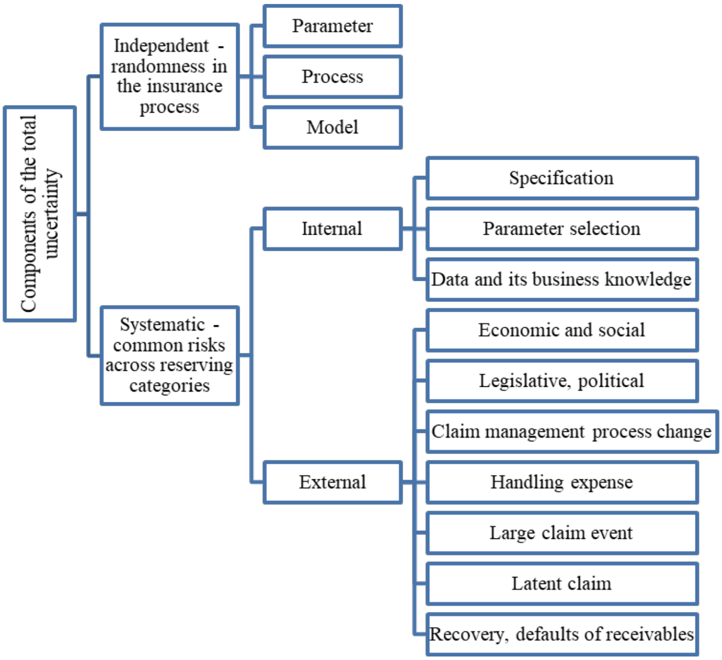


Fig. 3.3. Types of uncertainty for reserve setting and its capital requirements.

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

Systematic external uncertainty errors such as political and legal changes can lead to a higher reserve volume in the balance sheet and thus to additional capital costs and capital requirements. The author advises running different stress scenarios with the help of the decision tree and to choose a probability for each event. The reserve volume can then be compared with different approaches. It is important to note that if the reserve volume is underestimated in the economic balance sheet, then the required capital is also underestimated. However, the most important type of systematic risk in reserving is model risk. Model errors are difficult to detect. Detailed considerations are not made in some cases. The author recommends performing sensitivity and scenario analyses of the results, comparing the results with experience over time and backtesting the models.

Potential reserve and capital shifts can be tracked by avoiding a method as deterministic.

The use of stochastic methods is crucial in determining capital requirements. This approach is essential in business planning, mergers and acquisitions (M&A) and reinsurance pricing and is not constrained by modelling distributions. Scenario and sensitivity analyses help an internal capital modelling team understand a company's key drivers, decline and volatility in profitability.

The mathematical representation of prediction uncertainty is measured with the mean-squared error of prediction, which can be divided into two components for process and parameter estimation variance. Furthermore, the overall practice changes depending on which stochastic reserving method or procedure is used (Hindley, 2017, p.152):

$$MSEP(\hat{X}_{i,j}) \approx Var(X_{i,j}) + Var(\hat{X}_{i,j}), \tag{3.17}$$

where X denotes an unknown future value or claims best estimate;

$\hat{X}-$ is used to represent the estimators.

In the context of stochastic reserving, the formula is explored by several authors such as Taylor (2000) and Renshaw (1994) and is applied based on conditional probabilities by Mack (1993) and Merz & Wüthrich (2008). The deterministic Chain Ladder method is an underlying approach for a stochastic technique used in further study, that is, the bootstrap Chain Ladder. As the method is simulation based, it produces an estimate of the full distribution of future claims and operates with a one-year time horizon basis. Claim distribution finding is the key reason why a stochastic reserving technique is used in the model and specific distributions for each line of business will be later used for the risk aggregation process in the copula approach and for finding an aggregated distribution. 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).

In a standard application of the bootstrap in which data are assumed to be independent and identically distributed, resampling with replacement transpires from the data. In regression-type problems, the data are usually assumed to be independent and not identically distributed because the means (and possibly the variances) depend on covariates. Therefore, in regression-type problems, bootstrap residuals are commonly used rather than the data themselves, as the residuals are approximately independent and identically distributed, or can be made so. For generalised linear models (GLMs), a range of extended definitions of residuals exist, and the precise form is dictated by the underlying modelling distribution (see McCullagh & Nelder (1989)). For the over-dispersed Poisson Chain Ladder model, the Pearson residuals for bootstrapping are used in the current study. Dropping the suffices that indicate the origin and development year, the Pearson residuals r_p are defined as follows:

$$r_p = \frac{IC-\hat{m}}{\sqrt{\hat{m}}}, \tag{3.18}$$

where $\hat{m}$ - the fitted incremental claim;

IC - denotes the incremental claim amount.

Algorithm of procedure is defined in the over-dispersed Poisson Chain Ladder model (see

England & Verrall (2002) and Appendix 7). The author has not identified a need to apply tails from primary data and therefore sets the last development factor as 1. However, it may change for the other company. The bootstrap process involves resampling with replacement from the residuals. A bootstrap data sample is then created by inverting formula (3.18) using the resampled residuals together with the fitted values. Given a resampled Pearson residual r_p^* together with the fitted value m, the associated bootstrap incremental claims amount IC^* is given by

$$IC^* = r_p^* \sqrt{\widehat{m}} + \widehat{m} \, . \tag{3.19}$$

Resampling the residuals (with replacement) gives rise to a new triangle of past claims payments. Having obtained the bootstrap sample, the model is refitted and the statistic of interest calculated. Strictly, the author ought to fit an over-dispersed Poisson GLM to the bootstrap sample to obtain a bootstrap reserve estimate. However, the author can obtain identical reserve estimates using a standard Chain Ladder methodology. At this point the usefulness of the bootstrap process becomes apparent. The method is built in R software and the author does not need any other special software to fit the model. Having fitted the Chain Ladder model to the bootstrap sample and obtained forecast incremental claims payments, the second stage of the procedure is invoked, which replicates the process variance. This procedure is achieved by simulating an observed claims payment for each future cell in the run-off triangle, using the bootstrap value as the mean and employing the process distribution assumed in the underlying model, which, in this case, is the over-dispersed Poisson model. The procedure is repeated a large number of times, each time providing a new bootstrap value and simulated forecast payment. For each iteration, the reserves are calculated by summing the simulated forecast payments. The set of reserves obtained in this manner forms the predictive distribution, from which summary statistics, such as the prediction error, can be obtained (i.e., simply the standard deviation of the distribution of reserve estimates). A more detailed description of the bootstrap procedure is given in England and Verrall (2002) and Hindley (2017).

The general procedure of a non-parametric residual resampling bootstrap with regard to claims best estimate is as follows (Hindley, 2017) (see Appendix 7):

1. Define a statistical model that is appropriate for modelling the claim development process. This model will produce the estimates of future claim payments.
2. Fit this model to an observed data triangle.
3. Appropriately determine the defined residuals between the fitted statistical model and the observed data.
4. Use Monte Carlo simulation to produce random selections of the residuals (with replacement).
5. Use the randomly generated residuals to generate new ‘pseudo data’ analogues to the observed data sample.
6. Re-fit the statistical model to each version of the pseudo data and predict the forecasts of future claims payments, ensuring that the process error is incorporated in a suitable manner.
7. Finally, examine the distribution of the forecasts to produce the estimates of the prediction error in relation to the uncertainty caused by both parameter and process

errors.

In the context of capital requirement setting in internal modelling, the author of this Doctoral Thesis is interested in a one-year time horizon. Therefore, with regard to the reserving area, the focus is on one-year claim development and its distributions. Merz and Wüthrich (Merz & Wuthrich, 2014; Merz & Wüthrich, 2008) have examined how claim development for one year can be derived using the bootstrap Chain Ladder method. Meanwhile, Boumezoued *et al.* (2011) and Diers (2008) have summarised the main advantages of the bootstrap methodology.

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

For insurers, managing volatility is important for the efficient deployment of capital. Traditionally, insurers have tried to achieve this process by diversifying across different lines of business, geographical zones or across different companies in an insurance group (Kielholz, 2000). The Baltic non-life insurance market typically operates in Estonia, Latvia and Lithuania and has the opportunity to diversify its portfolio geographically. However, for efficient capital allocation it is important to know the risk-adjusted cost of capital for each product activity. To properly assess whether an activity is value-adding or value-destroying, capital must be allocated to the individual product activities in relation to risk. An insurer can improve its profitability by simply shifting capital to more productive activities and reducing the capital required for the less productive activities (Kielholz, 2000). For an insurer, these theoretical ideas have a lot of real-world applications. In the beginning, insurers need tools for calculating the cost of capital and comprehending the volatility and risk associated with the various business lines. Understanding the effects of monetary and market conditions on the cyclicality of the business lines should be one of these instruments (Kielholz, 2000). The more exposure an insurance company bears, the more capital it needs.

Management shall answer to questions ‘how insurer can optimize their capital structure with changes in risk profile’ and ‘what are the sources of capital and how insurer 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, 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. Generally, target a stable capital funding structure in addition solvency and leverage ratios and manage toward these targets over time. Insurer shall include external growth due to macroeconomic environment and internal growth. External growth for Baltic non-life insurance market can be modelled by taking into account GDP growth and there is no need for more complex model based on hypothesis testing. The following model and hypothesis testing is provided by the author in Section 1.2. The key rules for capital allocation are depicted in Fig. 3.4.

Capital efficiency KPIs, required capital, and solvency ratio affect dividend policy. The intention of management would be to provide a stable dividend policy. Wilson (2015) has stated and summarised the three main concepts of dividend policy in Allianz SE insurance company. These concepts are as follows: regular percentage pay-out of net profit by providing optimal dividend yield; dividend no less than the previous year, resulting in a predictable income for shareholders; and discipline where the dividend policy is subject to a sustainable solvency ratio of 160%. Such conditions cannot be found in the disclosures of Baltic non-life insurance companies.

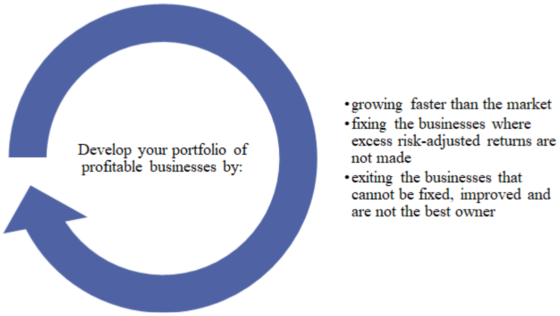


Fig. 3.4. Rules of capital allocation and corporate strategy.

Source: Created by the author based on Wilson (2015).

If the rules of capital allocation and if no M&A is planned, then capital can and should be returned to shareholders, either in the form of dividend distribution or share repurchases. The increase of total asset value cannot be targeted in the long run. These studies collectively imply that organizations that don't define goals like asset expansion are frequently rewarded by the capital markets. Many financing alternatives along the standard approaches (i.e., debt-equity) are available, continuing used to finance the insurer's investment in operating businesses and as operating leverage. These alternatives include asset-backed financing, senior unsecured bonds, loans and deposits, subordinated liabilities, hybrid capital or auxiliary funds, and shareholders paid-in capital. The cost of capital can be assessed using the Capital Asset Pricing Model or the Discounted Cash Flow Model. If the required capital is assessed using an alternative method or an internal capital model, it is mandatory to apply validation standards based on the Solvency II directive. In developing the process, the author advises implementing the actuarial control cycle (see Fig. 3.5), which is a conceptual framework for describing the processes required for the development and ongoing management of the product.

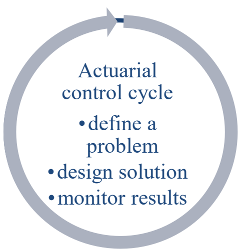


Fig. 3.5. Actuarial control cycle.

Source: Created by the author based Bellis *et al.* (2010).

Bellis *et al.* (2010) describes how actuarial cycle should be implemented in model validation. It is based on a simple problem-solving algorithm. First, define the problem. Second, design the solution. Finally, monitor the results. It may be repeated or at any stage returned to an earlier step. Bellis *et al.* (2010) describes that this problem-solving process is universal and it could be applied to any field of activity.

Framework via cycle should be extended and implemented in validation process of alternative capital management methods. Fig. 3.6. illustrates validation process stages.

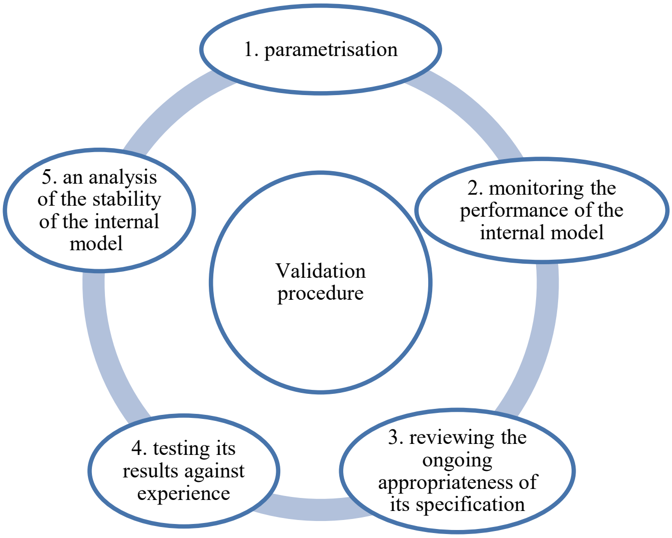


Fig. 3.6. Validation process.

Source: Created by the author based on European Parliament (2009).

Doctoral Thesis develops and describes a methodology of an alternative capital requirement model and its application to perform better quantification of non-life reserving risk with internal model under the Solvency II framework.

Amount for setting aside required capital is in level with event which occurs once in 200 years (VaR_{α}, $\alpha=0.005$). This creates difficulties in back-testing process. Therefore, the author of Doctoral Thesis advice to perform reserving sufficiency tests on regular basis. Next, determining optimal retention level for reinsurance treaties.

Finally, it is advised to follow the latest research papers which focus on tail risk measurement and application of copulas for insurance industry. Multivariate tail dependence has not been studied widely for insurance sector and continues to be under developing stage.

3.4. Digitalisation as alternative capital management method for reserve risk

This chapter recommends digitisation as an alternative method of capital management. For all insurers (including 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). The IT artificial intelligence (AI) technology is needed for claims management. Its possibilities and the resulting implications for the Baltic non-life insurance market (or EU insurers) are summarised in Fig. 3.7.

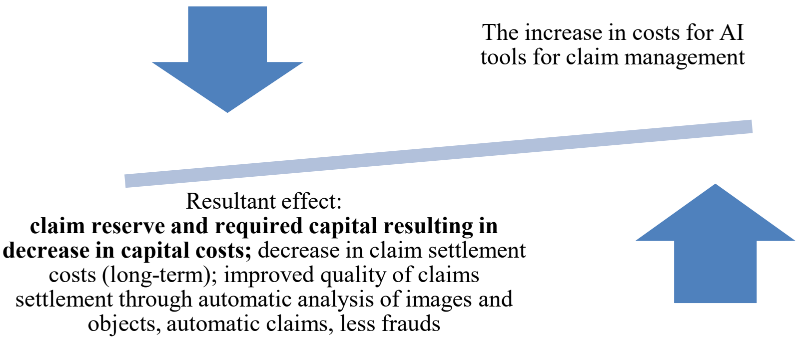


Fig. 3.7. Resultant effect of the use of AI technologies for insurers.

Source: Created by the author.

Digitalisation is discussed in research papers from insurance online services and it's usage centricity for Baltic non-life insurance market by Baranauskas & Raišienė (2021). Usage centricity improves and helps to maintain customer centricity strategy in insurance company. This also helps to increase and maximises the long-term financial value and sustainability of Baltic non-life insurance market. Digital tools in claim management helps to settle and register claim faster, affects also overall reserve volume in economic balance sheet and helps to minimise required capital for reserve risk. Digitalisation would help to maintain the average annual business growth 11% for Baltic non-life insurance market, which is higher than the Baltic GDP average annual growth (see Fig.1.1). Based on reserve structure the majority (more than 70% 2016-2020, see Fig. 1.11) of reserve is for motor products (liability and own damage) in Baltic non-life insurance market. But Baltic citizens, customers of Baltic non-life insurance market should also look for a deeper sense of financial security, not just an auto policy.

In this section of the quantitative case study, digitisation is recommended as an alternative method for capital management. The author has not found any quantitative studies on how the required capital for reserve risk of non-life insurers in the EU changes when digitisation tools are used (Scopus search terms "digital" and "insurance" and "capital" and "reserve"). The advantage of using digitalisation as an alternative method for capital management is that it does not need to be approved by the supervisory authority. However, the regulator must approve the first proposed internal model for reserve risk and there must be extensive documentation and sufficient procedures in place.

A quantitative case study is presented to measure digitalisation. The novelty of the case study results lies in the identification of a quantitative measure in a Baltic non-life insurance company that helps to calculate the impact of the required capital for reserve risk due to digitalisation. The analysis is conducted using primary data from a Baltic non-life insurer for a specific homogeneous risk group where claims can be reported through different channels (call centre, mobile application, online homepage, mail, post). Author has chosen one company in Baltic non-life insurance market that offers several digitalisation tools. Claim reserve will be calculated for next years' payments with several claim handling speeds by using data till 2020. Claims data is not publicly available for every product on the aggregated market. The calculations can be reproduced by the companies on the basis of the algorithm provided (see Fig. 3.8). The key method applied is Chain Ladder which was given in Tarbell (1934) and formula (2.2) – (2.6).

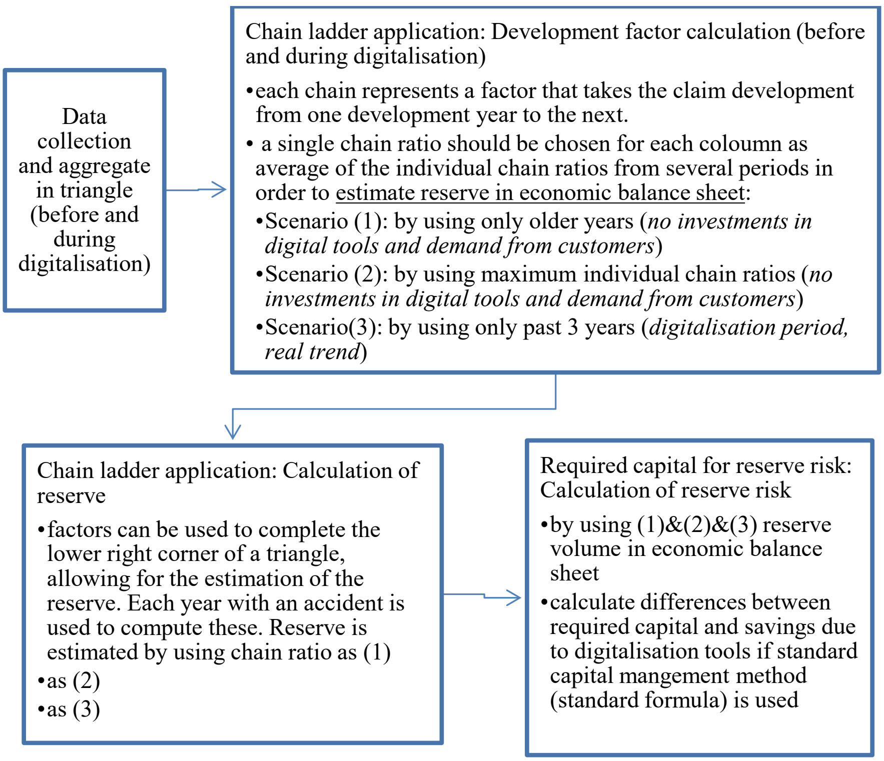


Fig. 3.8 Algorithm of calculation of digitalisation impact on required capital for reserve risk.

