MILLIMAN REPORT

Economic capital modeling: Practical considerations

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Introduction

Insurance companies are exposed to risks whose nature results either from their core business activity or from external events such as a financial crisis or the development of a pandemic. While insurance companies emerge from the aftermath effects of the COVID-19 pandemic, additional risks have joined the pool of existing ones, such as liquidity risk or emerging risks including climate risk, artificial intelligence (AI), cyber risk, and geopolitical tensions and conflicts.

To navigate through an age of uncertainty and a world at risk, sound risk management is of paramount importance for insurance companies to identify, monitor, and manage their risks. It is inherent to the insurance market that insurance companies hold capital to carry risks to ensure a high probability of meeting their obligations to their policyholders.

One tool available to insurance companies to understand their inherent risks are economic capital models. There are two important components of economic capital:

- Available capital: How much capital an insurance company holds in excess of its obligations.
- Required capital: How much capital an insurance company should hold to withstand an adverse scenario The required capital can be determined based on local insurance regulations and/or an internal view of senior management.

Economic capital means different things to different people. At a minimum, economic capital refers to the amount needed to cover the tail risk of potential losses. The perspective on which this amount is determined can differ between companies and jurisdictions. In some jurisdictions the term “economic” is interpreted as meaning market-consistent, whereas in others the term is interpreted as a real-world expectation. While the basis on which the economic capital is determined can differ, the concept can be used in a similar way. At its core, the concept is used to determine how much capital a business intends to hold to meet the risks inherent in its liabilities, investments, and business operations, on top of what is already held as reserves.

There is therefore an interest from different stakeholders (i.e., shareholders, regulators, credit rating agencies, etc.) in establishing what is a “correct” level of capital such that:

- The capital held is not too high, since this leads to inefficient use of capital and excessive cost of insurance.
- The capital is held is not too low, since this leads to an unacceptable risk of insolvency.

This information can then be used for multiple purposes, such as:

- Risk monitoring
- Hedging and risk mitigation
- Capital optimization and allocation
- Pricing
- Asset-liability management (ALM) and investment strategies.

To determine its available capital and required capital, an insurance company must:

- Determine the balance sheet as a starting point for economic capital modeling.
- Identify the relevant risks.
- Decide how to measure these risks.
- Decide how to model potential losses based on the measured risks.

This paper describes some of the key components and design choices when modeling economic capital and how these can differ across jurisdictions. Some of the key aspects are discussed in this paper:

- Whether to take a market-consistent or real-world approach to determining the balance sheet.
- Which risks to include in an economic capital model.
- Some of the challenges faced when measuring different types of risk drivers.

- Important modeling choices for determining economic capital:
  - One year versus multi-year risk time horizon.
  - How to aggregate different risks together.
  - Whether or not to include potential management actions.
  - Techniques to reduce the computational intensity of economic capital models.

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Glossary of acronyms and abbreviations

ABBREVIATION	
ORGANIZATIONAL & REGULATORY TERMS	
EIOPA	European Insurance and Occupational Pension Authority
ESG	Environmental, Social and Governance
IAA	International Actuarial Association
IAIGs	Internationally Active Insurance Groups
IAIS	International Association of Insurance Supervisors
ICS	Insurance Capital Standard
IFRS	International Financial Reporting Standards
LICAT	Life Insurance Capital Adequacy Test
NAIC	National Association of Insurance Commissioners
ORSA	Own Risk and Solvency Assessment
OSFI	Office of the Superintendent of Financial Institutions
RBC	Risk Based Capital
SCR	Solvency Capital Requirement
SST	Swiss Solvency Test
VM	Valuation Manual
TECHNICAL TERMS	
AI	Artificial Intelligence
ALM	Asset & Liability Management
CAT	Catastrophe
CTE	Conditional Tail Expectation
EAD	Exposure-at-Default
ES	Expected Shortfall
LGD	Loss-Given-Default
PCA	Principle Component Analysis
RC	Required Capital
RFR	Risk free rate
TVaR	Tail Value at Risk
TVOG	Time Value of Options and Guarantees
VaR	Value at Risk

1. What is economic capital?

When discussing economic capital, we need to distinguish between:

- Available capital: The excess of the value of the company's assets over its liabilities.
- Required capital: The amount of available capital an insurance company stands to lose in an adverse scenario given a certain probability.