Source: Created by the author.

First step is data gathering in triangle (see Section 2.4). Then claim reserve will be calculated with several claim handling speeds (3 scenario analysis):

(1): Claim payment speed, development factor is taken as average of 2011-2014.

(2): Claim payment speed, development factors are taken as maximum in 2011-2014.

(3): Claim payment speed, development factor is taken as 2017-2020 and assumed in future for reserve calculation which is real trend.

Then, the required capital for the reserve risk is calculated using the EU standard capital method (standard formula). Finally, the required capital is compared with and without investments in digitalisation tools. Fig. 3.9 shows the primary data in the form of a triangulation.

	Development year:								
Accident year:	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
2012&2011	1.44	1.80	1.81	1.81	1.81	1.81	1.81	1.81	1.81
2013	2.02	2.18	2.21	2.21	2.21	2.21	2.21	2.21	
2014	2.37	3.11	3.16	3.16	3.16	3.16	3.16		
2015	2.19	2.61	2.61	2.61	2.61	2.61			
2016	1.93	2.43	2.45	2.45	2.45				
2017	2.74	3.36	3.37	3.40					
2018	6.12	6.98	7.06						
2019	7.97	8.72							
2020	5.90								

Fig. 3.9 Cumulative primary claim data 2011-2020 Baltic non-life insurer X, EUR million

Source: Created by the author from Company X (2021)

Next, individual chain ratio for each accident year is calculated (see Fig. 3.10).

	Development year:								
Accident year:	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Ratios									
2012&2011	-	1.2501	1.0022	1.0008	1.0001	1.0004	1.0005	1.0000	1.0000
2013	-	1.0787	1.0117	1.0000	1.0020	1.0000	1.0000	1.0000	
2014	-	1.3135	1.0140	1.0009	1.0000	1.0000	1.0000		
2015	-	1.1913	1.0000	1.0002	1.0000	1.0000			
2016	-	1.2587	1.0094	1.0005	1.0000				
2017	-	1.2287	1.0014	1.0094					
2018	-	1.1399	1.0123						
2019	-	1.0946							
2020	-								

Fig. 3.10 Individual chain ratios for events

Source: Calculated by the author.

It can be seen that claim speed has increasing trend. Settlement of claim speed is derived as in formula (3.20). 25% of claim development occurred in 2011 after the second year of accident. However, only 9% remained in 2019 and protentional remaining 2% will be settled in future years (yet unknown).

$$Individual\ ratio_{2019;1} = \frac{8.72}{7.97} = 1.0946\ . \qquad (3.20)$$

Chain Ladder method requires to choose a single ratio for each column (development year) and average of the individual ratios are chosen:

(1) from period 2011-2014.

(2) maximum individual ratio 2011-2014.

(3) real average ratio from 2017-2020. Table 3.1. represents calculated development factors for upcoming development years.

Table 3.1

Development factors applied for reserve calculation

Year:	2	3	4	5	6	7	8	9
Scenario 1: 2011-2014	1.2164	1.0103	1.0006	1.0007	1.0001	1.0001	1	1
Scenario 2: Highest - all	1.3135	1.0140	1.0094	1.0020	1.0004	1.0005	1	1
Real: 2017-2020	1.1329	1.0089	1.0040	1.0000	1.0000	1.0001	1	1

Source: Calculated by the author.

From Table 3.1. it can be seen that the 2017-2020 ratios are significantly lower than 2011-2014, with claims being processed and reported faster than before digitisation. Next, the reserves are calculated using different ratios: (1) if claims reporting and settlement were equal to the 2011-2014 period, (2) if claims reporting and settlement were equal to the longest settlement period, (3) if claims settlement were at the speed of digitisation 2017-2020. The reserve estimate using the latest claims trends and implemented digital tools is 45% lower than if the speed of claims reporting remained unchanged and no digital tools were used in 2020.

Table 3.2

Calculated claim reserve in economic balance sheet for property product, EUR million

Development factors (digitalisation stage) application scenario	Reserve	Digitalisation effect for 2020 claim reserve on economic balance sheet
Scenario 1: 2011-2014	1.44	-0.45
Scenario 2: Highest - all	2.45	-1.47
Real: 2017-2020	0.99	0.00

Source: Calculated by the author.

Last, required capital for reserve risk is calculated using formula (2.7). SCR for reserve risk depends from standard deviation of reserves expressed as fraction from its volume. Standard volatility of reserves for property product based on standard capital management method, standard formula is 8%.

Table 3.3

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
Scenario 2: Highest - all	0.59	-0.35
Real: 2017-2020	0.24	0.00

Source: Calculated by the author.

Table 3.3. 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 an alternative methods to capital management

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 author has described two alternative management methods for reserve risk in detailed: internal model and digitalisation. The internal capital modelling team should consider the types of uncertainty errors in the model that will improve reality. Uncertainty errors includes also the importance of using expert judgment during the reserving process. 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 author advice to apply copulas for risk aggregation. 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 author advice 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 and normal copula is chosen as primary 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 is not applied due to not built-in goodness-of-fit tests in R software in empirical study.

For Baltic non-life insurers digitalisation means more than simply upgrading mobile applications and information technology systems. It has direct impact also on required capital, key performance indicators and the value of company. If digital technologies are integrated and in place, then digitalisation as alternative management method is used by re-assessing the key risks, e.g., automatic claim payments or faster settling of claims leads to less claim reserve in economic balance sheet. The digitalisation of claims management should be a top priority for companies by making them customer-oriented. The advantage of digitalisation as an alternative method for capital management compared to the internal model is that it does not have to be approved by the supervisory authority.

The required capital for reserve risk can be improved by an alternative capital management method such as digitalisation. The novelty of the case study results lies in the identification of a quantitative measure that helps to calculate the impact of the required capital for reserve risk due to digitalisation. The author has selected a company and a product in the Baltic non-life insurance market that offers several digitisation tools. The results show that the reserves on the economic balance sheet have decreased by 45% and the required capital for a given product has decreased by 60% over the period 2011-2020. The same procedure can be applied to other products to assess the effectiveness of 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.

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

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

Claim reserve in economic balance sheet

Explanations and detailed steps are given to understand the alternative capital management method proposed by the author, to perform capital allocation and to compare the cost of capital between the standard approach and the proposed method. In this section, only four lines of business are described in detail, namely property insurance (Property), 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. In the 4.2. section, various case studies are presented by aggregating capital for different products and calculating the potential capital gains or losses. In general, there can be products where loss occurrence has a strong correlation and vice versa. 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 on end of 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 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 EUR thousand).
Source: Collected by the author from one Baltic non-life insurer (Company X, 2021).

The reserve is subsequently calculated for each line of business using the Chain Ladder model and formula 2.2–2.6 in Section 2.2. The analysis is conducted in statistical software R 3.5 (R Core Team, 2018) and Fig. 4.2 are produced using the package ‘actuar’ (Dutang *et al.*, 2008).

See Appendix 8 for an example of R-coding. The claim reserve calculation process is at the core of non-life insurers' financial and capital management. It determines what is recognised on the balance sheet for outstanding claims, affects future premiums charged to customers and influences the capital held to support financial stability. The higher the reserve volume, the higher the overall risk and the higher the capital required. Table 4.2 shows the calculated loss reserve for each line of business, which is defined in an economic balance sheet.

Table 4.2

Reserve for each line of business in economic balance sheet (in EUR thousand)

	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.

The structure of reserve volume in the case study is also similar to the Baltic non-life insurance market (see Fig.1.11). More than half of the reserves are in the MTPL line, followed by the GTPL and property lines of business. The choice of claim distribution and the aggregation of reserves in the balance sheet are the crucial next step for economic capital, i.e. alternative capital management. The author of this Doctoral Thesis subsequently performs an assessment of the specific distribution with the best fit for claims of a particular line of business. The 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 is used. 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 AIC information score is used and the lowest AIC is the best fit. The author used both visual and test in order to avoid underestimate tails which are important for required capital setting. The probability distributions of the data, their histograms, theoretical densities and numerical results of the AIC tests as well as the Q-Q plots are shown in Fig. 4.2 to Fig. 4.6 and Annex 9. For the given data, several claim distributions are possible. However, the most important aspect is that the claim has a positive value. Distributions such as gamma and log-normal are therefore often used in assessments. The well-known distributions used in non-life insurance are presented in Fig. 4.2. 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. Mixture distribution models for estimating capital requirement needs should be applied. For example, the C&S financial line has the same loss drivers as the exposures default modelling under credit risk assessment in the banking sector, where the Weibull, exponential is frequently applied (Jiménez & Mencía, 2009). Loss distribution for all the lines of business tend to be right-skewed (Eling, 2012). The same characteristic typifies the Baltic non-life insurance market. This feature explains the main principle regarding the large number of attritional claims and the small frequency of large claims. The Baltic region is not exposed to a large number of natural catastrophes. However, property and C&S products also have extreme tails in the Baltic region. Danish fire losses are extremely exposed with respect to skewness, as analysed by Barndorff-Nielsen (1997), and skew-*t* distribution can be similarly applied (Eling, 2012). Consideration of the skew-*t* distribution for Baltic non-life insurance data with other products could be considered in further research and proposals by the author considering the impact of climate change on natural catastrophes in the future. In the context of capital modelling, such a process may lead to an underestimation of capital if the following analysis has not been carried out. It proves that the determination of capital must go far beyond compliance when using standard methods of capital management (i.e. the standard formula).

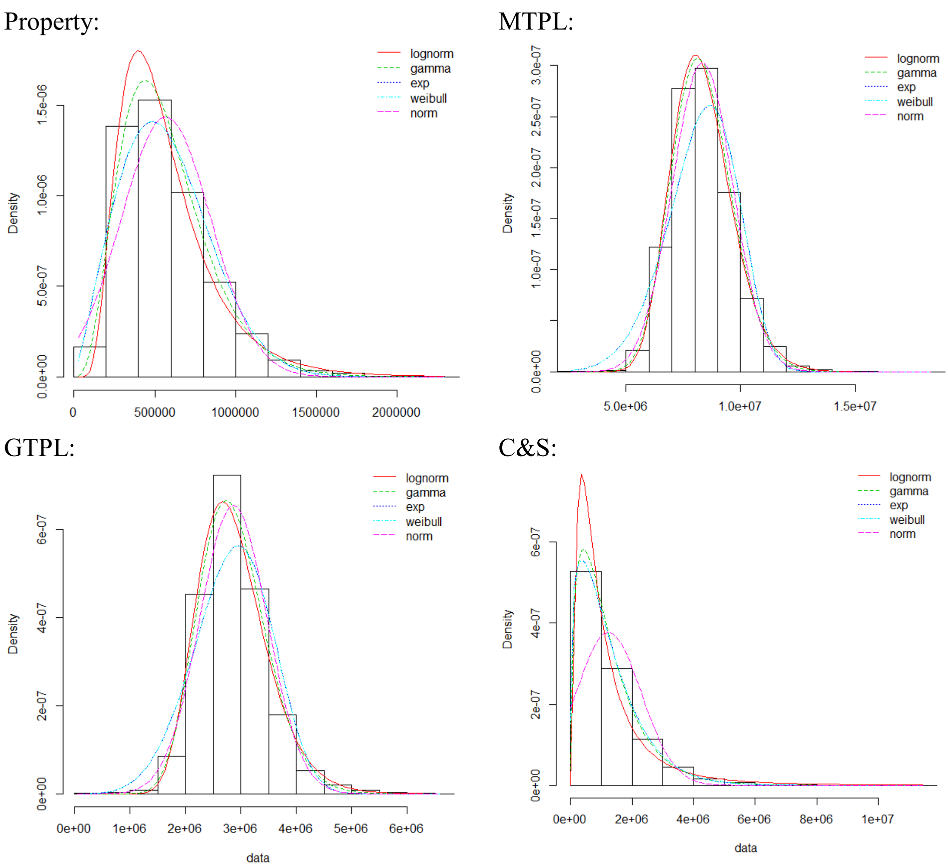


Fig. 4.2. Histogram and theoretical densities for used insurance products.

Source: Created by the author.

The hypothesis that the empirical distribution belongs to a certain type of distribution is tested. The choice of benchmark models is based on their use in actuarial science (i.e. log-normal, gamma, exponential, Weibull and normal). All benchmark models are implemented in the R packages fitdistrplus and MASSVisual tests are also performed and the decision for the empirical distribution is explained (see Fig. 4.3. and Table 4.3).

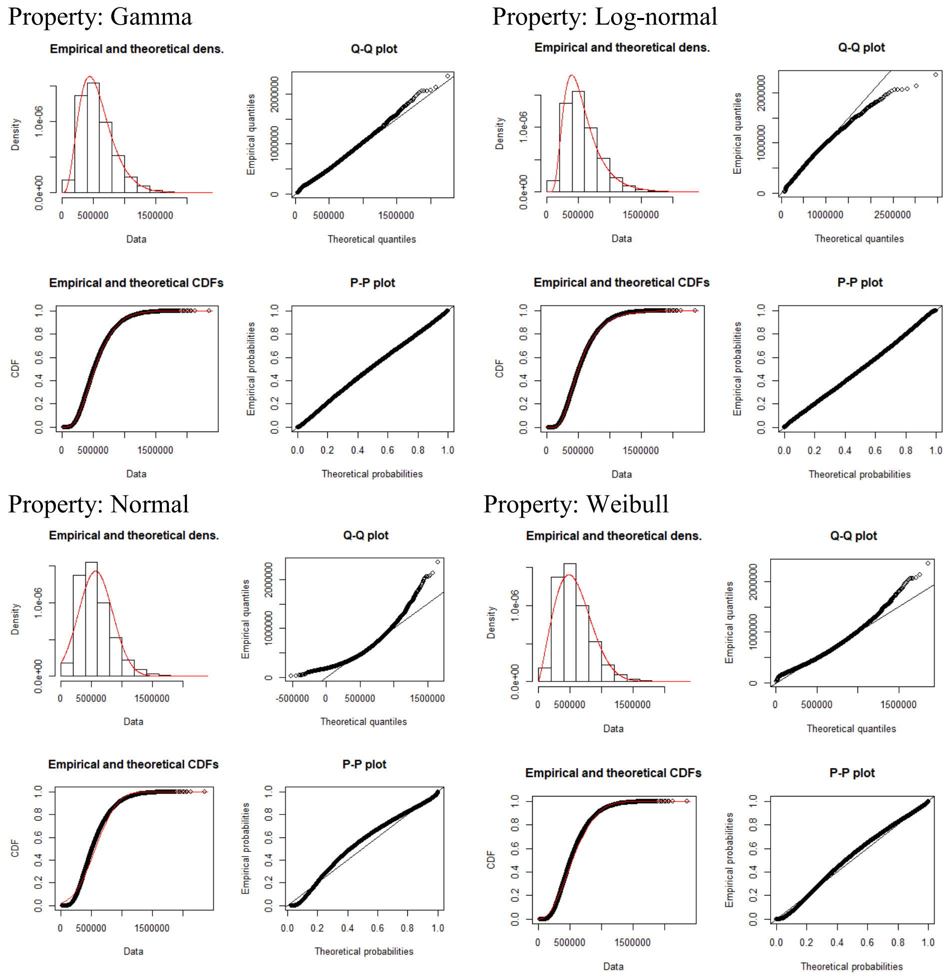


Fig. 4.3. Empirical and theoretical densities for Property LoB.

Source: Created by the author.

Table 4.3

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

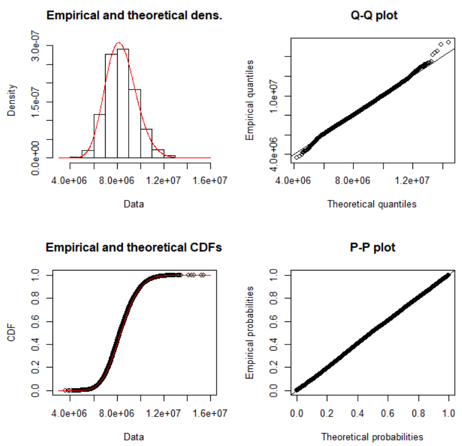
	AIC information score	Interpreting AIC	Visual test Q-Q plot	Decision
Gamma	276 579	best fit	best fit in tail	Gamma
Weibull	277 323			
Normal	278 719			
Lognormal	276 711	second best fit	second best	
Exponentional	277 323			

Source: Calculated by the author.

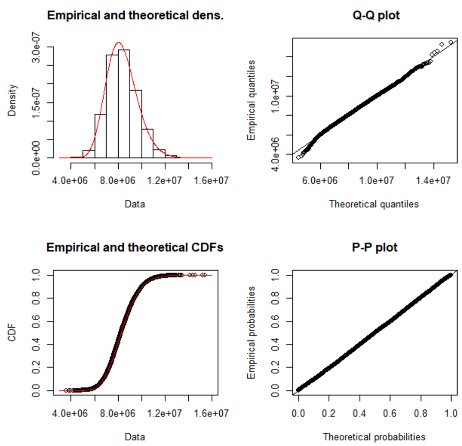
The claim distribution best fit for property product in the AIC test is for gamma and Weibull (see Table 4.3). The best fit based on the visual Q-Q plot in Fig. 4.3. is for gamma with best fit also in tail, followed by log-normal. The gamma distribution is finally chosen by the author because the AIC value for this distribution is the smallest. The decision process is shown in Table 4.3.

The claim distribution with the best fit for the MTPL product in the AIC test is for gamma, log-normal (see Annex 9). The best fit based on the visual Q-Q plot in Fig. 4.4. is for log-normal with best fit also in the tail, followed by gamma. The author ultimately chose the log-normal distribution. The analysis of claim distribution best fit confirms that standard capital management methods could result in potential capital shifts.

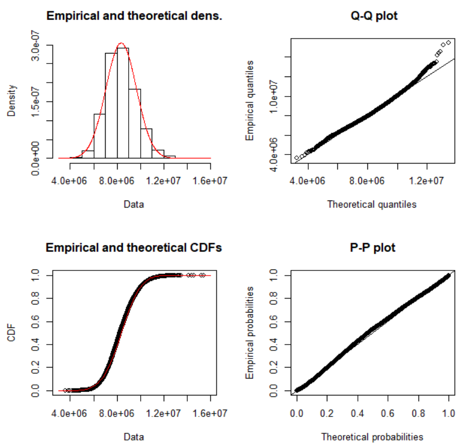
MTPL: Gamma



MTPL: Log-normal



MTPL: Normal



MTPL: Weibull

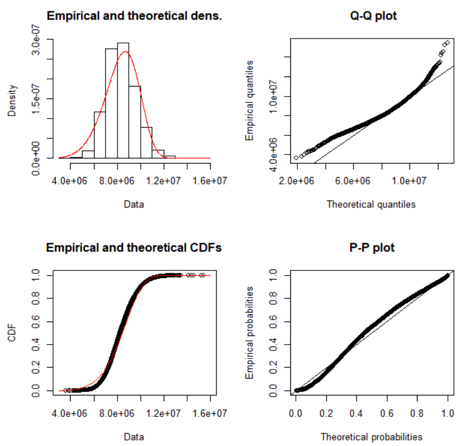


Fig. 4.4. Empirical and theoretical densities for the MTPL lines of business.

Source: Created by the author.

The author would like to highlight that in practice, many sub-groups could be needed for risk aggregation and capital setting for MTPL. These sub-groups can be long-term annuities payments or material damage, foreign or domestic claims, suffering claims or bodily injury claims. It is necessary also consider how long time claim handling process goes if alternative capital management methods are applied. An excessively short time horizon can result in the underestimation or overestimation of the allocated capital. The claim distribution best fit for the GTPL product in the AIC test is for gamma, normal. The best fit based on the visual Q-Q plot in Fig. 4.5. is for log-normal with best fit also in tail, followed by gamma. Log-normal distribution is eventually selected by the author (see Annex 9). Time horizon and length of claim handling are both important for MTPL and GTPL.

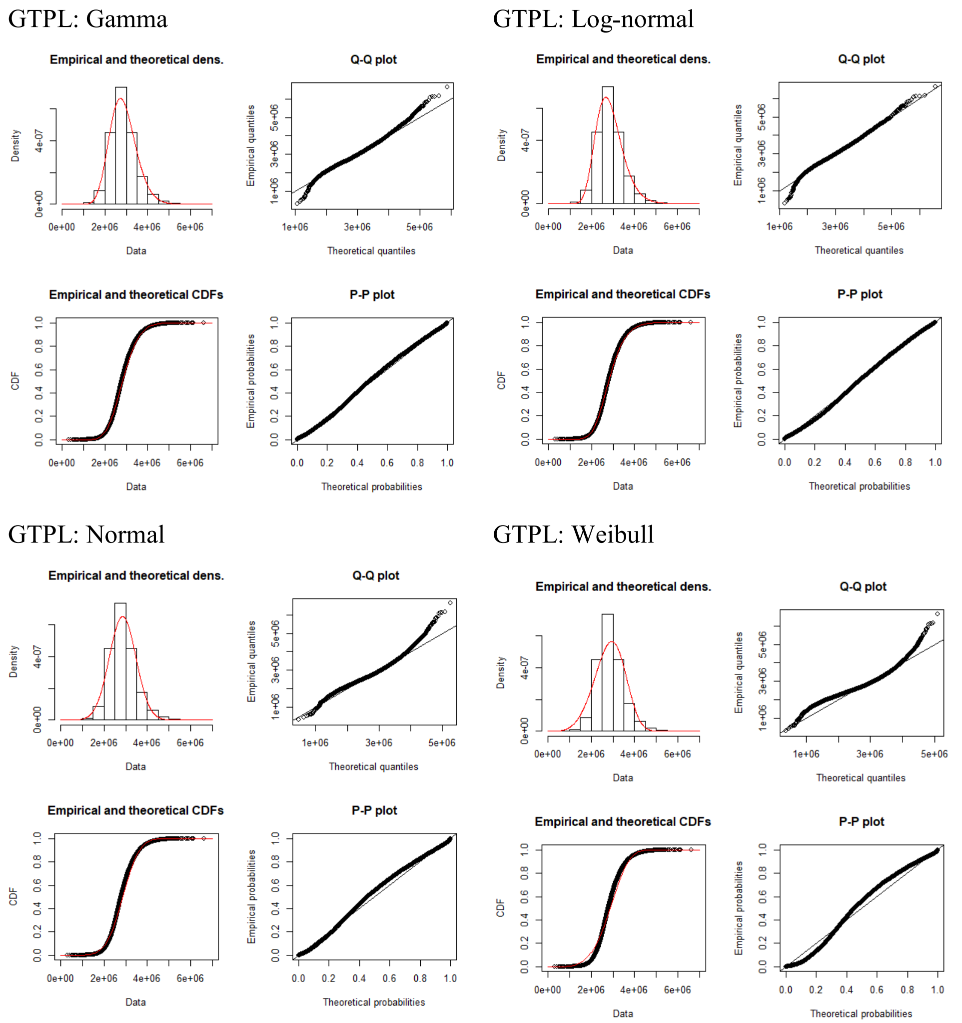


Fig. 4.5 Empirical and theoretical densities for the GTPL line of business.

Source: Created by the author.

The claim distribution best fit for the C&S product in the AIC test is for gamma, Weibull, exponential (see Annex 9). The best fit based on the visual Q-Q plot in Fig. 4.6. is for Weibull with best fit also in tail, followed by gamma. The gamma distribution is ultimately chosen by the author because the gamma distribution has the lowest AIC value.

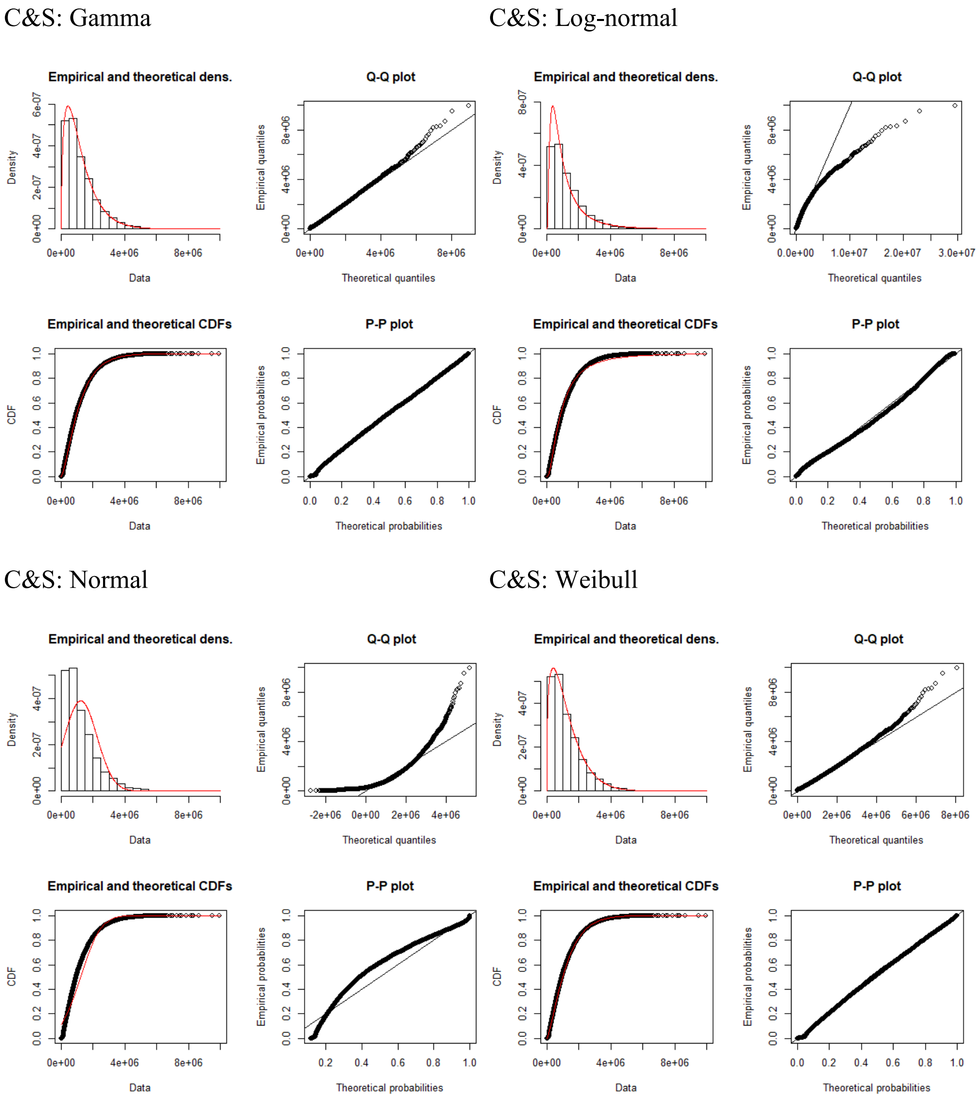


Fig. 4.6 Empirical and theoretical densities for the C&S line of business.

Source: Created by the author.

Annex 9 shows the full decision-making process for selecting distribution. The reserve distribution process has shown that visual test is also important to avoid misjudging the upper or lower tail.

Calculation of the correlation matrix between the lines of business

The primary data for each accident year are shown in Table 4.2. The amounts are claims paid and claims reported but not yet settled. Considering the time series of ten years, the Pearson and rank or Spearman coefficients for the correlation matrix are derived (see Table 4.4.). A significant difference between the correlation matrices is shown, resulting in a potential capital shift compared to the use of standard and alternative capital management methods. Average ranks per each year is presented in Appendix 10.

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 average cost of line of business is one of the possible alternatives to determine the correlation between line of business proposed by Forte *et al.* (2012). For the Baltic non-life insurance market, however, this could be misleading as product coverage expands and insurance density increases year on year (see Fig. 1.2.) and calculation without deductibles could be required. The Baltic statistical offices and the local insurance association also do not publish the average claims development (as is common in advanced markets like Germany). In this case, market data could also be used. Next, crisis is unquestionably the most notable recent example of this type of problem when the number of losses rose, but the correlation was also higher highlighted by Biard *et al.* (2008).

The calculated Spearman's rho between business lines is wide ranging. Credit and surety insurance shows a weak linear correlation between the other lines of business. This is due to the different factors for the frequency and severity of losses, which are shown in Table 4.1. Financial lines are affected by the economic downturn and less by wage inflation and shortages of spare parts. MTPL and Property show a very strong linear correlation due to the same type of claims for property losses (e.g. engine spare parts). MTPL data do not include long-term cash flows and annuities.

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, insurance risk aggregation.

Table 4.5 shows the results of the two-sided p-values of each correlation coefficient by using a t-distribution with $n-2$ degree of freedoms. Author has the following:

- Null hypothesis H_0: the correlation between the two variables is zero.
- Alternative hypothesis H_a: the correlation between the two variables is not zero,

there is significant correlation.

Evidence to conclude the presence of a statistically significant correlation, between GTPL and MTPL, property and MTPL, and Property and GTPL with significance level of *α=0.05*.

Table 4.5

Testing the significance of the correlation coefficient - *p*-values and *t*-test value

	MTPL	C&S	GTPL	Property
	p-value, *t*-score for a correlation coefficient:			
MTPL				
C&S	0.23, 0.78			
GTPL	0.00, 5.46	0.40, 0.27		
Property	0.00, 6.88	0.32, 0.49	0.00, 4.99	
	Decision:			
	Hypothesis Ƕ$_0$ the correlation is not statically significant.			
	Hypothesis Ƕ$_a$ the correlation is statically significant.			
MTPL				
C&S	Ƕ$_0$ accept			
GTPL	Ƕ$_0$ reject	Ƕ$_0$ accept		
Property	Ƕ$_0$ reject	Ƕ$_0$ accept	Ƕ$_0$ reject	

Source: Calculated by the author.

An inflation index could also be applied, using a specific rate for each event country. This approach is crucial, especially when there are inflationary pressures. At the very least, a general consumer price index could be considered. However, it is important to understand the product specifics and changes in deductibles, premium calculation and limits that could set the cap on claims and total losses. There are also different actuarial methods to take inflation into account when calculating reserves in the economic balance. If the loss ratio method is used, a premium adjustment by the general consumer price index must also be taken into account to reflect the future cash flow of claims incurred and the capital required to cover the reserve risk.

Proposed algorithm and calculation of capital with the internal model

The computational algorithm proposed by the author is shown in Fig. 4.7. 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. 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.

The next step is to process the data and finally to verify the data. The data used for the internal capital model should comply with the requirements according to the Solvency II directive. The data strategy, management is not led by the internal capital modelling team. It is usually led by the company's data officer. The author suggests creating an algorithm also for sensitivities, scenarios and backtests and including a loop that takes into account new research.

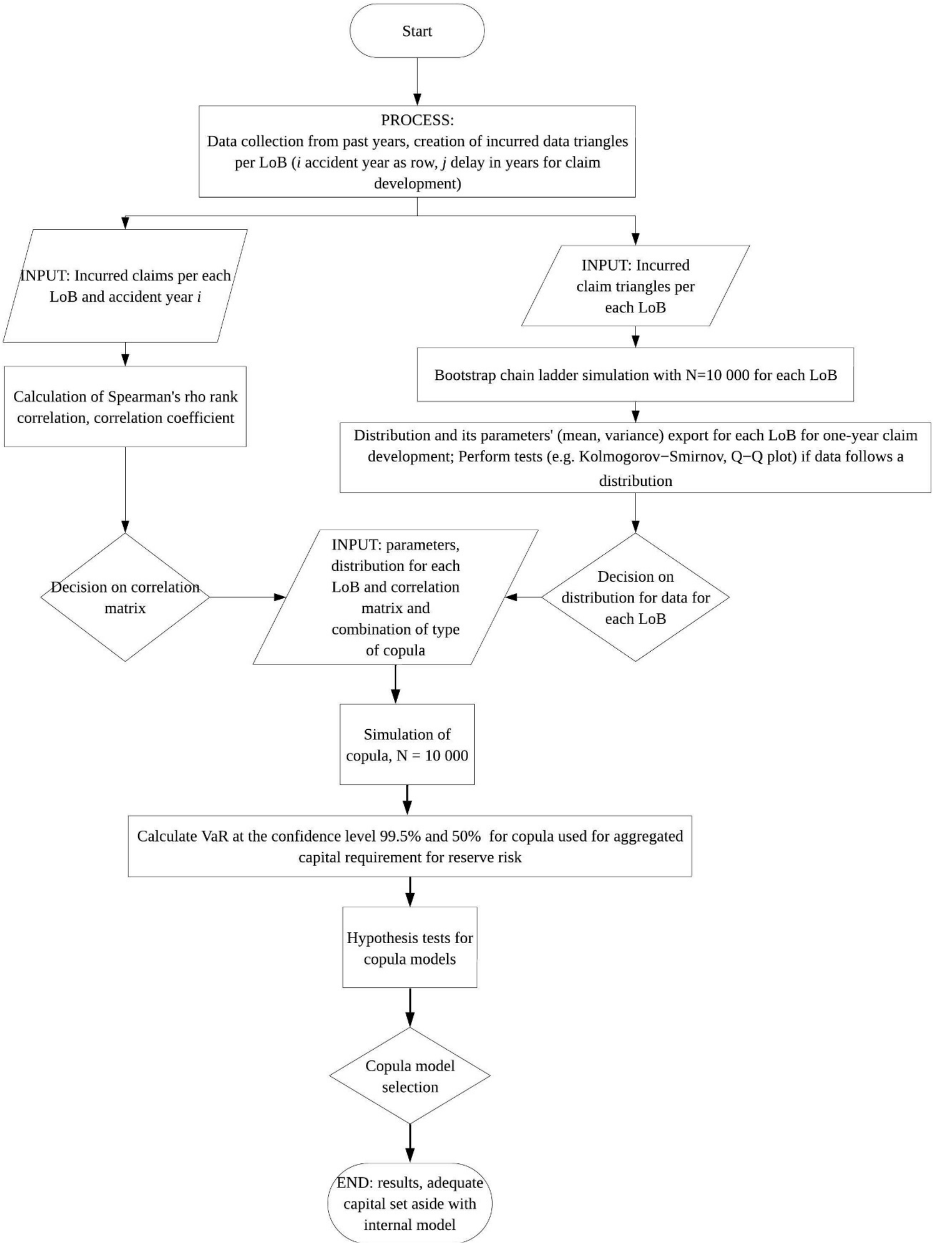


Fig. 4.7 Practical approach: Algorithm for alternative capital management using internal capital modelling (R coding in Appendix 8).

Source: Created by the author.

The R documentation with the packages and key functions can be found in Fig. 4.8. The complete R coding can be found in Appendix 8. The calculation of the required capital for the standard approach is carried out in the Microsoft Excel environment.

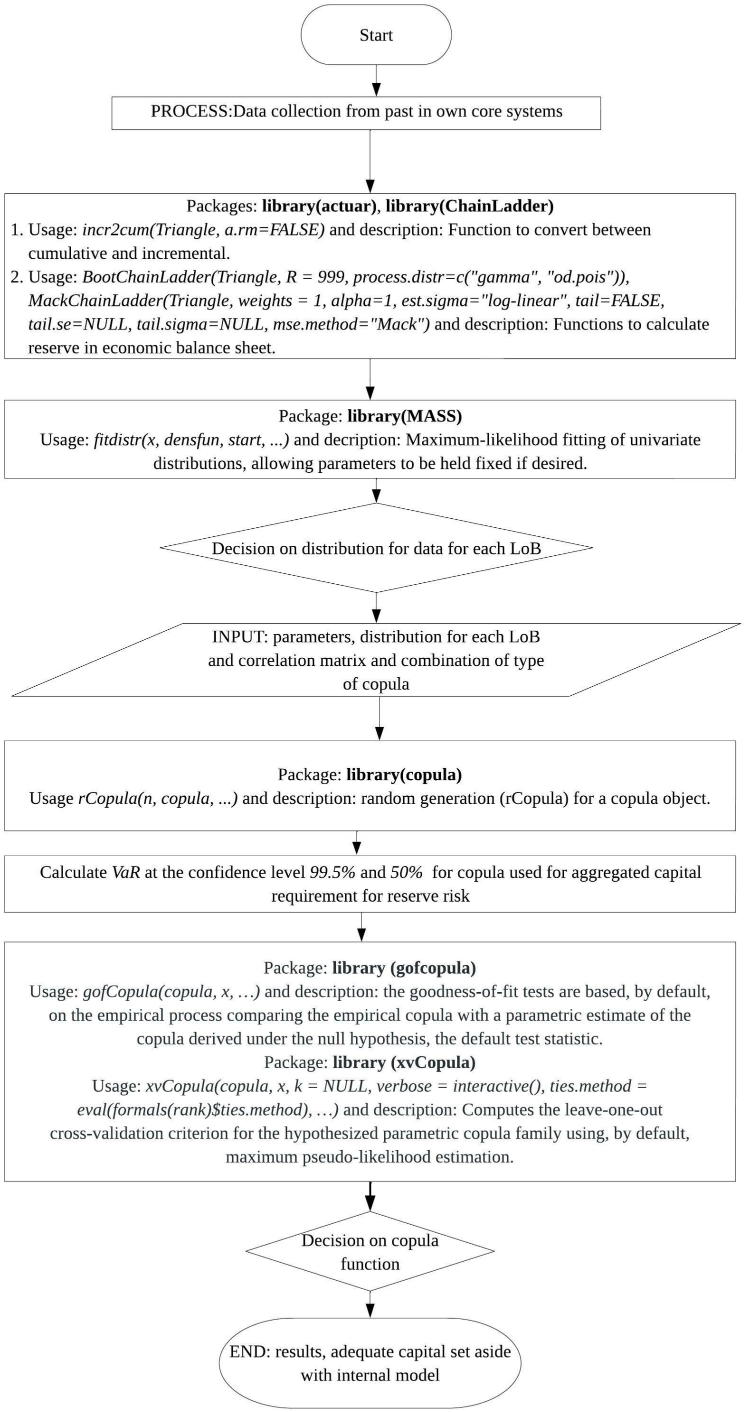


Fig. 4.8 Key functions and packages applied for new model (R coding in Appendix 8).