The primary focus of this paper will be the determination of the required capital, i.e., what risks we should distinguish, how we measure these risks, and how we aggregate these risks (Chapters 4 and 6). There is a relationship between the available capital and the required capital in that the valuation of the balance sheet that determines the available capital can also influence how the required capital is determined. Conversely, any change in the required capital may have a direct impact on the amount of available capital, which in some cases may require a capital injection. This will be discussed in further detail in Chapter 3.

We must also distinguish between economic capital and statutory capital:

- Statutory capital: The amount of available capital and required capital as defined by the relevant regulations.
- Economic capital: The amount of available capital and required capital based on a company's view of its risk.

Many companies also determine the capital positions based on the model of a rating agency or of multiple rating agencies. These models tend to have a broader view on the financial position, risk, and strategy of the company.

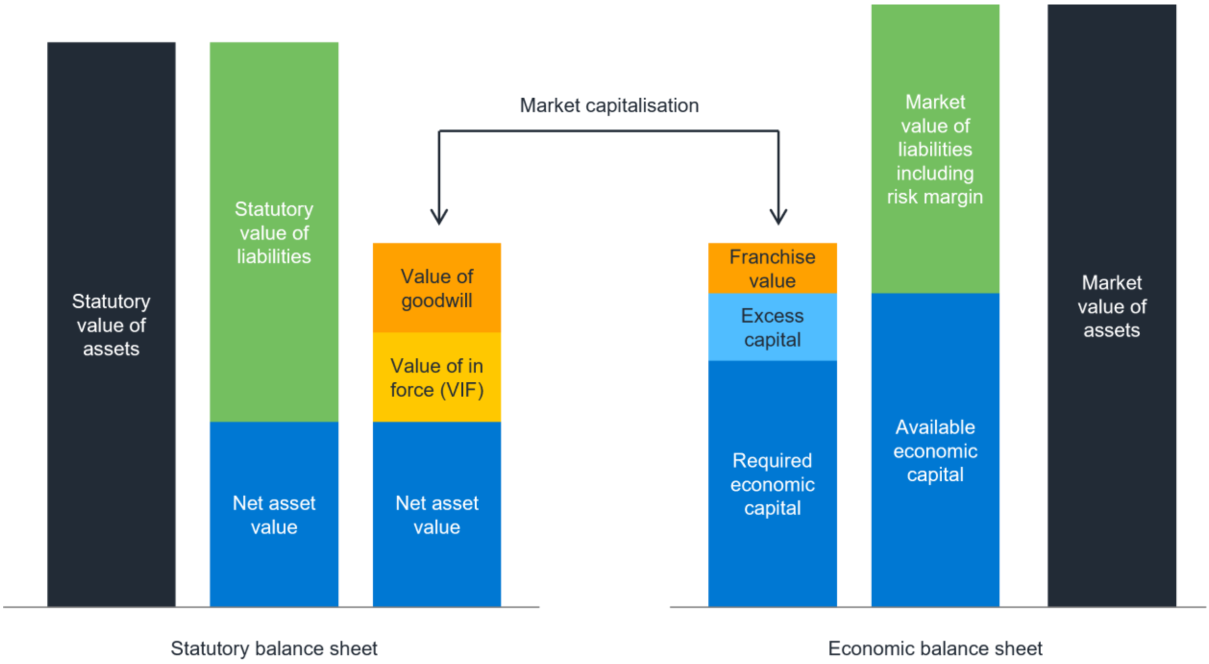
Historically, statutory solvency was determined holistically through prudence in the valuation of assets and liabilities and a formulaic approach for required capital based on the overall nature and size of the business. However, during the course of the early 1990s, this one-size-fits-all approach was coming under serious scrutiny. The U.S. General Accounting Office (GAO) reported 176 life and health insurer insolvencies between 1975 and 1990, with 80% of these insolvencies occurring after 1982. The substantial number of insolvencies clearly identified the inherent problems with fixed-capital standards. One problem was that fixed-capital standards did not address the variation in fundamental risks across sectors and companies. Life insurers' balance sheets (assets and liabilities) were becoming increasingly complicated, and practitioners and regulators alike started to consider more of a bottom-up, risk-based approach to assessing life company financial health and solvency. A good example of the developments at the time was the publication of the Society of Actuaries Dynamic Financial Condition Analysis Handbook, which for the first time addressed in earnest complicated issues such as the modeling of collateralized mortgage obligations, which by the early 1990s were a significant proportion of U.S. life company asset holdings. By the end of that decade and into the early 2000s, there was serious momentum within companies to take more of an economic view of their business, and among regulators globally to take more of a principles-based approach to statutory reserves and capital.

In the early 1990s, the National Association of Insurance Commissioners (NAIC) established a working group to look at the feasibility of developing a statutory RBC requirement for insurers. In 1992, NAIC adopted a life RBC formula, which was implemented in 1993.

All of this was to lay the foundations for what was to shortly come with C3 Phase I and II in the United States, and Solvency II in Europe. Today, there is often strong alignment between how companies assess capital internally from a true risk-based perspective (economic capital) and how the regulators view capital (statutory capital), albeit that statutory frameworks will always lean more on the side of conservatism and solvency protection as opposed to aligning 100% with the economics.

The following diagram illustrates the relation between the statutory and the economic balance sheet, where the statutory balance sheet is based on a book-value perspective (assets and liabilities based on historical cost or amortized cost) and the economic balance sheet is based on a market-value perspective. In some jurisdictions though, statutory and economic balance sheet may both be on a market-value basis.

FIGURE 1: DIFFERENT VIEWS OF CAPITAL



2. What are the benefits of economic capital analysis?

One of the underlying principles of an insurance market is that insurance companies hold capital in order to take on risks and absorb the inevitable fluctuations in experience. They do so in a way that will maintain a high probability of having the financial resources needed to meet their obligations to their customers. The providers of this capital (e.g., shareholders in an insurance company) want to earn an adequate return, and the cost of this return on capital needs to be allowed for in the pricing of the insurance. Therefore, there is an interest in establishing what is a “correct” level of capital under given parameters so that:

- The capital on which the providers of capital are expecting to earn a return is not too high, since this leads to inefficient use of capital and excessive cost of insurance.
- The capital is not too low, since this leads to an unacceptable risk of insolvency.

For these reasons, economic capital can be a useful tool for all constituencies interested in the financial health of an insurance company. This information can then be used for multiple purposes, such as:

- Risk monitoring: commonly companies have implemented a risk management cycle in which measurement and reporting of risks are identified as essential parts. In every step of the cycle the risks are measured and monitored. The outcomes of the risk quantification are compared with the risk tolerance at a strategic level and the risk tolerances or risk limits at a more detailed level. If necessary, actions may be taken to stay between the lower and upper limits. Multiple risk measures can be used in the risk monitoring process. The frequency is dependent on the volatility of risks. Economic risks are monitored very frequently (up to daily for equity risk) to less frequently for trend risks like longevity risk.
- Hedging and risk mitigation: Hedging and other types of risk mitigation (like reinsurance, rebalancing assets) generally come with a cost. That can be a direct cost and/or a reduction of future returns. The reduction of capital from hedging leads to a lower cost of holding capital, and the comparison of the cost of the risk mitigation and the cost of the change in capital will support the decision making process.
- Capital optimization and allocation: For insurance groups with multiple subsidiaries, net asset value can be reallocated to give subsidiaries more or less room to take risk. This can help to facilitate growth of portfolios by writing new business, but also with managing market risks within the risk tolerance.
- Pricing: every new contract leads to an amount of required capital; The cost of that capital is included in the pricing via a risk margin.
- Asset-liability management (ALM) and investment strategies

Economic capital can be of benefit to insurance companies, investors, and rating agencies, as well as regulators. Regulators tend to assess an insurance company’s financial health primarily based on its statutory solvency position. Where the statutory capital has limitations in the assessment of the risk, regulators tend to have other measures in place to cover these gaps. They expect companies to have reliable reporting and risk monitoring governance and processes in place. Besides ALM, hedging, and reinsurance, companies use Own Risk and Solvency Assessments (ORSAs), stress testing, crisis planning, and resilience planning to identify, measure, and manage risks. These processes may leverage on an insurance company’s economic capital model.