Source: Created by the author.

The process involves four steps: Data collection, calculation of the correlation matrix, calculation of the reserves in the economic balance sheet and analysis of the best-fitting distribution, and risk aggregation with copula simulation and selection of the model by conducting hypothesis tests. The summary of the inputs and the decision on the distributions (previously presented in Fig. 4.2.) are shown in Fig. 4.9.

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

Source: Created by the author.

The simulation results, required capital by applying the sample data presented in this section, are shown in Table 4.6. 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: normal copula and *t*-copula. 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 4.6

Case study with skewed data – capital requirement for aggregated reserve risk for insurance company regarding MTPL, property, GTPL and C&S (in EUR million)

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 (4 degrees of freedom)	21.76	12.97	8.78

Source: Calculated by the author.

The second simulation is carried out without the C&S reserve, as its share of the total reserve structure on the market in 2020 is less than 6% (see Fig. 1.8.). Next, the C&S data in the triangle is sparse and insufficient to calculate a stable reserve and thus the capital required for reserve risk. Therefore, the author has checked how the internal model also works with three business units.

The case study without C&S shows the required capital for the reserve risk when there is 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 EUR 3.17 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.

Finally, the author has used R version 3.5.1 and package copula by Hofert *et al.* (2018), package gofCopula by Okhrin *et al.* (2021) is used. The model is selected by using goodness-of-fit tests in line with Part 3. As shown in Table 4.6, *t*-copula with 4 degrees of freedom (Option B) is rejected (Part 3, H_0 defined in formula (3.6) with significance at the 0.05). The model with normal copula cannot be rejected based on the hypothesis testing (see Table 4.8). Null hypothesis is rejected for *t*-copula if degrees of freedom is 4 with 3 products. Model selection with cross-validation criterion (see formula 3.16.) shows preferred copula family based on ranked first (the highest value) and *p*-value is not the reason for copula family rejection. See R coding and outputs in Appendix 8 page 168.

Table 4.8

Goodness-of-fit and model selection results for copulas

Approach	Statistic, *p*-value based on Parametric Bootstrap	Cross-validation criterion test	Conclusions
R package functions	*gofcopula()*	*xvcopula()*	
	Skewed data in portfolio, 4 products		
Option A: Normal copula	0.0123 and 0.9985	2.81	H_0 cannot be rejected, plausible
Option B: using *t*-copula (4 degrees of freedom)	0.1782 and 0.0005	-11521.14	reject H_0
	No tails, skewed data in portfolio, 3 products		
Option A: Normal copula	0.0192 and 0.8027	5.25	H_0 cannot be rejected, plausible
Option B: using *t*-copula (4 degrees of freedom)	0.2135 and 0.0005	-623.24	reject H_0

Source: Calculated by the author.

The alternative capital management method proposed by the author can be adjusted by adding other copulas such as skew-*t*, clayton copula and by calculating the reserves in the economic balance sheet according to other methods. All these changes in methods would not change the algorithm of the alternative capital management method proposed by the author. Several scenarios and summary of case studies are described in the next section.

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

A standard approach to capital requirements is considered to compare the cost of capital and the capital management plan between a standard approach and the proposed alternative approach. In addition, the difference in the cost of capital between the capital determination using a standard capital management method (or standard formula) and the alternative capital management method proposed by the author may be calculated. The capital according to a standard model in the Solvency II framework is calculated from claim reserve in the economic balance sheet and three standard deviations, which represent the parametric VaR with a confidence level of 99.5% for a log-normal distribution with a given correlation matrix. More detailed descriptions can be found in the previous parts of Thesis. The capital (in EUR million) can be derived using the standard approach, taking into account the reserve in Table 4.2 using the correlation matrix and volatility measures according to Table 2.2, the steps to calculate the total capital for 4 products according to formula (2.7) and the total volatility measure according to formula (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 from a company have different Spearman's rank correlation matrices and volatilities. Finally, applying the Baltic Spearman's rank correlation matrix for non-life insurance (as in Table 4.2) and the Baltic volatility measures (Appendix 9), the required capital amount (in EUR million) for 4 products is 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 4.9) 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 4.9

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 are based on the proposed algorithm. The analysis also aims to show the sensitivity of the capital requirement when using different risk aggregation, correlation methods, number of products (with less skewed data and product with skewed data C&S), as well as the importance of analysing the underlying distribution. The reserves and insurance products used in the simulation are the same as in Table 4.2. All parameters of the input data used for the aggregated loss distribution in an internal model,a standard model are presented in Table 4.10.

Table 4.10

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

Line of business	MTPL	GTPL	C&S	PROPERTY
Underlying distribution for reserve	Log-normal			
Mean	15.93	14.86	13.96	13.25
Standard deviation used	0.09	0.11	0.17	0.1
Claim reserve, *VaR* 50% (in EUR million)	8.35	2.88	1.18	0.57

Source: Calculated by the author.

The aim is to show that the potential capital requirement shifts can be reduced and can be different using an alternative capital requirement model or a standard model for the Baltic non-life insurance companies, the cost of capital can even be increased in a one-year period. Otherwise, there is a significant risk to the capital reserves of each line of business. The author has calculated the capital requirement using a standard formula and an internal model based on a copula approach and the reserve in the economic balance sheet of the Baltic non-life market over 10 years period (tail coefficient for the 10th year is 1). The sensitivity of the required capital can be assessed by applying the correlation matrix with strong correlation coefficients, then by applying the correlation matrix with weak correlation coefficients. The same correlation matrix is used for standard and alternative approaches. The calculation algorithm does not differ from those described in the previous sections. The correlation between all business areas is positive, i.e. 0.25 and 0.90 (Table 4.11). The scenario with a high correlation for all products could occur in the case of a high inflation rate leading to reserve insufficiency, which is consistent with the definition of reserve risk. The scenario could have an impact on the Baltic non-life insurance market and overall financial stability, taking into account the annual sliding inflation rate of 16.9% announced by the Central Statistical Office of Latvia (2022) from 2021 in Latvia.

Table 4.11

Linear correlation matrix used for a standard and an 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 the capital shifts are shown in Table 4.12. All input parameters given in Fig. 4.9 are included in the code, namely mean, standard deviation and correlation between the lines of business. The solvency capital requirement is calculated using two copulas-based approaches - normal copula and *t*-copula - when the degree of freedom is 4. Such degree of freedom number is chosen based on the fundamentals of copula theory. The theory states that if the degree of freedom is high, the simulation results will give similar results to a normal copula. The higher the number of degrees of freedom, the more similar the results between the *t*-copula and a normal copula. The author has conducted six scenarios and sensitivity analyses. Scenarios 1-4 consider four dimensions, products, while scenarios 5-6 consider three dimensions, products for risk aggregation. The scenarios are described separately.

Scenario 1: This scenario applies a low correlation and volatility measure in line with the EU. As shown in Table 4.12, a capital gain of 4.70% is achieved using a normal copula and a minor insufficiency of -0.39% is observed when using the *t*-copula.

Scenario 2: High correlation (0.90) and volatility measure in line with EU is applied. As shown in Table 4.9, the capital gain is 3.11% using a normal copula and 2.59% using the *t*-copula.

Scenario 3: High volatility measure and low, positive correlation coefficient (i.e. 25%) is used. As shown in Table 4.10, the proportions of minor capital insufficiency using a normal copula and a *t*-copula are -0.39% and -0.69%, respectively.

Scenario 4: The author has used a scenario consistent with that described in detail in the previous sections by primary data. Scenario 3 differs from Scenario 4 by a correlation matrix assumption. Scenario 4 is classified as data with a high correlation coefficient and a high volatility measure. This scenario can be interpreted as one of the worst-case scenarios and as potentially insufficient capital. The difference as a percentage of reserve risk is significant. As shown in Table 4.12, the percentage of capital insufficiency using a normal copula and a *t*-copula is 6.07% and 11%, respectively.

Scenario 5: This scenario has only three dimensions, products (without C&S), a low volatility measure and a low correlation. As shown in Table 4.12, a capital gain of 5.9% is achieved with a normal copula and -1.84% with a *t*-copula.

Scenario 6: This scenario has only three dimensions, products (without C&S), a low volatility measure and a high correlation. As shown in Table 4.12, the capital gain is 6.36% for a normal copula and 4.24% for a *t*-copula.

The settlement period for these specific lines of business is long, and insurance loss distributions are usually skewed (Meyers, 2005). Therefore, a tail correlation exists. By adding more products to the new internal model, *t*-copula, skew *t*-copula might be better suitable for future research taking into account the fact that tail correlations can also occur. The author advises that the choice of degree of freedom should be less than 10 so as to capture tail dependence. 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). Therefore, the author believes that for this case study and for insurance industry overall, *t*-copula would be more appropriate than a normal copula. The following conclusion does not follow from the hypothesis test (see Table 4.8), as there are only short tails for these specific company productsm-liabilities are not included.

Table 4.12

Simulation results of the scenario and case studies analysis (in EUR million)

Approach	***VaR* 99.5%**	**Reserve in economic balance sheet**	**Capital for reserve risk**	**Capital gain or loss versus standard in %**
Scenario 1 – low volatility measure and low correlation (4 products)				
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 (4 products)				
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 4.9, 4 products)				
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. (4 products)				
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.

In the case of EU insurers, however, this could be different, as the research by Munroe *et al.* (2015) shows. This would apply to the majority of insurers with products that have long-term liabilities. However, in order to assess the appropriateness of the data for the Baltic company data, this company-specific research should be continued. The results of the empirical study by Bermúdez *et al.* (2013) show that the required economic capital in the case of the *t*-copula is 10% higher than when using the standard formula. The authors conclude that the economic capital with *t*-copula can be up to 11% higher than with the standard formula.

However, companies with a narrow distribution of reserves for products, the saving in required capital is higher. This is shown by Scenario 5 and Scenario 6, which exclude C&S data with skewed distribution. 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 also applies to the leading non-life insurers in the Baltic non-life insurance market.

Models with a normal copula (Option A) cannot be rejected based on the chosen primary data. Such conclusion is for 3 dimensions (without C&S) and 4 dimensions. The settlement period for these specific lines of business theoretically is long, and insurance loss distributions could be skewed (case of C&S). Therefore, a tail correlation occurs. *t*-copula could be more appropriate in future studies, increasing products with skewed data in model, taking into account the fact that a tail correlation can also occur for major lines of business.

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 empirical study shows that the simplest copula - the normal copula - can be used as a solution to reduce the required capital requirement (in the case of narrow distributions) and improve required capital adequacy. The solution also helps to obtain an improved capital adequacy ratio and to plan sufficient required capital costs. It is important to note that the Baltic non-life insurance market is developing (insurance density, coverage and sum insured are increasing) and that the available experience may be insufficient for extreme events as required by the Solvency II framework requires. Therefore, it is important to repeat the simulation with new data sets. The required return on capital in relation to the cost of financing can vary depending on the capital market and the region. The author advises using at least 6% as the cost of capital, which corresponds to the calculation of the risk margin under Solvency II. The savings in the cost of capital can then be calculated as the multiplication of the rate and the capital gains.

Conclusions on the development of a new alternative capital 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, Zariņa *et al*., 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.

The author had no need to assess the reserve risk for older claims (older than 10 years) and applied tail coefficient 1. However, it might be necessary to revise a reserve method provided in the algorithm. Next, large claim, extreme event analysis and reinsurance trieties can be examed seperatelly. Subsequently, large claim, the analysis of extreme events and reinsurance contracts can be examined separately. The same algorithm can be used, but external data and market data are needed.

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 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. Alternatively, the required capital for reserve risk can be improved by an alternative capital management method as digitalisation.

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, "with the application of an alternative capital management methods, a more accurate assessment of capital requirement that cover reserve risk and a reduction in the cost of capital in 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 in 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 claim reserve occupy 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 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.
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 can be used by 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. This 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 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 Baltic non-life insurance have not been investigated. There are no research papers published by 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, 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 degrees of freedom are 4 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 of 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.
29. Applying the standard method for the required capital in the Baltic and EU markets is impossible to apply more complex interdependencies and dynamic economic, including fluctuations in inflation rate.
30. 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.
31. 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.
32. The claim run-off reserve experience can be used as the backtesting is limited due to the fact that the required capital is set at a high confidence level.
33. The Theses defence in the Doctoral Thesis have been confirmed.

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 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.*

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APPENDICES

Appendix 1

Secondary data used in analysis of Baltic insurance market development

Units: EUR thous.

Period	Legal name of company	2015	2016	2017	2018	2019	2020	2016	2017	2018	2019	2020	2020
Position		Gross written premium						Solvency ratio					SCR
Lietuvos draudimas	Akcine draudimo bendrove "Gjensidige"	152 563	182 738	228 315	252 783	266 999	253 608	200%	150%	150%	163%	159%	71 256
ERGO	ERGO Insurance SE	121 044	136 777	166 885	183 827	193 309	194 141	129%	122%	122%	131%	140%	56 713
BTA	BTA Baltic Insurance Company, AAS	55 700	132 109	162 979	207 193	222 680	206 814	127%	131%	131%	137%	136%	50 920
IF	If P&C Insurance AS	133 200	130 781	138 751	162 666	149 046	152 243	267%	274%	274%	292%	236%	67 607
GJENSIDIGE	Akcine draudimo bendrove "Gjensidige"	68 401	75 634	115 104	115 544	119 662	112 625	138%	118%	118%	155%	190%	27 987
BALTA	Apdrošinašanas akciju sabiedriba BALTA	67 173	75 610	88 922	104 722	113 758	107 261	163%	133%	133%	170%	163%	27 322
BALCIA	Balcia Insurance SE	50 033	72 027	96 878	105 000	87 225	61 368	146%	128%	117%	124%	151%	28 999
SWEDBANK	Swedbank P&C Insurance AS	59 251	71 118	90 046	113 970	130 604	129 557	176%	151%	150%	141%	164%	30 143
SEESAM	retired	56 414	59 122	64 515	71 979	78 200	0						
COMPENSA	"Compensa Vienna Insurance Group", akcinė draudimo bendrovė		45 150	54 533	73 001	84 198	121 454	134%	107%	135%	156%	199%	40 367
INTERRISK	retired	20 277	23 090	0	0	0	0						
BAN	"Baltijas Apdrošināšanas Nams" apdrošināšanas akciju sabiedrība	13 746	13 735	16 953	19 451	16 496	12 301	143%	137%	113%	143%	171%	2827
INGES	Inges Kindlustus AS	2 295	5 785	6 194	8 065	8 153	5 536	186%	158%	106%	155%	168%	4 193
SALVAS	Salva Kindlustuse AS	19 093	19 330	20 585	20 940	20 817	20 454	179%	206%	226%	213%	239%	8 845

Source: annual and SFCR reports (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)

Appendix 1 continued

Units: EUR thous.

Company/ Period	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Position	IFRS Claim reserve									
AB Lietuvos draudimas	39 334	38 262	35 263	38 646	51 003	56 109	76 670	90 276	109 956	123 484
ERGO	26 794	44 714	54 917	57 808	64 498	68 088	67 606	153 045	95 201	108 226
BTA	65770.14	70 362	78677	96 807	53 251	56 938	101 389	129 566	138 846	138 846
IF	70 537	76 921	80 150	81 416	85 575	89 387	100 541	77 852	120 672	131 587
GJENSIDIGE	25 072	27 101	26 707	25 168	30 261	57 525	57 658	55 070	56 596	51 663
SWEDBANK	6 468	7 756	9 998	11 622	14 827	17 075	24 835	29 688	33 961	34 631
Position	Gross written premium									
AB Lietuvos draudimas	102 319	132 111	121 757	119 536	152 563	182 738	228 315	252 783	266 999	253 608
ERGO	38 754	91 336	108 186	107 953	121 044	136 777	166 885	183 827	193 309	194 141
BTA	118 857	142 420	159 702	177 859	121 044	155 199	162 979	207 193	222 680	206 814
IF	113 900	115 166	116 906	122 574	133 200	130 781	138 751	162 666	149 046	152 243
GJENSIDIGE	51 099	62 619	67 954	61 056	67 173	75 634	115 104	115 544	119 662	112 625
SWEDBANK	39 035	42 434	45 643	51 878	59 862	71 118	90 046	116 118	130 604	129 557

Year	2016	2017	2018	2019	2020	2020						
Company	SCR	SCR	SCR	SCR	SCR	BSCR	Market	Counterparty	Life	Health	Non-life	Operational
AB Lietuvos draudimas	42 397	52 603	59 922	65 442	71 256	67 945	21 275	6 034	1 172	4 903	55 080	7 729
BALTA	16 517	21 994	25 845	26 721	27 322	24 062	6 118	2 082	253	3 900	19 895	3 260
BTA	29 212	38 954	44 491	48 526	50 920	46 481	15 628	7 192	2 527	4 790	34 279	6 139
COMPENSA	8 217	8 914	14 480	16 699	40 367	40 135	18 030	6 545	186	2 611	26 904	4 530
ERGO	38 093	45 393	54 080	57 126	56 713	50 930	6 716	3 700	461	3 030	46 539	5 783
GJENSIDIGE	30 617	32 169	29 906	30 487	27 987	24 598	3 412	2 756	1 348	3 362	21 348	3 389
IF	50 253	53 363	57 682	62 062	67 607	63 098	23 646	6 642	421	900	46 973	4 509
SWEDBANK	19 978	25 497	30 932	35 799	30 143	30 782	3 152	6 998	91	1 232	25 507	3 932

Company	*BTA*	*GJENSIDIGE*	*AB Lietuvos draudimas*	*ERGO*	*IF*
Year	Liquid assets as the sum of cash, deposits, corporate and government bonds and equities in economic balance sheet				
2020	233 900	119 951	282 477	220 457	349 376
2019	221 965	109 806	247 212	179 503	336 404
2018	208 685	104 753	208 022	151 406	304 873
2017	183 389	99 417	175 238	128 898	279 971
2016	125 153	105 018	140 286	109 554	257 149

Source: annual and SFCR reports (AB Lietuvos draudimas, 2020; BALTA, 2020; BTA, 2020; COMPENSA, 2020; ERGO, 2020; GJENSIDIGE, 2020; IF, 2020; SWEDBANK, 2020)

Appendix 1 continued

Units: EUR million

Gross written premium by countries	EE	LV	LT	DE	AT	PL	SE
2016	438	316	333	70 760	8 821	6 971	8 657
2017	504	367	430	75 150	9 112	8 697	9 028
2018	586	438	473	78 313	9 437	9 007	9 937
2019	613	446	504	82 189	9 825	9 471	10 360
2020	525	395	521	85 034	10 091	8 886	11 44

Source: EIOPA (2020b)

	Position*	1	2	3		1	2	3		1	2	3		1	2	3
2016	Overall Baltic non-life market	950	585	342	LV	262	Not used		LT	285	Not used		EE	403	Not used	
2017		1121	659	380		300	187	95		370	213	144		452	259	141
2018		1280	755	424		351	230	117		412	228	154		516	297	153
2019		1359	800	444		356	229	116		449	249	166		554	322	161
2020		1298	739	422		332	198	113		481	260	176		484	281	134

Source: EIOPA (2020b)

*[1] Net Premiums earned; [2] Net Claims incurred;[3] Expenses incurred

Appendix 2

Secondary data used in analysis of reserve development for non-life insurance market

Units: EUR thous.