We see a distinction between the usability of economic capital modeling between the United States and European jurisdictions:

- The statutory framework in Europe, Solvency II, has a standardized set of principles based on which the solvency position is determined applicable to all insurance companies. There is, however, an option to apply for an internal model with the supervisor. This has allowed insurance companies to use their economic capital models to form the basis of their statutory capital. While some differences between economic capital and statutory capital may remain, the option for internal models has allowed for companies to steer largely in line with their economic models.
- The statutory capital framework in the United States, risk-based capital (RBC), is in principle based on a standardized set of rules established by NAIC. Insurers must hold the statutory requirement under the RBC framework, a primarily factor-based capital framework that differs from what the economic capital is. While economic capital models can lead to different insights than the statutory RBC capital regime, the additional time and effort on top of statutory reporting have caused some insurers in the United States to shift away

from the use of economic capital models. However, U.S. statutory reporting has been gradually shifting to a principle-based framework, under which tail market risks for some products would have to be stochastically evaluated. In those cases, the fundamental difference between the U.S. statutory capital and European statutory capital is that the United States focuses on tail (market risk) events that arise over a long period of time from a historical realistic perspective while Europe focuses on tail (all risk) events that happen in the next year from a market-consistent perspective. Differences between the statutory framework and economic capital models and the interpretability of EC results can make it difficult for executives to act on results of economic capital models.

3. Lenses to economic capital

A significant source of differences between economic capital models across different jurisdictions is the view of risks, which can take a market-consistent (which in its purest form is also known as risk-neutral) approach, or a real-world approach. For example, in Europe, there is a focus on market-consistent valuation combined with a shorter risk time horizon, while in the United States the focus is on a longer risk time horizon combined with real-world expectations. In this chapter we discuss the concepts of market-consistent versus real-world approaches to valuation of the balance sheet, and how economic capital is viewed across different jurisdictions.

The valuation of the balance sheet forms the basis of determining the required capital. Different approaches can be taken to the determination of the balance sheet. In section 3.1 we first explain the market-consistent valuation approach. In Section 3.2 we compare how it differs from a real-world approach. In Sections 3.3 onward we look at the application of EC in different jurisdictions.

3.1 MARKET-CONSISTENT VALUATION

Market-consistent valuation of assets

Market-consistent valuation has developed over the years, and the International Financial Reporting Standards (IFRS) have formalized a hierarchy in methods to determine the value of assets:

- **Level 1:** Quoted market prices in active markets for identical assets.
- **Level 2:** Inputs other than quoted prices included within Level 1 that are observable for the asset, either directly or indirectly.
- **Level 3:** Unobservable inputs for the asset, used when observable inputs are not available.

Examples of assets valued using quoted prices are bonds, equities, and many vanilla derivatives. Loans are an example of an asset class valued using the level 2 methodology. Although loans are not actively traded in public markets, they can be valued using yields derived from comparable bonds. For certain asset classes, assumptions are needed for valuation that cannot be derived from market prices. An example would be the pre-payment option on a mortgage, which is at the discretion of the mortgage holder. As mortgage holder behavior cannot be derived from market data, an insurance company should use alternative sources of information to determine its best estimate expectation for valuation. This is preferably based as much as possible on historical data but can incorporate expert opinion. These models and assumptions would fall under level 3 of the valuation hierarchy.

For certain asset classes, cash flows are dependent on market parameters. This is the case with derivatives such as equity call options and interest rate swaps. While vanilla derivatives are actively traded and thereby have a market observable price, more complicated derivatives require valuation methods to deal with the optionality embedded in these financial instruments. These assets are usually valued using a risk-neutral valuation method.

Market-consistent valuation of liabilities

As highlighted earlier, while assets are often actively traded in the market, this is not the case for insurance liabilities. This leads to some challenges when attempting to determine a market-consistent value. In principle, the market-consistent valuation of life insurance liabilities is based on the projection of expected cash flows, which are then discounted with an appropriate interest rate to account for the time value of money. The discount rate of liabilities and how to reflect a market-consistent risk premium for non-financial risks have been topics of considerable debate.

To determine the expected cash flows, best estimate assumptions are used for the non-economic parameters such as mortality rates, lapse rates, disability rates, etc. As opposed to the traditional reporting where assumptions are mostly prescribed, these assumptions need to be updated over time as new information becomes available. This can lead to volatility in the value of liabilities not seen in traditional book value accounting. It is market practice to review such assumptions at least on a yearly basis, and maybe even more frequently in case of significant events.

In principle, discounting should be based on the risk-free interest rate term structure as, conditional on the assumed scenario for non-economic assumptions, the expected cash flows are certain. Many jurisdictions that have adopted a market-consistent approach have acknowledged that using purely the risk-free interest rate for discounting expected liability cash flows can lead to unwanted effects for insurance companies with long-duration liabilities. Such insurance companies typically invest in longer-duration assets with a "hold to collect" investment strategy.

The market value of the assets covering the liabilities is volatile, and the volatility does not purely reflect a change in expected default rates but is also driven by changes in implicit risk premia. Volatility in the risk premia of assets can lead to a decline in asset value, which in turn would lead to lower available capital. Such a decline is not necessarily the result of an increase in expected losses. The volatility adjustment under Solvency II is an example of a mechanism that allows for the discount rate of liabilities to reflect to some degree the risk premia embedded in asset spreads that are not reflective of expected default rates. This leads to more stability in the available capital.

Another key aspect of the liability discount curve is the long-term discount rate assumption. In different jurisdictions that have adopted a market-consistent framework there is a recognition that, beyond a certain tenor, some financial instruments, such as long-tenor interest rate swaps, are no longer available on an efficient market. The Solvency II regime prescribes the use of available market data from the interest rate swap market up until a certain tenor, referred to as the last liquid point, and beyond this point the discount rate is extrapolated to an estimated long-term average interest rate.

The “volatility adjustment” and extrapolation beyond the last liquid point in Solvency II are part of what are referred to as the long-term guarantee measures. These concepts are not unique to the Solvency II standard. The updated international accounting standard for insurance contracts, IFRS 17, and the ICS framework have adopted/allowed for similar mechanisms. The exact mechanism or parameterization can differ between regimes, but the concept is similar.

To ensure that the value of liabilities is market consistent, the inherent uncertainty in insurance liabilities needs to be accounted for, as no third party would take over the liabilities without being compensated for the underlying insurance risk. The scope of risks accounted for in the uncertainty margin is usually the risks other than market risks, because for market risks the risk premium is already embedded in the market information used. There are different ways to compensate for the uncertainty in insurance liabilities. The following methods are commonly used for determining the margin for uncertainty:

- **Value at risk:** The amount an insurance company stands to lose given a certain probability percentile.
- **Cost of capital:** The cost of holding the capital to cover the uncertainty over insurance risks.
- **Provisions for adverse deviations**: Adding margins to the best estimate assumptions for various risk factors.

Market-consistent value of liabilities also includes the value of any options or guarantees embedded in the insurance contracts. These are usually valued through Monte Carlo simulations of the expected cash flow projections using risk-neutral scenarios.

3.2 MARKET-CONSISTENT VERSUS REAL-WORLD?

Foundational to economic capital is the often hotly debated topic of whether a market-consistent or real-world lens should be taken. Both have their pros and cons, and both lenses can provide insights into the business and its underlying risk exposures.

Under a market-consistent approach, assets and liabilities are viewed from the perspective of immediate liquidation. In that regard, it can be considered an “exit price,” i.e., the market price to transfer the risk. For assets, this is fairly straightforward in that, at least for publicly traded assets, prices can be taken from observable market data. For liabilities, however, taking a “market-price” view is more challenging, as insurance contract liabilities do not have a “public market” and are generally illiquid with no observable price. Thus, while conceptually the market-consistent approach may seem as though it is more objective than subjective, there is some element of judgment involved because of the nature of the liabilities. Adhering to market-consistent valuation, no arbitrage will be assumed, liabilities are assumed fully hedged, and all assets are assumed to earn the risk-free rate.

Under a real-world view of economic capital, the focus is on the evaluator's view of risk rather than the market's view of risk. Typically, this will involve taking a long-term realistic (best estimate) view of future economic conditions and projecting future asset and liability cash flows according to these assumptions, and discounting to a present value reflecting the uncertainty in insurance cash flows through discount rates higher than risk-free rates. Clearly, with so much of the valuation reliant on subjective elements, there is a considerable degree of judgment involved. Often historical market data is used to help inform the real-world view, but ultimately this is a forward-looking view so that history alone cannot be used for calibration. Under a real-world approach to valuation, risk premiums may be recognized and actual hedging reflected.

There are a number of relative strengths and weaknesses to the two approaches that are important to bear in mind in making a decision over which approach to take and in interpreting the results from valuations using each approach.

Under the market-consistent framework, perceived strengths include:

- Consistency in the valuation of assets and liabilities.
- Relatively objective, and thus less prone to manipulation.
- Completeness, in that it captures the cost of options and guarantees.
- Up to date with regard to capturing market inputs.
- For companies that operate across multiple jurisdictions, readily enables a consistent approach to be taken across the business.
- Consistency with International Financial Reporting Standards for insurance contracts (IFRS 17).
- Facilitates comparability between companies.