	Annuities	Medical expense	Income protection	Motor vehicle liability	Other motor	Marine, aviation and transport	Fire, other damage to property	General liability	Credit and suretyship	Legal	Assistance	Various
	Solvency II gross premium and claim reserve in 2020 (best estimate)											
BTA	56 334	7 053	1 998	57 669	16 433	3 393	18 619	11 109	8 303	13	1 877	129
ERGO	14 933	672	2 545	70 008	12 141	6 116	27 569	10 218	4 612	219	412	
IF	12 041	2 754	521	72 923	12 699	1 784	27 021	26 402	0	0	0	0
GJENSIDIGE	14 139	4 559	682	40 155	8 543	353	10 472	3 078	1 717	0	103	200
COMPENSA	14 182	2 933	1 206	30 646	13 278	671	32 094	5 098	1 359	0	382	419
BALTA	7 556	5 749	845	26 271	11 149	163	12 254	2 856	6 384	0	398	98
Swedbank	3 467	-193	321	11 892	-167	0	218	-193	0	0	0	858
AB Lietuvos draudimas	17 696	4 474	2 120	87 885	21 797	742	31 426	9 013	3 960	0	0	2 066
	Solvency II gross claim reserve in 2020 (best estimate)											
BTA	56 334	2 054	867	41 561	6 572	2 947	5 978	10 673	8 670	1	1 072	106
ERGO	14 933	244	1 086	51 719	4 072	5 419	20 074	8 845	2 424	0	0	0
IF	12 041	1 143	323	63 379	5 624	1 674	23 958	25 366	0	0	0	0
GJENSIDIGE	14 139	933	184	24 892	2 550	221	5 356	2 337	990	0	0	0
COMPENSA	14 182	850	650	18 162	5 770	687	22 229	5 566	1 145	0	1	841
BALTA	7 556	1 032	265	20 054	4 007	201	9 232	2 170	3 295	0	217	38
Swedbank	3 467	153	794	9 526	3 928	0	6 121	547	0	0	0	3 436
AB Lietuvos draudimas	17 696	2 022	1 261	64 330	7 286	735	21 201	7 563	2 573	0	0	2 228

Source: annual and SFCR reports (AB Lietuvos draudimas, 2020; BALTA, 2020; BTA, 2020; COMPENSA, 2020; ERGO, 2020; GJENSIDIGE, 2020; IF, 2020; SWEDBANK, 2020)

Units: EUR thous.

	Annuities	Medical expense	Income protection	Motor vehicle liability	Other motor	Marine, aviation and transport	Fire, other damage to property	General liability	Credit and suretyship	Legal	Assistance	Various
	Solvency II gross premium and claim reserve in 2019 (best estimate)											
BTA	50 267	8 025	2 013	0	67 104	21 483	5 299	19 862	11 914	8 362	5	2 295
ERGO	14 415	1 000	2 114	0	71 752	12 416	1 458	16 940	9 123	3 510	376	521
IF	10 786	2 993	483	0	68 112	12 536	1 653	21 102	24 982	0	0	0
GJENSIDIGE	12 574	4 914	839	0	44 751	10 689	305	9 110	3 500	1 894	0	146
COMPENSA	2 288	397	498	0	20 087	6 648	160	8 563	869	471	0	34
BALTA	6 082	5 302	907	0	25 870	11 069	312	14 472	2 717	4 919	0	672
Swedbank	2 778	75	201	0	13 287	-167	0	-1 502	-379	0	0	0
AB Lietuvos draudimas	15 420	3 310	2 158	0	83 073	22 294	644	24 314	7 812	2 589	0	0
	Solvency II gross claim reserve in 2019 (best estimate)											
BTA	50 267	2 105	760	0	45 229	8 070	4 779	7 454	11 126	6 834	4	1 174
ERGO	14 415	488	1 125	0	50 820	4 802	1 146	11 716	7 940	2 294	0	0
IF	10 786	1 141	273	0	59 189	6 071	1 582	17 727	23 868	0	0	0
GJENSIDIGE	12 574	1 442	239	0	29 483	3 675	171	3 939	2 800	1 861	0	127
COMPENSA	2 288	253	175	0	10 740	2 377	158	4 710	923	401	0	0
BALTA	6 082	1 670	360	0	18 374	4 386	310	9 119	2 046	2 059	0	382
Swedbank	2 778	584	787	0	10 191	3 928	0	5 254	460	0	0	0
AB Lietuvos draudimas	15 420	1 534	1 155	0	58 462	8 755	551	16 616	6 574	1 557	978	0

Source: annual and SFCR reports (AB Lietuvos draudimas, 2020; BALTA, 2020; BTA, 2020; COMPENSA, 2020; ERGO, 2020; GJENSIDIGE, 2020; IF, 2020; SWEDBANK, 2020)

Appendix 2 continued

Units: EUR thous.

	Annuities	Medical expense	Income protection	Motor vehicle liability	Other motor	Marine, aviation and transport	Fire, other damage to property	General liability	Credit and suretyship	Legal	Assistance	Various
	Solvency II gross premium and claim reserve in 2018 (best estimate)											
BTA	42 864	2 153	693	0	43 211	8 580	4 497	10 163	9 750	6 241	2	1 141
ERGO	12 655	712	950	0	44 309	4 797	295	6 585	7 785	676	526	129
IF	10 467	1 200	370		53 638	6 350	1 502	17 133	18 758	0	0	0
GJENSIDIGE	10 177	3 325	543	0	14 105	6 318	134	5 168	636	176	0	134
COMPENSA	1 299	239	155	0	10	3	156	5	488	203	0	2
BALTA	3 838	1 480	596	0	15 648	3 960	389	45 012	1 928	1 418	0	162
AB Lietuvos draudimas	10 865	1 086	1 145		46 368	8 617	492	9 208	7 614	1 233		
Swedbank	2 041	305	534	0	9 104	4 003	0	5 927	500	0	0	0
	Solvency II gross claim reserve in 2018 (best estimate)											
BTA	42 864	7 131	1 862	0	62 768	21 877	4 578	16 552	10 185	9 689	0	2 145
ERGO	12 655	1 188	2 529	0	69 348	18 157	545	13 384	9 420	856	538	387
IF	10 467	3 108	522	0	63 956	13 014	1 561	20 293	19 422	0	0	0
GJENSIDIGE	10 177	4 897	856	0	43 861	8 939	812	9 797	3 913	2 193	0	215
COMPENSA	1 299	353	461	0	20 030	6 624	146	7 914	572	233	0	36
BALTA	3 838	3 994	1 006	0	22 227	10 073	427	48 582	2 309	3 613	0	358
AB Lietuvos draudimas	10 865	2 593	2 852	0	68 120	21 937	518	15 797	8 649	1 889	0	0
Swedbank	2 041	-156	-84	0	12 192	1 497	0	1 567	-55	0	0	0

Source: annual and SFCR reports (AB Lietuvos draudimas, 2020; BALTA, 2020; BTA, 2020; COMPENSA, 2020; ERGO, 2020; GJENSIDIGE, 2020; IF, 2020; SWEDBANK, 2020)

Appendix 2 continued

Units: EUR thous.

	Annuities	Medical expense	Income protection	Motor vehicle liability	Other motor	Marine, aviation and transport	Fire, other damage to property	General liability	Credit and suretyship	Legal	Assistance	Various
	Solvency II gross premium and claim reserve in 2017 (best estimate)											
BTA	33 716	1 667	293	0	34 913	7 207	897	5 353	7 859	7 716	4	865
ERGO	10 762	663	1 006	0	34 643	5 653	370	6 900	5 771	510	467	109
IF	9 557	1 096	294	0	43 358	6 212	1 980	15 209	21 279	0	0	0
GJENSIDIGE	9 666	1 543	490	0	33 465	2 621	271	3 396	3 895	2 325	0	132
COMPENSA	736	44	154	0	7 401	2 183	149	1 139	301	19	0	0
BALTA	2 147	1 205	337	0	9 487	3 291	608	5 719	1 671	851	0	175
AB Lietuvos draudimas	9 066	628	832	0	33 943	8 178	611	11 292	582	1 263	0	0
SWEDBANK	1 862	808	375	0	6 077	3 820	0	6 186	409	0	0	0
	Solvency II gross claim reserve in 2017 (best estimate)											
BTA	33 716	1 667	293	0	34 913	7 207	897	5 353	7 859	7 716	4	865
ERGO	10 762	663	1 006	0	34 643	5 653	370	6 900	5 771	510	467	109
IF	9 557	1 096	294	0	43 358	6 212	1 980	15 209	21 279	0	0	0
GJENSIDIGE	9 666	1 543	490	0	33 465	2 621	271	3 396	3 895	2 325	0	132
COMPENSA	736	44	154	0	7 401	2 183	149	1 139	301	19	0	0
BALTA	2 147	1 205	337	0	9 487	3 291	608	5 719	1 671	851	0	175
AB Lietuvos draudimas	9 066	628	832	0	33 943	8 178	611	11 292	582	1 263	0	0
Swedbank P&C Insurance	1 862	808	375	0	6 077	3 820	0	6 186	409	0	0	0

Source: annual and SFCR reports (AB Lietuvos draudimas, 2020; BALTA, 2020; BTA, 2020; COMPENSA, 2020; ERGO, 2020; GJENSIDIGE, 2020; IF, 2020; SWEDBANK, 2020)

Appendix 2 continued

Units: EUR thous.

	Annuities	Medical expense	Income protection	Motor vehicle liability	Other motor	Marine, aviation and transport	Fire, other damage to property	General liability	Credit and suretyship	Legal	Assistance	Various
	Solvency II gross premium and claim reserve in 2016 (best estimate)											
BTA	11 535	1 112	474	0	29 097	4 538	690	3 103	5 276	390	2	293
ERGO	7 716	611	1 066	0	30 662	5 213	668	13 855	6 177	632	0	165
IF	9 068	1 059	372	0	38 291	5 713	2 902	13 699	17 548			
GJENSIDIGE	8 970	1 194	636	0	33 166	3 425	489	4 290	3 566	1 765	0	199
COMPENSA	507	68	117	0	19 191	1 733	5	638	265	0	0	6
BALTA	1 402	973	161	0	8 513	2 889	859	4 367	2 641	551	0	140
AB Lietuvos draudimas	6 734	418	892	0	26 318	6 049	751	5 554	4 366	568	0	0
SWEDBANK	1 772	392	331	0	3 632	2 695	0	4 475	313	1 198	0	0
	Solvency II gross claim reserve in 2016 (best estimate)											
BTA	11 535	1 112	474	0	29 097	4 538	690	3 103	5 276	390	2	293
ERGO	7 716	611	1 066	0	30 662	5 213	668	13 855	6 177	632	0	165
IF	9 068	1 059	372	0	38 291	5 713	2 902	13 699	17 548			
GJENSIDIGE	8 970	1 194	636	0	33 166	3 425	489	4 290	3 566	1 765	0	199
COMPENSA	507	68	117	0	19 191	1 733	5	638	265	0	0	6
BALTA	1 402	973	161	0	8 513	2 889	859	4 367	2 641	551	0	140
AB Lietuvos draudimas	6 734	418	892	0	26 318	6 049	751	5 554	4 366	568	0	0
Swedbank P&C Insurance	1 772	392	331	0	3 632	2 695	0	4 475	313	1 198	0	0

Source: annual and SFCR reports (AB Lietuvos draudimas, 2020; BALTA, 2020; BTA, 2020; COMPENSA, 2020; ERGO, 2020; GJENSIDIGE, 2020; IF, 2020; SWEDBANK, 2020)

Appendix 2 continued

Liabilities positions in Baltic economic balance sheet, units: EUR million	2016	2017	2018	2019	2020
Technical provisions – non-life	731.64	828.57	982.95	1 018.19	1 005.95
Technical provisions – non-life (excluding health)	681.38	774.26	924.33	962.58	955.17
Technical provisions calculated as a whole	0	0	0	0	0
Best Estimate	652.93	740.84	882.12	915.49	905.12
Risk margin	28.45	33.42	42.21	47.10	50.05
Technical provisions - health (similar to non-life)	50.25	54.31	58.62	55.61	50.78
Technical provisions calculated as a whole	0	0	0	0	0
Best Estimate	47.47	51.18	54.31	50.37	44.89
Risk margin	2.78	3.12	4.32	5.24	5.88
Technical provisions - life (excluding index-linked and unit-linked)	653.20	640.29	716.25	786.30	875.34
Technical provisions - health (similar to life)	- 53.36	- 48.26	- 48.00	- 48.49	- 56.32
Technical provisions calculated as a whole	0	0	0	0	0
Best Estimate	- 68.42	- 61.73	- 62.97	- 63.52	- 73.85
Risk margin	15.06	13.46	14.98	15.04	17.53
Technical provisions – life (excluding health and index-linked and unit-linked)	706.55	688.57	764.24	834.79	931.67
Technical provisions calculated as a whole	0	0	0	0	0
Best Estimate	640.86	616.88	689.51	753.24	826.03
Risk margin	65.70	71.69	74.73	81.56	105.63
Technical provisions – index-linked and unit-linked	1 015.08	949.63	939.70	1 173.24	1 293.14
Technical provisions calculated as a whole	463.24	497.51	485.61	300.31	330.40
Best Estimate	518.01	415.06	410.72	826.28	918.81
Risk margin	33.83	37.06	43.38	46.65	43.95
Other technical provisions					
Contingent liabilities	0.07	0.10	0	0	0
Provisions other than technical provisions	6.32	4.78	4.36	4.77	9.45
Pension benefit obligations	0.93	1.03	1.53	1.71	1.82
Deposits from reinsurers	29.65	29.49	41.75	48.72	54.48
Deferred tax liabilities	21.96	22.67	21.82	24.72	25.20
Derivatives	0	0	0.02	0	0.01
Debts owed to credit institutions	0.05	0.01	0.07	0.90	1.46
Financial liabilities other than debts owed to credit institutions	3.92	2.95	3.09	39.71	25.36
Insurance & intermediaries payables	48.81	55.47	58.36	55.38	80.13
Reinsurance payables	16.21	27.80	17.93	29.78	25.90
Payables (trade, not insurance)	46.13	43.06	39.93	41.87	47.72
Subordinated liabilities	25.88	15.83	23.12	22.83	20.89
Subordinated liabilities not in Basic Own Funds	1.71	0.21	0	0	0.11
bordinated liabilities in Basic Own Funds	24.17	15.62	23.12	22.83	20.78
Any other liabilities, not elsewhere shown	25.04	25.96	38.63	46.14	50.85
Total liabilities	2 624.88	2 647.67	2 889.49	3 294.28	3 517.70

Source: EIOPA (2020b)

Appendix 3

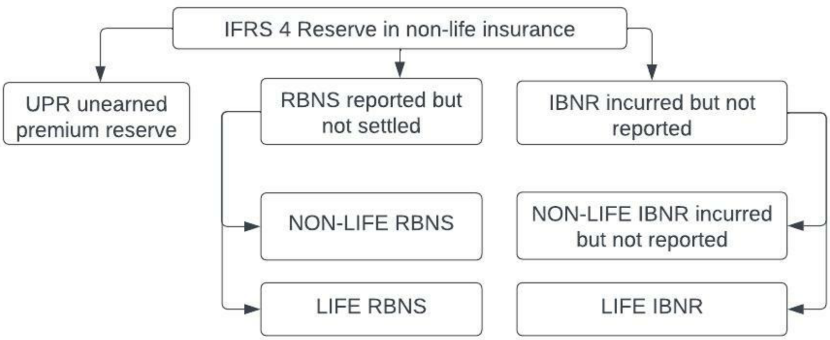
Types of reserves, technical provisions under Solvency II framework for non-life insurers

Solvency II technical provisions

Non-life / Life	Type	Group	Solvency II balance sheet		LIABILITIES - ASSETS
			ASSETS	LIABILITIES	
Non-Life Technical Provisions	Non-life products (except life technical provisions)	**Premium reserve**	Recoverable from reinsurance contract	Gross Best Estimate of premium provisions	Net Best Estimate of Premium Provisions
		Claim reserve	Recoverable from reinsurance contract	Gross Best Estimate of claim provisions	Net Best Estimate of Claims Provisions
		Risk margin	No such	Risk margin	Risk margin
		TOTAL	Recoverable from reinsurance contract	Technical provisions - total	Technical provisions minus recoverables from reinsurance
Life Technical Provisions	Annuities stemming from non-life insurance contracts	**Premium reserve**	No such	No such	No such
		Claim reserve	Recoverable from reinsurance contract	Gross Best Estimate of claim provisions	Net Best Estimate of Claims Provisions
		Risk margin	No such	Risk margin	Risk margin
		TOTAL	Recoverable from reinsurance contract	Technical provisions - total	Technical provisions minus recoverables from reinsurance

Source: created by the author based on European Parliament, & Council of the European Union (2014).

IFRS 4 basic reserve types that can be used in order to calculate Solvency II reserves.



Sum of RBNS and IBNR is called as claim reserve. Source: created by the author.

Appendix 3 continued

Position	**Claim reserve**	**Premium reserve**	**Risk margin**
	Non-life technical provisions for non-life insurers are made of **claim reserve + premium reserve + risk margin**		
Definition	is the discounted best estimate of future cash flows related to incurred events prior to the valuation date	is the discounted best estimate of future payments, future costs, future not incurred events related to policies that the insurer is obliged to at the valuation date	is the intended to be the balance that another insurer taking on the liabilities at the valuation date would require over and above the best estimate
Calculation	using **non-life reserving techniques** (triangulation)	using unearned premium reserve, future instalments, expected combined ratio	by applying cost-of-capital approach, using discounting and required for net of reinsurance reserve
Position in economic balance	liabilities side: gross reserve, asset side: reinsurance part in reserve		in liabilities side
Requirement for SCR calculation	under non-life and health **reserve risk**	under non-life and health premium risk	no SCR
In scope of required capital for non-life reserve risk under Solvency II, author's proposed internal model	**yes**	no, under premium risk based on definition and reserve calculation techniques	no, required capital for this economic balance sheet item is not needed
	Life technical provisions for non-life insurers are made of claim reserve + risk margin		
Calculation	using mainly **life techniques** which covers longevity, mortality risk		by applying cost-of-capital approach, using discounting and required for net of reinsurance reserve
Requirement for SCR calculation	life risk		no SCR
In scope of required capital for non-life reserve risk based on Solvency II, author's proposed model	no, must be reflected by using also life techniques, methods for life risk assessment		no, required capital for this economic balance sheet item is not needed

Source: created by the author

Appendix 4

Correlation matrix, segmentation, standard deviations for non-life reserve risk sub-module

Parameters for calculation of reserve risk using standard capital management approach (standard formula) presented in European Parliament & Council of the European Union (2014):

s \ t	1	2	3	4	5	6	7	8	9	10	11	12
1	1	0,5	0,5	0,25	0,5	0,25	0,5	0,25	0,5	0,25	0,25	0,25
2	0,5	1	0,25	0,25	0,25	0,25	0,5	0,5	0,5	0,25	0,25	0,25
3	0,5	0,25	1	0,25	0,25	0,25	0,25	0,5	0,5	0,25	0,5	0,25
4	0,25	0,25	0,25	1	0,25	0,25	0,25	0,5	0,5	0,25	0,5	0,5
5	0,5	0,25	0,25	0,25	1	0,5	0,5	0,25	0,5	0,5	0,25	0,25
6	0,25	0,25	0,25	0,25	0,5	1	0,5	0,25	0,5	0,5	0,25	0,25
7	0,5	0,5	0,25	0,25	0,5	0,5	1	0,25	0,5	0,5	0,25	0,25
8	0,25	0,5	0,5	0,5	0,25	0,25	0,25	1	0,5	0,25	0,25	0,5
9	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	1	0,25	0,5	0,25
10	0,25	0,25	0,25	0,25	0,5	0,5	0,5	0,25	0,25	1	0,25	0,25
11	0,25	0,25	0,5	0,5	0,25	0,25	0,25	0,25	0,5	0,25	1	0,25
12	0,25	0,25	0,25	0,5	0,25	0,25	0,25	0,5	0,25	0,25	0,25	1

	Segment	Lines of business, as set out in Annex I, that the segment consists of	Standard deviation for gross premium risk of the segment	Standard deviation for reserve risk of the segment
1	Motor vehicle liability insurance and proportional reinsurance	4 and 16	10 %	9 %
2	Other motor insurance and proportional reinsurance	5 and 17	8 %	8 %
3	Marine, aviation and transport insurance and proportional reinsurance	6 and 18	15 %	11 %
4	Fire and other damage to property insurance and proportional reinsurance	7 and 19	8 %	10 %
5	General liability insurance and proportional reinsurance	8 and 20	14 %	11 %
6	Credit and suretyship insurance and proportional reinsurance	9 and 21	12 %	19 %
7	Legal expenses insurance and proportional reinsurance	10 and 22	7 %	12 %
8	Assistance and its proportional reinsurance	11 and 23	9 %	20 %
9	Miscellaneous financial loss insurance and proportional reinsurance	12 and 24	13 %	20 %
10	Non-proportional casualty reinsurance	26	17 %	20 %
11	Non-proportional marine, aviation and transport reinsurance	27	17 %	20 %
12	Non-proportional property reinsurance	28	17 %	20 %

Appendix 5

Extended literature review

Source: summarised by the author.

No.	Paper	Name of article	Year	RQ1. What is internal model under Solvency II framework?	RQ2. What are weaknesses of standard formula for non-life reserve risk?	RQ3. What are possible solutions and alternative approaches to solve EIOPA Solvency II standard formula problem?
1	(Biard *et al.*, 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	2008	The **goal** of paper is to examine possible impact to SCR in internal models due to dependences and how ruin probabilities change in case of heavy- tailed claim amounts (in practice it is especially for MTPL line of business). Authors concede that usually SCR internal model consists of approximation of **finite-time ruin probabilities**. Finite-time is used because SII framework use 12 months' time horizon.	Authors indicate that claim amounts can become from independent (i.i.d) (in ideal world) to strongly positively dependent (realistic scenario). It is simple because there are different kind of sum insured, regions and risks in portfolio. Therefore, **possible correlation crises** can occur. For example, economic conditions can create strong positive correlation for claim amounts.	Authors suggest that this problem can be solved with marginal distribution (copula approach). Different kind of dependence models (positive correlations, basic scenario, complex scenario) are used in study. **<u>Conclusion:</u>** -in case of claim amounts with heavy-tailed distribution with **positive dependence** it will **not affect** ruin probability in monotonic way if case count is large enough. It means that problem can arise for small companies. -in case of more complex dependent cases solution (**type of copula**) depends on state, claim amount count and severity. Well known **normal copula** is one of solution.
2	(Kemaloglu & Gebizlioglu, 2009)	Risk analysis under progressive type II censoring with binomial claim numbers	2009	Authors indicates that model should use risk measure that can precise calculate possible maximum loss with given confidence level. Therefore, when claimed amounts are paid to policyholders also reserves and capital are properly set aside and allocated for business portfolio.	Authors concedes that **claim count and size can be differently distributed** therefore total portfolio loss depends on it. Secondly it can arise issues in solvency and reserving, too. Authors describe that for small companies' capital can be sufficient (low ruin probability) if premium income, premium sufficiency is large enough.	Authors suggest (and it is also the **goal** of paper) to derive a **distribution function model** for total claim size. Authors suggest keeping higher reserves if certain parameters are not high enough and insurer wants to hold certain safety (solvency) level. Article illustrate example how it can be calculated using **ruin theory.** **<u>Conclusion:</u>** Authors provided article do not clearly answer to RQ3, RQ2 but authors indicate that one of problem in daily business can be reserve insufficiency therefore also under SII framework reserve risk can occur. Provided risk analysis model using **ruin theory** can be implied in yearly risk assessment ORSA, too. It can be one of the alternative methods in capital management.

No.	Paper	Name of article	Year	RQ1. What is internal model under Solvency II framework?	RQ2. What are weaknesses of standard formula for non-life reserve risk?	RQ3. What are possible solutions and alternative approaches to solve EIOPA Solvency II standard formula problem?
3	(Wouwe *et al.*, 2009)	Application of classical and robust Chain Ladder methods: Results for the Belgian non-life business	2009	Authors partially consider that using internal model non-life insurer has to be able to estimate future claims reserves as precise as possible.	Solvency II standard formula is as simple as possible. Standard formula under SII framework does not use stochastic models but **simple deterministic method** (also for reserve risk). Authors claim that many insurers in EU use simple Chain Ladder method for reserving (positive fact mentioned by authors it is distributed free). Problems appear in case of high reserves confidence level when also SCR increases and higher amount aside from business is put by insurer. Authors complain that logically insurers would like to reduce solvency capital requirements if possible. Also **outlying date** is identified as problem by authors. **Outliers** are daily practice in real business data. **Outliers** have large impact to SCR and OCR	Authors suggest using **robust statistics** and 2 methods (deterministic and robust Chain Ladder method) are used in paper and results are compared by authors. 10 years Belgium statistics is used. Results are identically the same using data without outliers, using both methods OCR result difference between both methods using triangles with outliers is 40 percentages. **Conclusion.** SCR and OCR can be set in right way by using **inverse estimation model** and **robust Chain Ladder method.** The used reserving method must be with **character -robust**. Robust model meaning is to handle variability (SCR, OCR) and detect suspicions observations.
4	(Ohlsson & Lauzeningks, 2009)	The one-year non-life insurance risk	2009	Major part of the literature non-life risk is ultimo risk not one time year horizon. Model that uses short time horizon, one year perspective using the most appropriate reserve risk simulation approaches. Liabilities over next 12 months are to be assessed.	**Too short time horizon** in internal models in insurance companies, one year perspective SII. The goal of paper is clarifying one year risk concept and describing simulation approaches in particular for one-year reserve risk. CAT risk is outside of scope. Used cost-of-capital approach. Special case of approach is bootstrap methods. Claim reserve risk also called as one year run-off. Risks that could appear in the financial statements which relates to risks that could appear in financial statement over one year and does not take the long-term nature of insurance into account.	Authors summarize algorithm how to do modelling for one-year reserve risk by steps and providing methods that has been discussed till this research. Firstly, should do calculation for reserves on valuation date using Chain Ladder, Generalized Cape Cod method, Mack Chain Ladder. Authors suggest that Bornhuetter Ferguson method is not good practice for internal model. Conclusion: Risk margin do not affect reserve risk.

Appendix 5 continued

No.	Paper	Name of article	Year	RQ1. What is internal model under Solvency II framework?	RQ2. What are weaknesses of standard formula for non-life reserve risk?	RQ3. What are possible solutions and alternative approaches to solve EIOPA Solvency II standard formula problem?
5	(Bargès *et al.*, 2009)	TVaR-based capital allocation with copulas	2009	Model that helps to do sufficient capital reserving where coherent amounts are allocated for each line of business.	Authors mention that dependence between the different lines of business is construction of **multivariate distribution**. Therefore, standard formula does not fit for risk aggregation and use of a linear correlation matrix can be inappropriate.	Authors propose to use **copula** approach - tool that represents dependence between variables. Authors use **tail value at risk** (Expected Shortfall) as advised by CEIOPS (the Committee of European Insurance and Occupational Pensions Supervisors). **Farlie-Mogenstern copula** is used in article in case of more than two variables are considered.
6	(Savelli & Clemente, 2011)	Hierarchical structures in the aggregation of premium risk for insurance underwriting	2011	Despite article subject is premium risk not reserve risk authors describe general non-life risk issues, too. Authors indicate that adequately improvement of the correct way to describe the diversification effect on the capital requirement can be obtained by an internal model.	Authors suggest using copula approach in order to solve **diversification effect problem**. Standard linear correlation matrix gives only approximate effect of diversification.	Authors present an alternative method based on calibration factors (proposed by Sandstrom (2007)) and based on normal power approximation. In case of much skewed data formula cannot be used. For risk aggregation elliptical copulas and hierarchical Archimedean copulas. Authors claim that choice of copula could be problematic if insufficient data is available. Authors suggest also using empirical multipliers derived by the simulation under independence assumption.
7	(Arbenz *et al.*, 2012)	Copula based hierarchical risk aggregation through sample reordering	2012	Authors mention that internal model helps to do risk aggregation more appropriate.	Risk aggregation is mentioned as only problem.	Authors suggest using copula approach for risk aggregation using Well know Monte Carlo simulation technique. Internal model for solvency capital requirements is generally very high dimension. Therefore, authors indicate that different kind of copula should but authors also indicate that a copula family with tree dependence model is relatively easy.

Appendix 5 continued

No.	Paper	Name of article	Year	RQ1. What is internal model under Solvency II framework?	RQ2. What are weaknesses of standard formula for non-life reserve risk?	RQ3. What are possible solutions and alternative approaches to solve EIOPA Solvency II standard formula problem?
8	Ercole & Paolo (2020)	Bayesian Internal Model for Reserve Risk: An Extension of the Correlated Chain Ladder	2020	Quantifying a non-life insurer's reserve risk in accordance with Solvency II regulations is the goal of an internal model.	Obligation distribution forecasting for the coming year.	In comparison to other well-known models to calculate reserve risk, the one-year CCL has proven to be a reliable substitute. Author believes that this model has more to offer than the Merz-Wüthrich formula and the market-wide parameter since it more accurately depicts the risks associated with the claims reserve and collects much more information about the unpredictability of loss liabilities.
9	(Forte *et al.*, 2012)	Claims reserving uncertainty in the development of internal risk models	2012	Authors describe internal model as flexible model that helps to evaluate a specific risk profile.	Non-life insurance liabilities usually **take several years** but reserve risk under Solvency II framework is calculated for **one year** therefore authors indicate that in academic literature discussions Were happened how one year reserve risk can be quantified. Authors coincide that used Solvency II risk measure to asses also reserve risk is value at risk. But this risk measure **works in case of normal market conditions**. Authors finally presented that: -current methodology is only deterministic; -variability measure depends on probabilistic structure; -insurers because of best estimate definition; *VaR* 50% could lead management select methodology for claim reserve assessment that gives the lower result; -use of unique variability measure for all EU companies could lead to over capitalization.	Authors suggests: - Using stochastic approaches; - Use internal model for reserve risk because of great importance. Back testing analysis can help to set validation criteria.

Appendix 5 continued

No.	Authors	Name of article	Year	RQ1. What is internal model under Solvency II framework?	RQ2. What are weaknesses of standard formula for non-life reserve risk?	RQ3. What are possible solutions and alternative approaches to solve EIOPA Solvency II standard formula problem?
10	(Bermúdez *et al.*, 2013)	A correlation sensitivity analysis of non-life underwriting risk in solvency capital requirement estimation	2013	Model with the regulator's previous authorization.	Authors concede that dependence between risks is problem under Solvency II and reminds that correlation is hot topic in insurance industry.	Authors propose to use and shows with real business data SCR aggregation using **Monte Carlo simulations, copula (only Gaussian and Student-*t* are used), and linear regression techniques** under one year horizon as it is set by Solvency II framework. Authors compare internal and standard model results. A result depends on selection of margins. In case of Student's *t*-margins necessary economic capital is by 10% higher than using standard formula. Using Gaussian margins required capital is even lower than using standard formula.
11	(Diers & Linde, 2013)	Modelling parameter risk in premium risk in multi-year internal models	2013	Despite article subject is premium risk not reserve risk authors describe general non-life risk issues, too. Model where companies' individual risk-based capital standards are determinate and tool for financial modelling ad scenario analysis in insurance industry.	Standard formula includes in reserve risk process and parameter risk.	For parameter risk modelling that is also part of reserve risk can use these methods - **asymptotic normality, bootstrap, Bayenses approaches**. Reserve risk can be influenced by **strategic management decision,** such as reinsurance.

No.	Authors	Name of article	Year	RQ1. What is internal model under Solvency II framework?	RQ2. What are weaknesses of standard formula for non-life reserve risk?	RQ3. What are possible solutions and alternative approaches to solve EIOPA Solvency II standard formula problem?
12	(Diers & Linde, 2013)	The multi-year non-life insurance risk in the additive loss reserving model	2013	Authors do not precisely say internal model definition, interpretation but reserve risk internal model authors' interpretation is as one-year variances of claim development results in future years.	Authors suggest to think **in long term perspective not one year horizon** how is set by Solvency II framework. Authors also claim that management should know how much external capital would be needed in case of worst scenario at least in business plan period time horizon 3-5 years.	Authors use **additive loss reserving method** for quantitate reserve risk assessment. Time horizon problem can be solved during ORSA process (own risk solvency assessment) proving potential risk assessment for multi-year period.
13	(Araichi & Belkacem, 2014)	Solvency capital for non-life insurance: Modelling dependence using copulas	2014	Internal model includes full assessment taking into account potential dependencies between insured risks.	Authors indicate that despite linear correlation is frequently used in practice (also in Solvency II framework) it is not appropriate approach because of market volatility and in reality, exists **mainly non-linear dependence relationships** between risks.	Authors suggest that using **copula approach** is more appropriate. Authors used 2 line of business- motor third party liability and motor own damage. Authors proved that for this 2 lines dependence are non-linear. Therefore, SCR internal was lower than SCR standard formula (using Clayton copula).

Appendix 5 continued

No.	Paper	Name of article	Year	RQ1. What is internal model under Solvency II framework?	RQ2. What are weaknesses of standard formula for non-life reserve risk?	RQ3. What are possible solutions and alternative approaches to solve EIOPA Solvency II standard formula problem?
14	(Slim & Mansouri, 2015)	Reserve risk analysis and dependence modelling in non-life insurance: The Solvency II project	2015	Internal model is model that provides better estimates of solvency funds.	Authors coincide that there is no independence between different branches and it is not a case using standard formula. 9/11 event showed that many branches can occurred from one event. The occurrence of these risks influences entire financial basis of insurance and therefore **risks are not independent**.	Authors suggest using **copula** approach. **Clayton's copula** provides good fit. Also, future research should be **Credibility theory**.
15	(Munroe *et al.*, 2015)	A Solution for Solvency II Quantitative Requirements Modelling with Long-Tail Liabilities	2015	Authors summarize that internal model can be used as alternative method to standard formula as long as internal model follows the Solvency II principles and is approved by regulator.	Authors signal that the main issue of standard formula is **proportionality proxy**. Regarding to reserves risk capital is proportional to technical reserves.	Authors suggest not relying on proportionality proxy providing alternative method for long -tail liabilities assessment under Solvency II framework. As one good example authors mention Meyers (2012) alternative model. Authors use **loss reserving modelling method** using **bootstrap method** for paths modelling as residuals is i.i.d and highly non-random in calendar year direction.
16	(Alm, 2015)	A simulation model for calculating solvency capital requirements for non-life insurance risk	2015	Internal model helps to avoid all hotly discussed issues the last few years.	Authors summarize that problem discussed in academic literature is **dependencies between insurance types**. Secondly, **distributional assumptions are very explicit in the former**.	Authors have described simulation procedure (for long duration liabilities) by simulating using **Monte Carlo, predicting liabilities duration, creating own correlation matrix between line of business**. Authors' findings are that uncertainty in prediction trend for ultimate claim amount is top issue building internal model.

Appendix 5 continued

No.	Paper	Name of article	Year	RQ1. What is internal model under Solvency II framework?	RQ2. What are weaknesses of standard formula for non-life reserve risk?	RQ3. What are possible solutions and alternative approaches to solve EIOPA Solvency II standard formula problem?
17	(Araichi & Belkacem , 2014)	Solvency capital requirement for a temporal dependent loss in insurance	2014	Internal model helps to evaluate the suitable capital amount.	Issue is temporal dependence structure among claim amounts (losses) or dependence among losses.	Authors suggest using authors' novel **autoregressive conditional amount (ACA) model** in order to solve dependence issue and behaviour of claim amounts. Similar modelling is used already using credibility theory modelling. It very important to choose best model because then also quantile will be set correctly therefore also SCR. Authors have introduced with fully new term - *VaR* ACA.
18	(Fersini & Melisi, 2016)	Stochastic model to evaluate the fair value of motor third-party liability under the direct reimbursement scheme and quantification of the capital requirement in a Solvency II perspective	2016	Internal model helps to assess 'ability to meet with an assigned probability, the random liabilities described by a realistic probabilistic structure'.	Authors prove that standard formula **may** significantly **underestimate reserve risk**. Authors proved also that internal model's provided algorithm **shows greater variance** than standard formula.	Authors proposed to use method that falls into category **individual claim loss reserving methods** (extension of Fersini and Melisi (2015) model). For aggregative reserve risk **normal copula** is used.
19	(Dacorogna *et al.*, 2018)	Solvency capital estimation, reserving cycle and ultimate risk	2016	Internal model has the same main principles as SII regulation.	Standard formula does not capture **dependences between losses over time, reserving actuary behaviour and reserving cycle**.	The Merz-Wuthrich formula is standard approach in insurance industry for calculating one-year reserve risks whether its assumptions are fulfilled or not. Therefore, authors propose to use **original approach** for assessing one year reserve risk. Firstly, authors assume that loss development behaves as a stochastic process using **ge**ometric **Brownian motion**.