Perceived weaknesses of the market-consistent framework include:

- There is no liquid market for liabilities, so not a true market value.
- In practice, companies generally manage as a going concern.
- It does not allow (credit) spreads in the liability valuation where the spreads can be realized when it is earned in the real world. As a result, many of the product types typically written in the United States that are investment-oriented products and rely on spreads from fixed-income asset investments (such as deferred annuities) may require substantial capital.

Under the real-world framework, perceived strengths include:

- It can reflect a more realistic view of the company based on historical data, e.g., assuming realistic spread earnings.
- In reality, the insurance market is not in practice an efficient market, and hence the concept of no arbitrage does not exist in the real world. In practice, liabilities are not actively traded in an open market; moreover, there are many reasons for buying and selling insurance products that are unrelated to price – for example, a policyholder may have a preferred agent that they like to deal with. The real-world approach permits such nuances to be brought into the valuation.
- Provides an opportunity to manage a life operation that meets customer needs (such as deferred annuities with guaranteed return exceeding risk-free rates) in a manner that other frameworks cannot do, and thus offers the ability to use the uniqueness of a life insurer's balance sheet.

Perceived weaknesses of the real-world framework include:

- Relative subjectivity in assumptions.
- Economic assumptions vary among insurers so comparability across companies is challenging.
- Embedded options are not always valued.

Whether a market-consistent or real-world perspective should be used for economic capital comes down to how a life insurer wants to run its business. Neither approach is “right” or “wrong.” Under a market-consistent approach, the life insurer can be thought of as an intermediary, providing customers with access to things in the market that they otherwise may not have access to or know how to get access to. Under a real-world approach, the life insurer can be thought of as more than just an intermediary and is creating something that otherwise does not exist in the market. Take, for example, a fixed deferred annuity and its taxability. In concept, a fixed deferred annuity could be replicated by going to the market and investing in a fund or mix of assets, conditional on expectations for the insurance component. But in the real world, what an insurer is able to do is provide additional benefits around that, such as crediting rate guarantees. Individuals could, in theory, self-assemble the components that replicate a fixed deferred annuity (e.g., a portfolio of bonds plus derivatives for any optionality or guarantees), but few people would have the expertise to do that. Under the real-world approach, recognition is given to life insurers for providing valuable benefits and services that the market-consistent approach does not capture.

While in the market-consistent approach the valuation of assets and liabilities is usually performed under a risk-neutral measure, it is important to note that the determination of required capital requires an assessment of how the value of the balance sheet fares under shocked conditions, and for that purpose it is common practice that the shocks are calibrated to historical real-world results. The risk-neutral approach is a useful tool used for the valuation of options and guarantees that circumvents the need for knowing risk premiums. However, on its own it does not answer the question of what amount of capital to hold, as it does not give insight into the real-world risk that an insurance company is exposed to.

We see different preferences for market-consistent versus real-world approaches taken by regulators across jurisdictions, hence naturally for companies operating in a particular jurisdiction there may be more of a leaning to one approach versus another. In the sub-sections that follow, we examine the different perspectives across jurisdictions—specifically Europe, the United States, Canada, and Asia—as well as consider the approach being adopted according to the Insurance Capital Standards (ICS) developed by the International Association of Insurance Supervisors (IAIS).

3.3 EUROPE

In 2016 the European Commission implemented the Solvency II framework, which was a major revision of the solvency regime for insurers in the European Union. The objective of Solvency II was to be more realistic than the previous European Union solvency basis in assessing the capital requirements for insurers. Solvency II was developed from the perspective that it should give supervisors the option to intervene in a timely fashion if an insurance company is deemed inadequately capitalized, and either liquidate the company or have another insurance company take it over. This has led to three key characteristics of the Solvency II regime and economic capital modeling in general in the European region:

- Market-consistent valuation as the basis for determining the balance sheet.
- A risk-based capital approach taking into consideration underwriting, market, credit and operational risk.
- A one-year time horizon for risk assessment.

The Solvency II framework starts by defining the approach for the valuation of assets and liabilities in order to determine the available capital. It then specifies which risk drivers are recognized and how these risk drivers should be stress shocked in order to determine the impact on the available capital. The outcomes of the shocks of the different risk drivers are then aggregated. The resulting amount is considered the amount of available capital the insurance company stands to lose in a one-in-200 adverse scenario. There is a standardized set of requirements based on which every insurance company can calculate the one-in-200 required capital. This set of requirements is called the Standard Formula. In addition to the Standard Formula, insurance companies can also apply for an internal model with the local regulator. The basis for the internal model is often derived from the economic capital model developed internally.