Appendix 5 continued

No.	Paper	Name of article	Year	RQ1. What is internal model under Solvency II framework?	RQ2. What are weaknesses of standard formula for non-life reserve risk?	RQ3. What are possible solutions and alternative approaches to solve EIOPA Solvency II standard formula problem?
20	(Fröhlich & Weng, 2018)	Parameter uncertainty and reserve risk under Solvency II	2017	Internal model provides SCR using *VaR* with confidence level 99.5%.	Authors' citation 'Since the uncertainty about variance parameters has a significant impact on the tail of a corresponding predictive distribution, appropriate risk capital estimates for high quantiles cannot be derived from these results.	Reserve risk internal model consist of 2 parts - process and parameter. Authors have investigated only parameter risk as part of internal model. Authors do assessment and finalized that **bootstrapping approach is not appropriate** to model parameter uncertainty and does not guarantee required confidence level. Authors suggest using **Frohlich and Weng (2015) model authors' adaption** -particular process distribution combined with inversion method. From other side authors also suggest that it is needed **for new ideas, approaches different from used for classical reserving**.
21	(Bølviken & Guillen, 2017)	Risk aggregation in Solvency II through recursive log-normal	2017	Internal model and standard formula must be in balance between accuracy and simplicity. Secondly, it cannot be too costly, time consuming.	Dependencies between risks especially in case of heavy tails, skewness.	Authors suggest replacing linear correlation matrixes with **copula**. Authors suggest using **log-normal** distributions with a **parameter capturing skewness** using **Monte Carlo**. Authors for approximations used Clayton copula and Cornish-Fisher method and suggest doing tests with others distributions.

No.	Paper	Name of article	Year	RQ1. What is internal model under Solvency II framework?	RQ2. What are weaknesses of standard formula for non-life reserve risk?	RQ3. What are possible solutions and alternative approaches to solve EIOPA Solvency II standard formula problem?
22	Moro, E.D., Krvavych, Y. (Moro & Krvavych, 2017)	PROBABILITY OF SUFFICIENCY OF SOLVENCY II RESERVE RISK MARGINS: PRACTICAL APPROXIMATIONS	2017	Internal model consists of market-consistent valuation techniques such as Replicating Portfolio, Valuation Portfolio and Cost of Capital (CoC).	**Dependence modelling** and reserve distribution **uncertainty**.	Authors show practical implementation using both EU and Australian legislation for reserve risk profile using 'standard formula' style. Authors propose **to use distribution-free approach**. For pure reserve risk profile **Cornish-Fisher** approximation is used. For risk aggregation authors suggest used **copula approach** for example Gaussian copula. Authors' provided algorithm can be used for internal capital modelling case of non-hedge able insurance liabilities (non-life).
23	Araichi, S., Peretti, C.D., Belkacem, L. (Araichi *et al.*, 2017)	Reserve modelling and the aggregation of risks using time varying copula models	2017	Authors indicate that internal model (appropriate risk assessment) will cover every risk and will be adjusted in a way that the bankruptcy probability of the given company will be sufficiently low. And that permits to meet their future obligations in time, all while retaining a good reputation.	Authors indicate that **independent losses assumption** that is used in standard formula **is wrong**. By ignoring dependence structure between line of business less capital requirement is needed.	Authors propose to use **Generalized Autoregressive Conditional Sinistrality** model for analysing the evolution in time of dependence and time varying **copula functions** for aggregate risks. Therefore, varying Gumbel copula with the GACSM provide an adequate number of reserves and Solvency capital.

Appendix 5 continued

No.	Paper	Name of article	Year	RQ1. What is internal model under Solvency II framework?	RQ2. What are weaknesses of standard formula for non-life reserve risk?	RQ3. What are possible solutions and alternative approaches to solve EIOPA Solvency II standard formula problem?
24	Butaci, C., Dzitac, S., Dzitac, I., & Bologa, G. BUTACI *et al.*, (2017)	Prudent decisions to estimate the risk of loss in insurance	2017	A model that allows the simulation of the financial situation of the company for a one-year horizon and will also offer a measure of the capital requirements needed in order to avoid with a 99.5 % probability the company ruin one year later.	Risk aggregation and model type; lack of extreme theory implemented in SCR module.	The necessity **of the extreme value theory** approach in order to estimate the risk of loss for the insurance issue, for example, adjusting Fréchet (G1) law (in our case Chi2), or to choose a low realistic prudential level, using the adjusted Gumbel (G 2) law (in our case Gamma or Weibull).
25	Ferriero, A. Ferriero (2016)	Solvency capital estimation, reserving cycle and ultimate risk	2016	Pure reserve internal model definition: a stochastic model for the evolution of the reserves for a non-life insurance run-off portfolio that captures the dynamic of the reserving cycles.	Author indicates that deterministic approaches cannot represent dynamic of the reserving cycle.	In authors' proposed model it is assumed that the relative loss developments over time follow a **stochastic process with dependent increments**.
26	Hejazi, S.A.,& Jackson, K.R. Hejazi & Jackson, (2017)	Efficient valuation of SCR via a neural network approach	2016	Authors mentioned that: 1. The model that computes a key risk metric called the Solvency Capital Requirement (SCR); 2. The official description of the SCR is not rigorous and has led researchers to develop their own mathematical frameworks for calculation of the SCR.	Model type.	Authors proposed new approach **neural network approach** for SCR calculation for a large portfolio of an important class of insurance products called **Variable Annuities (VAs)**.

Appendix 6

Authors from Baltic with research papers in copula field

Paper identified in Scopus/Web of Science using keywords "Copula" and researchers from Baltic states:	Country	Science field group[1]	Scopus/ Web of Science
1	2	3	4
Adermann, V., Pihlak, M. (2005). Using copulas for modeling the dependence between tree height and diameter at breast height. *Acta et Commentationes Universitatis Tartuensis de Mathematica,* Vol. 9, pp.77-85.	Estonia	1.1.	
Bagdanovičus, V., Malov, S., Nikulin, M. (2008). Testing of the homogeneity of marginal distribution in copula model. *Elsevier* Masson *SAS*, Ser 1 346.	Estonia	1.1.	
Buteikis, A. (2020). *Multivariate copula-based integer-valued time series models: theory and applications.* Doctoral dissertation. Vilnius. Vilnius University. 104 p. DOI: 10.15388/vu.thesis.95	Lithuania	1.1.	
Buteikis, A. (2017). Copula based BINAR models with applications. *PPP*, 8 p. Available at: https://indico.uu.se › A.Buteikis_201708.pdf	Lithuania	1.1.	
Buteikis, A., Leipus, R. (2020). An integer-valued autoregressive process for seasonality. *Journal of Statistical Computation and Simulation* Vol. 90 Iss.3, pp.. 391-411.	Lithuania	1.1.	+
Buteikis, A., Leipus, R. (2019) A copula-based bivariate integer-valued autoregressive process with application. *Modern Stochastics: Theory and Application,* Vol. 6 Iss. 2, pp. 227-249.	Lithuania	1.1.	+
Buteikis, A. (2016). *Caussial copula modelling for integer-valued time series.* A thesis for the decree of doctor philosophy. University of Manchester. 228 p.	Lithuania	1.1.	
Fjodorovs, J. (2019). *Risk Forecast with Continuous Models for Evaluating Technology and Markets*. Ph.D. Thesis. Riga. RTU, 134 p.	Latvia	1.1.	
Fjodorovs, J. (2012). Copula based semiparametric regressive models. *Journal of applied mathematics,* Vol. V, pp.241-248.	Latvia	1.1.	
Fjodorovs, J., Matvejevs, A. (2013). Copula estimation for garch (1,1) processes. *12th Conference on Applied Mathematics. ALIMAT 2013, Proceeding.*	Latvia	1.1.	+
Fjodorovs, J., Matvejevs, A. (2012). Copula Based Semiparametric Regressive Models. *Journal of Applied Mathematics*, Vol.5, No.3, 241.-248.lpp. ISSN 1337-6365.	Latvia	1.1.	
Jurenoks, V., Jansons, V., Didenko, K. (2009). Investigation of Economic Systems Using Modelling Methods with Copula. *XI International Conference on Computer Modelling and Simulation (UKSim 2009)*, Cambridge, March 25-28. 2009. Cambridge: Cambridge University, pp. 311-316.	Latvia	5.2.	+
Jansons, V., Kozlovskis, K., Lāce, N. (2005). Portfolio Modelling Using the Theory of Copula in Latvian and American Equity Market. In: Simulation in Wider Europe: *19th European Conference on Modelling and Simulation (ECMS 2005)* / ed. by Y. Merkuryev ... [*et al.*], Latvia, Riga, 1-4 June 2005. Nottingham: European Council for Modelling and Simulation, 2005, pp.628-632. ISBN 1842331124.	Latvia	5.2.	+

1	2	3	4
Käärik, M., Käärik, E. (2010). Imputation by Gaussian Copula Model with an Application to Incomplete Customer Satisfaction Data. In: Lechevallier, Y., Saporta, G. (eds) *Proceedings of COMPSTAT'2010. Physica-Verlag HD,* pp. 485–492. https://doi.org/10.1007/978-3-7908-2604-3_48	Estonia	1.1.	+
Käärik,E., Käärik, M. (2009). Modeling dropouts by conditional distribution, a copula-based approach. *Journal of Statistical Planning and Inference.* Vol. 139 Iss. 11, pp.3830-3835. DOI: 10.1016/j.jspi.2009.05.020	Estonia	1.1.	+
Käärik, E. (2007). Modelling dropouts by conditional distribution, a copula-based approach. *The 8th Conference on Multivariate statistics. The 6th conference on Multivariate distributions with fixed marginal*. Tartu. 27th June 2007. 26 p.	Estonia	1.1.	
Käärik, M., Umbleja, M. (2011). On claim size fitting and rough estimation of risk premiums based on Estonian traffic insurance example. *International Journal of Mathematical Models and Methods in Applied Sciences,* Vol. 5 Iss. 1, pp. 17-24.	Estonia	1.1.	+
Käärik, E. (2007). *Handling Dropouts in Repeated Measurements Using Copulas.* Dissertationes Mathematicae Universitatis Tartuensis, 51, Tartu University Press, 99 p.	Estonia	1.1.	
Käärik, E. (2006). Imputation by conditional distribution using Gaussian copula. *COMPSTAT, Proceedings in Computational Statistics* 2006, Physica-Verlag, Springer, pp.1447-1454.	Estonia	1.1.	
Käärik, E. (2006). Imputation algorithm using copulas. In: Advances in Methodology and Statistics. *Sage Publication SRM Database of Social Research Methodology*, Ed. A. Ferligoj, Vol. 3 Iss. 1, pp.109-120.	Estonia	1.1.	
Käärik, E. (2005). Handling dropouts by copulas. In: *WSEAS Transactions on Biology and Biomedicine,* Iss. 1, 2, pp. 93-97.	Estonia	1.1.	
Käärik, M., Selart,A., Käärik, E., Liivi, J. (2011). The use of copulas to model conditional expectation for multivariate data. *ISI Proc. 58th World Statistical Congress,* pp. 5533-5536.	Estonia	1.1.	
Käärik, E. (2005). Handling dropouts by copulas. *In: WSEAS Transactions on Biology and Biomedicine*, Iss. 1, 2, pp. 93-97.	Estonia	1.1.	
Kalnača, A., Lokmale, I. (2020). Pragmatic aspects of Latvian predicative infinitive construction. *Studies about language = Kalbu studijos*, pp. 74-91.	Latvia	6.2.	+
Kuznina, J.(2011). *Usage of risk measures in management of investment portfolios: Case of insurance companies*. Summary of the doctoral Dissertation. Riga. BA school of business and finance. 88 p.	Latvia	5.2.	
Kollo, T., Pettere, G., Valge, M. (2017). Tail dependence of skew t-copulas. *Communications in Statistics-Simulation and Computation,* Vol. 46 Iss. 2, pp.1024-1034	Estonia, Latvia	1.1.	+
Kollo, T., Selart, A., Visk, H. (2013). *From multivariate skewed distributions to copulas.* In book: Combinatorial matrix theory and generalized inverses of matrices. Springer. India, pp. 63-72.	Estonia	1.1.	+

1	2	3	4
Kollo, T., Pettere, G.(2010). Parameter Estimation and Application of the Multivariate Skew t-Copula. No: *Copula Theory and Its Applications: Proceedings of the Workshop,* Polija, Warsaw, September 25-26. Berlin: Springer Berlin Heidelberg, pp. 289.-298. Available at: doi:10.1007/978-3-642-12465-5_15	Estonia, Latvia,	1.1.	
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Kollo,T., Käärik, M., Selart, A.(2018). Asymptotic normality of estimators for parameters of a multivariate skew-normal distribution. *Communications in Statistics-Theory and Methods,* Vol. 47 Iss. 15, pp. 3640-3855.	Estonia	1.1.	+
Kollo, T., Käärik, M., Selart, A. (2021). Multivariate Skew t-Distribution: Asymptotics for Parameter Estimators and Extension to Skew t-Copula. *Symmetry,* Vol. 13 Iss 6.1059. https://doi.org/10. 3390/sym13061059	Estonia	1.1.	+
Kozlovskis, K., Lāce, N. (2009). *Challenges of decision making in the Latvian equity market.* WMSCI 2006 - The 10th World Multi-Conference on Systemics, Cybernetics and Informatics, Jointly with the 12th International Conference on Information Systems Analysis and Synthesis, ISAS 2006 - Proc. Part 1, pp. 41 – 44.	Latvia	5.2.	
Kuzmina, J., Pettere, G., Voronova, I. (2009). Conditional Risk Measure Modeling for Latvian Insurance *Companies. Perspectives of Innovations, Economics and Business,* Vol.3, Iss.3, pp.59-61. ISSN 1804-0519. e-ISSN 1804-0527.	Latvia	5.2.	
Kuzmina, J., Voronova, I. (2011). Development of Investment Risk Management Models for Insurance Companies. *Economics and Management = Ekonomika ir vadyba, No. 16, pp.1147-1153. ISSN 1822-6515.*	Latvia	5.2.	
Kuzmina, J., Pettere, G., Voronova, I. (2010). Investments by Insurance Companies – Challenges and Opportunities. *Economics and Management*, 2010, No. 15, pp.979-985. ISSN 1822-6515.	Latvia	5.2.	
Kuzmina, J., Pettere, G., Voronova, I. (2009). Conditional Risk Measure Modeling for Latvian Insurance Companies. *Perspectives of Innovations, Economics and Business*, Vol.3, Iss.3, pp.59-61. ISSN 1804-0519. e-ISSN 1804-0527.	Latvia	5.2.	
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Matvejevs, A., Fjodorovs, J. (2013). *Copula Estimation for GARCH (1, 1) Processes. Proceeding of the 12th International Conference APLIMAT' 2013,* Slovakia, Bratislava, 5 – 7 Febriary, 2013. Bratislava: Slovak University of Technology in Bratislava, 2013, pp. 230-236. ISBN 978-1-63266-512-6.	Latvia	1.1.	
Manstavlčus, M., Lelpus, R. (2017). Bounds for Clayton copula. *Nonlinear Analysis: Modelling and Contro,* Vol. 22 No 2, pp. 248-260. doi: 10.15388/NA.2017.2.7.	Lithuania	1.1.	+

Appendix 6 continued

1	2	3	4
Pettere, G., Jansons, V. (2005). The best method for modelling a two-risk negative correlation portfolio. *Economics and Business,* Scientific *Proceedings of Riga Technical University*, 3 series, Vol. 10, RTU izdevn., Riga, pp. 90 – 100.	Latvia	5.2.	
Pettere, G. (2006). Optimal Equity Portfolio Modelling via Copulas. *CERAM Sophia Antipolis, European School of Business „39th Meeting Euro Working Group on Financial Modelling*", November 16-17, pp. 1 – 13.	Latvia	1.1.	
Pettere, G., Kollo, T. (2006). *Modelling claim size in time via copulas*. Transactions of 28th International Congress of Actuaries. 2006. Vol. 206, pp. 1-10.	Latvia, Estonia	1.1.	
Pettere, G., Kollo, T. (2011). Risk modeling for future cash flow using skew t-copula. *Communications in Statistics-Theory and Methods*. Vol. 40 Iss. 18, pp. 2919-2925. DOI: 10.1080/03610926.2011.562777	Latvia, Estonia	1.1.	+
Prančevičius, H., Šutienė, K. (2008). Copula effect on investment portfolio of an insurance company. *Technological and Economic Development of Economy,* Vol. 14 Iss. 3, pp. 344-373. https://doi.org/10.3846/1392-8619.2008.14.344-373	Lithuania	5.2.	+
Rupšys, P. (2015). *The use of copulas to practical estimation of multivariate stochastic differential equation mixed effects models*. AIP Conference Proceedings. Vol. 1684 Iss, 1, id.080011. DOI: 10.1063/1.4934322	Lithuania	1.1.	+
Rupšys, P., Petrauskas, E. (2022). On the Construction of Growth Models via Symmetric Copulas and Stochastic Differential Equations. *Symmetry,* Vol. 14 Iss.10, No 2127. 20 p.	Lithuania	1.1.	+
Stepčenko, D., Pettere, G. Voronova, I. (2015). Improvement of operational risk measurement under the solvency II framework. *Risk Governance and Control: Financial Markets and Institutions.* Vol.5 (2-1), pp.135-141. https://doi.org/10.22495/rgcv5i2c1art7	Latvia	5.2.	+
Stepčenko, D. (2016). *Risk management and measurement system development and its influence on Baltic insurance market*. Doctoral thesis. Riga. Riga Press. 160 p.	Latvia	5.2.	
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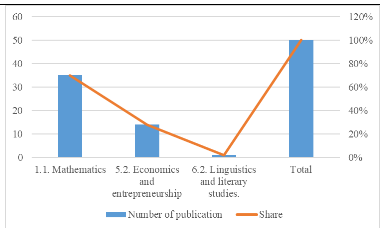
Selart, A. (2009). *Copula Based on Skew normal distribution.* In: 18th International Workshop on Matrices and Statistics 2009. June 23-27. Slovak Republic, pp.16.	Estonia	1.1.	

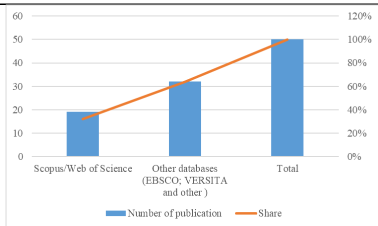
Source: created by the author.

[1]Based on "*Noteikumi par Latvijas zinātnes nozaru grupām, zinātnes nozarēm un apakšnozarēm. Pielikums. Ministru kabineta 2022. gada 27. septembra noteikumiem Nr. 595*."; 1.1. Mathematics; 5.2. Economics and entrepreneurship; 6.2. Linguistics and literature science.