3.4 UNITED STATES

In the United States, the statutory capital framework is defined by the RBC requirements. The statutory regulatory regime in the United States requires insurers to hold both a typically conservative statutory reserve and a (generally) factor-based capital balance. The reserve and capital components under the statutory framework are calculated separately from each other, which differs from a total balance sheet approach such as Solvency II or ICS calculations.

Unlike Solvency II, RBC is primarily a factor-based formulaic framework, with prescribed factors applied onto balances such as asset book value (rather than market value under the European or Canadian regimes), net amount at risk, and premium amount.

As the risks present in the U.S. insurance market have evolved since the initial introduction of the RBC, as well as regulatory developments across the Atlantic, the U.S. regulations have also evolved to include a more economic view of reserves and capital in recent years. As such, starting with the introduction of principle-based statutory capital for variable annuities (C3 Phase II), U.S. regulators have put in place principle-based reserve and capital frameworks for specific types of business, such as:

- Life products reserving (Under Section 20 of Valuation Manual (VM-20)).
- Variable annuities reserving (VM-21) methodology that also applies to required capital calculations.
- Non-variable annuities reserving (VM-22) expected to be implemented soon.

Under the new principle-based framework, reserve and capital calculations incorporate stochastic calculations simulating different interest rate, equity, and other financial market risk scenarios. The principle-based framework incorporates company-specific assumptions along with the real-world generated economic scenarios, introducing an economic lens to the statutory requirement.

Beyond the statutory requirement, and in light of the effects of the 2008 financial crisis, NAIC has also introduced ORSA reporting requirements for U.S. insurance companies, comparable to other jurisdictions. This requirement ensures that insurers are assessing if the statutory capital is sufficient, and in certain cases, also develop their own economic capital model based on an internal view of the risks.

3.5 CANADA

In Canada, the principles-based capital regime, Life Insurance Capital Adequacy Test (LICAT), has been in place since 2018. The LICAT capital regime is primarily shock-based, and for insurance risks includes various components for each type of insurance risks:

- Volatility: Taking random fluctuations into consideration.
- Catastrophe: Taking one-time, large-scale events into consideration.
- Level: Taking misestimation of best estimate assumptions into consideration.
- Trend: Taking future trend of best estimate assumptions into consideration.

This is further supported by an IFRS-based statutory reserving requirement, as well as the choice to use internal models for certain aspects of capital calculations.

3.6 ASIA

A recent study by Milliman on Asian capital regimes showed that while some countries in Asia still have a formulaic-based statutory regime, major insurance markets in Asia have moved to some form of a risk-based capital regime. These risk-based capital regimes have moved to a market-consistent valuation approach for the balance sheet and follow a modular approach for required capital based on a company-specific assessment that is sensitive to each insurer’s risk profile. The approach is typically consistent with the principles of Solvency II, ICS, and IFRS 17, although differences exist in the details. For solvency purposes, an increasing number of Asian capital regimes require companies to:

- Assess their assets on a market-value basis (e.g., Hong Kong, Indonesia, Singapore, Thailand, and Malaysia), although some markets are still measuring their assets using different accounting bases (e.g., China’s C-ROSS 2, Solvency I-like regimes such as Vietnam or India).

- Valuation of liabilities:
  - Based on a best estimate projection of expected cash flows discounted using market-consistent discount factors.
  - Takes into account the time value of options and guarantees (TVOG).
  - Includes a margin for uncertainty.

Although there is a trend toward a market-consistent framework, jurisdictions are moving at different paces, and many regulators in Asia seem to have taken a more practical approach that reflects market specifics while ensuring a reasonable degree of conservatism (e.g., the flooring of reserves in some markets, the lack of loss absorbing capacity of reserves in others). This leads to inconsistencies between risk-based capital regimes across the region. In most Asian markets there is less focus on internal economic capital modeling, as it tends to not drive distributable earnings, and the economic capital requirements tend to not be biting. There are some exceptions, for example Japan and Korea, where large insurance companies have been reporting market-consistent embedded value (MCEV) or European embedded value (EEV) as well as economic solvency ratio (ESR) based on internal models, and the day-to-day business planning is based on these models. The introduction of the Japan Economic Solvency Ratio (J-ESR) framework has even mandated that all Japanese insurers report ESR based on a consistent method adopted for ICS.