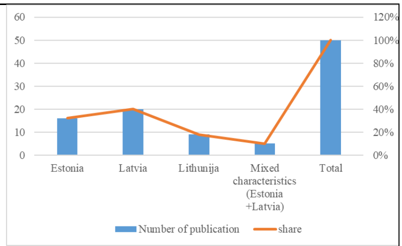
Branches of science	Number of publications
1.1. Mathematics	35
5.2. Economics and entrepreneurship	14
6.2. Linguistics and literary studies.	1
Total	50

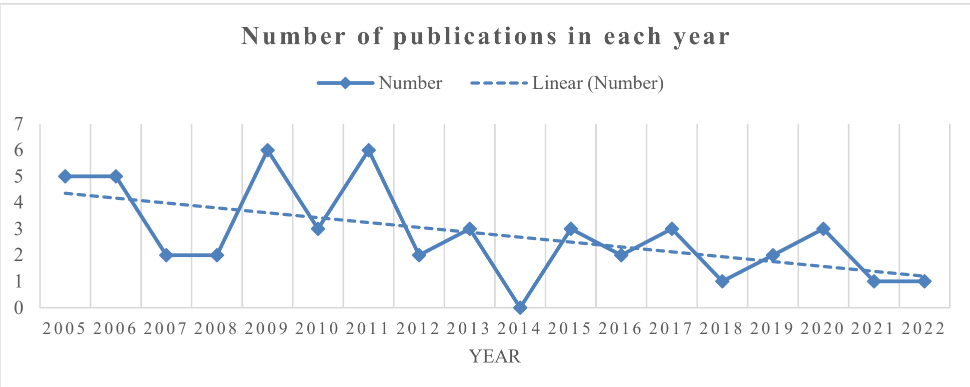


Databases	Number of publications
Scopus/Web of Science	19
Other databases (EBSCO; VERSITA and other)	32
Total	50



	Number of publications
Estonia	16
Latvia	20
Lithuania	9
Mixed characteristics (Estonia +Latvia)	5
Total	50





0 research papers are published by Baltic states researchers with keywords "Copula" and “reserve”.

Appendix 7

The bootstrap procedure

Algorithm is proposed by England & Verrall (2002, p.517-518)

A3.1 The bootstrap procedure is performed by completing the following steps, which can be performed without difficulty in a spreadsheet:

— Obtain the standard chain-ladder development factors from cumulative data.

— Obtain cumulative fitted values for the past triangle by backwards recursion, starting with the observed cumulative paid to date in the latest diagonal, using $\hat{D}_{i,n-i+1} = D_{i,n-i+1}$, and $\hat{D}_{i,k-1} = \hat{D}_{i,k}\hat{\lambda}_k^{-1}$.

— Obtain incremental fitted values, $\hat{m}_{ij}$, for the past triangle by differencing.

— Calculate the unscaled Pearson residuals for the past triangle using:

$$r_{ij}^{(P)} = \frac{C_{ij} - \hat{m}_{ij}}{\sqrt{\hat{m}_{ij}}}. \qquad \text{(A3.1)}$$

— Calculate the Pearson scale parameter ϕ, where:

$$\phi = \frac{\sum_{i,\, j n-i+1} \left(r_{ij}^{(P)}\right)^2}{\frac{1}{2}n(n+1) - 2n + 1}$$

that is, the sum of the Pearson residuals squared divided by the degrees of freedom, where the degrees of freedom is the number of observations minus the number of parameters estimated.

— Adjust the Pearson residuals using:

$$r_{ij}^{adj} = \sqrt{\frac{n}{\frac{1}{2}n(n+1) - 2n + 1}} \times r_{ij}^{(P)}$$

to replicate the bias correction using an analytic approach.

— Begin iterative loop, to be repeated N times ($N = 1000$, say):

  — Resample the adjusted residuals with replacement, creating a new past triangle of residuals.

  — For each cell in the past triangle, solve equation A3.1 for C, giving a set of pseudo-incremental data for the past triangle.

  — Create the associated set of pseudo-cumulative data.

  — Fit the standard chain-ladder model to the pseudo-cumulative data.

  — Project to form a future triangle of cumulative payments.

— Obtain the corresponding future triangle of incremental payments by differencing, to be used as the mean when simulating from the process distribution.

— For each cell (i, j) in the future triangle, simulate a payment from the process distribution with mean $\tilde{m}_{ij}$ (obtained at the previous step), and variance $\phi\tilde{m}_{ij}$, using the value of ϕ calculated previously.

— Sum the simulated payments in the future triangle by origin year and overall to give the origin year and total reserve estimates respectively.

— Store the results, and return to start of iterative loop.

A3.2 The set of stored results forms the predictive distribution. The mean of the stored results should be compared to the standard chain-ladder reserve estimates to check for errors. The standard deviation of the stored results gives an estimate of the prediction error.

Appendix 8

R program coding

R software (3.5.3 version) program coding examples and the key parts written by the author and using coding example parts from Hofert, M., *et al.* (2018), Dutang *et al.* (2008):

First step: Claim data uploading

```
library(actuar)
library(ChainLadder)
# data is a triangle
data <- read.csv(file="C:/Users/XXX/Documents/YTOTAL_CS.csv", header = FALSE, sep = ";",
                 stringsAsFactors = FALSE)
is.na(data)
data1 = as.matrix(as.data.frame(lapply(data, as.numeric)))
is.matrix(data1)
is.vector(data1)
is.recursive(data1)
is.atomic(data1)
tr.paid <- incr2cum(as.triangle(data1))
n <- dim(tr.paid)[1]
print(tr.paid)
plot(tr.paid, lattice=TRUE)
```

Second step: Reserve calculation in economic balance sheet

```
CL <- MackChainLadder(tr.paid)
plot(CL$f, xlab = "development year", ylab = "Chain Ladder factor") # development factors (year to
year)
lines(CL$f)
abline(1,0, col="gray")
print(CL$FullTriangle) # t
plot(CL, lattice =TRUE)
plot(CL, which=1)
plot(CL)
summary(CL)
BS.CDR <- CDR(BS.paid, probs= c(0.5, 0.995))
print(round(BS.CDR))
    BS.CDR.all <- CDR(BS.paid, probs=(1:R)/R) #
BS.CDR.all <- BS.CDR.all[nrow(BS.CDR.all),-c(1,2,3)]
v <- as.numeric(as.vector(BS.CDR.all[1,]))
qqnorm(v);qqline(v) # -> overestimates or underestimates the tail
```

Third step: hypothesis testing for claim distribution (Log-normal distribution)

```
ad.test(v)  ###Anderson-Darling tests
ksnormTest(v, title = NULL, description = NULL)
library(MASS)
f.v <- fitdistr(v,"log-normal")
print(f.v)
plot(qlnorm(ppoints(R), meanlog = f.v$estimate["meanlog"], sdlog = f.v$estimate["sdlog"]), v,
    main = "Lognormal QQ-plot",
    xlab = "theorectical logormal quantiles",
    ylab = "empirical quantiles for reserve risk")
abline(0,1)
# -> good fit of the lognormal distribution (as assumed by the standard formula)
f.v$aic ###x distribution fits if AIC is lower
plot(f.v)
summary(f.v)
f.v$estimate["meanlog"]
f.v$estimate["sdlog"]
```

Third step: hypothesis testing for claim distribution (Gamma distribution)

```
fit.gmme <- fitdist(v[v >= 0], distr = "gamma", method = "mle", lower = c(0, 0), start = list(scale =
1, shape = 1))
plot(fit.gmme)
fit.gmme$aic  ###x distribution fits if AIC is lower
fit.gmme$estimate["scale"]
fit.gmme$estimate["shape"]
#jaunais
ks.test(v+2, "pgamma", fit.gmme$estimate["scale"], fit.gmme$estimate["shape"] ) # two- sided,
exact
ks.test(v+2, "pgamma", fit.gmme$estimate["scale"], fit.gmme$estimate["shape"] , exact = FALSE)
    ks.test(v+2, "pgamma", fit.gmme$estimate["scale"], fit.gmme$estimate["shape"] , alternative =
"gr")
```

Third step: hypothesis testing for claim distribution (Weibull distribution)

```
fit.weibull <- fitdist(v[v >= 0], distr = "weibull", method = "mle", lower = c(0, 0))
plot(fit.weibull)
fit.weibull$aic
fit.weibull$estimate["scale"]
fit.weibull$estimate["shape"]
ks.test(v+2, "pweibull", fit.weibull$estimate["scale"], fit.weibull$estimate["shape"] ) # two-sided,
exact
ks.test(v+2, "pweibull", fit.weibull$estimate["scale"], fit.weibull$estimate["shape"] , exact =
FALSE)
ks.test(v+2, "pweibull", fit.weibull$estimate["scale"], fit.weibull$estimate["shape"] , alternative =
"gr")
```

Third step: hypothesis testing for claim distribution (Normal distribution)

```
fit.norm <- fitdist(v[v >= 0], "norm")
plot(fit.norm)
fit.norm$aic
fit.norm$estimate["mean"]
fit.norm$estimate["sd"]
ks.test(v+2, "pnorm", fit.norm$estimate["mean"] , fit.norm$estimate["sd"] ) # two-sided, exact
ks.test(v+2, "pnorm", fit.norm$estimate["mean"] , fit.norm$estimate["sd"] , exact = FALSE)
    ks.test(v+2, "pnorm", fit.norm$estimate["mean"] , fit.norm$estimate["sd"] , alternative = "gr")
```

Third step: hypothesis testing for claim distribution (Summary for distributions)

```
fit.lognorm <- fitdist(v[v >= 0],distr ="lnorm",method = "mle")
plot(fit.lognorm)
fit.lognorm$aic
fit.lognorm$estimate["meanlog"]
fit.lognorm$estimate["sdlog"]
ks.test(v+2, "plnorm", fit.lognorm$estimate["meanlog"]  , fit.lognorm$estimate["sdlog"] ) # two-
sided, exact
ks.test(v+2, "plnorm", fit.lognorm$estimate["meanlog"]  , fit.lognorm$estimate["sdlog"] , exact =
FALSE)
ks.test(v+2, "plnorm", fit.lognorm$estimate["meanlog"]  , fit.lognorm$estimate["sdlog"] ,
alternative = "gr")
summary(fit.gmme)
summary(fit.weibull)
summary(fit.norm)
summary(fit.lognorm)
fit.exp <- fitdist(v[v >= 0], distr = "weibull", method = "mle", lower = c(0, 0))
plot(fit.exp)
fit.exp$aic
fit.exp$estimate["scale"]
fit.exp$estimate["shape"]
summary(fit.exp)
ks.test(v+1, "pexp", fit.exp$estimate["scale"], fit.exp$estimate["shape"]  ) # two-sided, exact
ks.test(v+1, "pexp", fit.exp$estimate["scale"], fit.exp$estimate["shape"]  , exact = FALSE)
ks.test(v+1, "pexp", fit.exp$estimate["scale"], fit.exp$estimate["shape"]  , alternative = "gr")
g <- gofstat(list(fit.lognorm,fit.gmme, fit.exp,fit.weibull,fit.norm ), fitnames = c("lognorm","gamma",
"exp", "weibull", "norm"))
denscomp(list(fit.lognorm,fit.gmme, fit.exp,fit.weibull,fit.norm), legendtext = c("lognorm","gamma",
"exp", "weibull", "norm"))
g$chisqpvalue
g$chisqtable
g$adtest
g$cvmtest
g$kstest
```

Appendix 8 continued

Fourth step: risk aggregation, calculation of capital with *t*-copula

```
library(mvtnorm);library(copula);library(nor1mix);library(qrmtools);library(plot3D)
###th<-2.5  #pareto parameter
k<-15.07838  #mean of the lognormal
l<-0.09  #variance of the lognormal
m<-13.0066918  #shape of gamma
v<-0.1   #rate of gamma underlying the gamma
s<-14.7666787    #shape of gamma
r<-0.11     #rate of gamma underlying the gamma
#define lists of margins
qF<-list(qLN1=function(p)qlnorm(p,meanlog=k,
                          sdlog=l),
        qLN2= function(p)qlnorm(p,meanlog=m,
                          sdlog=v),
        qLN3= function(p)qlnorm(p,meanlog=s,
                          sdlog=r))
###generate
set.seed(271)
X<-sapply(qF,function(mqf)mqf(runif(10000))) #(10000,3)-matrix
plot(X)
###Nonparametric VaR estimate under a t-copula
VaR<-function(X,alpha, rho,df=4)
{
stopifnot(is.matrix(X),0 <= rho,rho<=1,length(rho)==1,
         0 < alpha, alpha < 1, length(alpha) >= 1)
n<-nrow(X)
      d<-ncol(X)
set.seed(271)
U<-rCopula(n,copula=tCopula(rho,dim=d,df=df))
rk<-apply(U,2,rank)
Y<-sapply(1:d,function(j) sort(X[,j])[rk[,j]])
S<-rowSums(Y)
(….)
quantile(S, probs=alpha,type=1, names=FALSE)}
(….)
alpha <- c(0.001,0.05,0.1,0.2,0.25,0.3,0.4,0.5,0.6,0.7,0.8,0.9,0.95,0.995,0.999)
rho <- seq(0,1, by=0.05)
grid <- expand.grid("alpha"=alpha,"rho"=rho)[,2:1]
VaR.fit<-sapply(rho, function(r)
   VaR(X, alpha=alpha,rho=r))
res <- cbind(grid, "VaR[alpha](L^'+')"=as.vector(VaR.fit))
```

Appendix 8 continued

Fifth step: hypothesis for copula model

```
library(gofCopula)
set.seed(1685)
###gofCopula(U, x = X,simulation = "mult")
set.seed(1685)
gofCopula(tCopula(dim = 3, dispstr = "un", df.fixed = TRUE, df = 4),x = X, simulation = "mult")
gofCopula(tCopula(dim = 3, dispstr = "un", df.fixed = TRUE, df = 10),x = X, simulation = "mult")
gofCopula(tCopula(dim = 3, dispstr = "un", df.fixed = TRUE, df = 80),x = X, simulation = "mult")
gofCopula(tCopula(dim = 3, dispstr = "un", df.fixed = TRUE, df = 275),x = X, simulation = "mult")
gofCopula(claytonCopula(dim = 3), x = X, simulation = "mult")
### Cross-Validation for the X Data Set
    summary(fitCopula(tCopula(dim = 3, dispstr = "un"), data = pobs(X)))
    library(numDeriv)
    library(future)
    plan(multiprocess)
    k<-50
    set.seed(4)
    xvCopula(tCopula(dim = 3, dispstr = "un", df = 4, df.fixed = TRUE), x = X, k=k)
###
plan(multiprocess)
k<-50
set.seed(4)
xvCopula(tCopula(dim = 3, dispstr = "un", df = 10, df.fixed = TRUE), x = X, k=k)
###
plan(multiprocess)
k<-50
set.seed(4)
xvCopula(tCopula(dim = 3, dispstr = "un", df = 275, df.fixed = TRUE), x = X, k=k)
###
plan(multiprocess)
k<-50
set.seed(4)
xvCopula(tCopula(dim = 3, dispstr = "un", df = 80, df.fixed = TRUE), x = X, k=k)
```

Fifth and sixth Step: other copula model

```
#####NORMALCOPULA
U<-rCopula(n,copula=normalCopula(rho,dim=d))
```

Output in fifth step: Goodness of fit testing for different copulas (case of 4 dimensions)

```
> set.seed(1685)
> ###gofCopula(U, x = X,simulation = "mult")
>
> set.seed(1685)
> gofCopula(tCopula(dim = 4, dispstr = "un", df.fixed = TRUE, df = 4),x = X, si$
  |======================================================================| 100%

        Multiplier bootstrap-based goodness-of-fit test of t-copula, dim. d =
        4, with 'method'="Sn", 'estim.method'="mpl":

data:  x
statistic = 0.17817, parameter1 = 0.0300200, parameter2 = -0.0010884,
parameter3 = 0.0065414, parameter4 = -0.0064149, parameter5 =
-0.0101520, parameter6 = -0.0040254, p-value = 0.0004995

>> k<-50
 > set.seed(4)
 > xvCopula(tCopula(dim = 4, dispstr = "un", df = 4, df.fixed = TRUE), x = X, k=$
  |======================================================================| 100%
 [1] -1152.14
 >
  > gofCopula(normalCopula(dim = 4, dispstr = "un"), x = X,simulation = "mult")
    |====================================================================| 100%

         Multiplier bootstrap-based goodness-of-fit test of Normal copula, dim.
         d = 4, with 'method'="Sn", 'estim.method'="mpl":

  data:  x
  statistic = 0.012274, parameter1 = 0.03825300, parameter2 = 0.00242120,
  parameter3 = -0.00013825, parameter4 = -0.01246400, parameter5 =
  -0.00729310, parameter6 = -0.00605250, p-value = 0.9985

  > set.seed(22)
  > k<-50
  > xvCopula(normalCopula( dim = 4, dispstr = "un"), x = X, k=k)
    |======================================================================| 100%
  [1] 2.814349
  >
```

The results are shown in Table 4.8 on page 109:

- ✓ log-likelihood AIC (function xvcopula): The highest should be used. The normal copula is more plausible (*t*-copula -1152 and normal 2.81);
- ✓ Parametric Bootstrap (function gofcopula): The lowest statistical value should be used. The normal copula is plausible and cannot be rejected at the 5% level (t-copula 0.1782 and normal 0.0122). *t*-copula should be rejected at the 5% level.

Appendix 9

Hypothesis testing for reserve distributions and average ranks

	AIC information score (R *fitdistr* AIC)	Interpreting the AIC results	Visual test based on Q-Q plot	Final decision	meanlog/scale	sdlog/shape	Volatility measure for standard approach
MTPL							
Gamma	309 900	best fit	second best fit				
Weibull	311 348						
Normal	310 124						
Lognormal	309 928	second best fit	best fit in tail	**Log-normal**	15.9257	0.1575	0.1575
Exponentional	311 348						
C&S							
Gamma	291 093	best fit	best fit in tail	**Gamma**	789 144	1.5513	0.2191
Weibull	291 252	second best fit	second best fit				
Normal	296 848						
Lognormal	291 585						
Exponentional	291 252	second best fit					
GTPL							
Gamma	294 593	best fit					
Weibull	295 827						
Normal	294 675	second best fit	second best				
Lognormal	295 101		best fit in tail	**Lognormal**	14.8430	0.2191	0.9117
Exponentional	295 827						
PROPERTY							
Gamma	276 579	best fit	best fit in tail	**Gamma**	128 622	4.4160	0.4948
Weibull	277 323						
Normal	278 719						
Lognormal	276 711	second best fit	second best				
Exponentional	277 323						

Source: created by the author.

Appendix 10

The calculated average ranks by line of business

Year	Line of business			
	MTPL	C&S	GTPL	Property
2012	1	3	1	1
2013	2	7	2	2
2014	3	4	3	3
2015	5	1	6	4
2016	6	8	4	5
2017	4	5	5	6
2018	8	9	9	7
2019	9	6	7	9
2020	7	2	8	8

Source: created by the author.

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