3.7 INSURANCE CAPITAL STANDARDS

The primary goal of the ICS is to enhance the financial stability and resilience of the global insurance industry. In principle, it is developed for large insurance groups that operate in multiple countries referred to as internationally active insurance groups (IAIGs).

In November 2019, the IAIS adopted ICS Version 2.0 for a five-year monitoring period, which began in January 2020. During this monitoring period, IAIGs were expected to report their ICS results to their group-wide supervisors, but the results are not yet used for regulatory capital requirements. The IAIS adopted ICS during its general meeting in December 2024.

On a conceptual level, ICS Version 2.0 has similar characteristics to Solvency II:

- Valuation based on market-consistent valuation principles for both assets and liabilities.
- A risk-based capital approach taking into consideration underwriting, market, credit and operational risk.
- A one-year time horizon for risk assessment.

Some countries are considering adopting ICS as their local regulatory capital standard. Japan, for example, will adopt an ICS-like J-ESR reporting framework starting from March 31, 2026. The Korean supervisor adopted K-ICS, which has been implemented since beginning 2023 and closely resembles the ICS v2.0. Taiwan insurers will adopt TW-ICS in January 2026.

3.8 EQUIVALENCE PRINCIPLE

As insurance groups operate in multiple countries, they may be exposed to different regulatory capital regimes of these jurisdictions. As calculating the regulatory capital under multiple regulatory regimes can be a significant operational burden, it can become an impediment for insurance groups to expand internationally. Supervisory authorities may investigate the equivalence of different regimes. If a supervisory authority grants an equivalence status to another jurisdiction, it means that the outcome of the respective regime is assumed equivalent to the outcomes of its own regulatory regime. This is important to insurance groups because it can avoid significant operational burdens. An example of this is that the European Commission has granted equivalence to the Swiss Regulatory regime. The IAIS is in the process of developing a methodology to assess whether different regimes are equivalent to ICS.[1]

1. International Association of Insurance Supervisors (December 2024). IAIS adopts Insurance Capital Standard and other enhancements to its global standards to promote a resilient insurance sector. Retrieved December 27, 2024, from: https://www.iaisweb.org/2024/12/iais-adopts-insurance-capital-standard-and-other-enhancements-to-its-global-standards-to-promote-a-resilient-insurance-sector/.

4. What types of risks should be considered?

An appropriate economic capital model should reflect all types of material risks that the insurer is exposed to. Materiality refers to the potential size of the impact the risk has on the ongoing business activity of the company. While different companies might be exposed to the same risk, the materiality might differ due to either the level of exposure or acceptance threshold. Thus, one company might decide to model a risk while another decides not to.

The Solvency II regime, introduced in 2009 through the Directive 2009/138/EC, was the first to introduce a harmonized, sound, and robust prudential risk-capital framework for insurance and reinsurance companies in the EU. It replaced the Solvency I regime, introduced in the early 1970s, that showed structural weaknesses such as not being risk-sensitive and the omission of a number of key risks (market, credit, and operational risks) that were either not captured at all in capital requirements or were not properly taken into account in the one-model-fits-all approach. Across the world, other jurisdictions from Singapore to Canada have also adopted similar risk capital frameworks, ensuring that key risks that insurers are faced with are appropriately reflected.

In this chapter we discuss the main risk categories as grouped in the Solvency II framework for the calculation of required capital. Different frameworks might group risks differently, but in essence they cover a similar spectrum of risks. In addition to the categories mentioned in the remainder of this chapter, companies might identify additional risks such as liquidity risk or emerging risks including climate risk, AI, cyber risk, and geopolitical tensions and conflicts.[2] In most jurisdictions, insurance companies are expected to perform an Own Risk and Solvency Assessment (ORSA) where they assess their own risks, including those they may not be covered in their statutory and economic capital.

4.1 RISK CATEGORIES

In the remainder of this chapter, we will discuss the following main risk categories. These risk categories are in line with the SII framework[3] as well as the ICS framework.[4]

- Underwriting risk (insurance risk)
- Market risk
- Counterparty default risk (credit risk)
- Operational risk

Although risks are categorized based on the SII framework, the categories presented are common across many other regulatory capital frameworks across the world.

Under Solvency II, strategic risks, reputational risks, ESG (environmental, social and governance) risks, legal & compliance risks are not measured separately, but are included in the amount of capital for operational risk. Via the own risk and solvency assessment (ORSA), companies are expected to assess the aforementioned risks and determine if the charge for operational risk is appropriate. A capital add-on may be applicable if the operational risk charge underestimates the risks.

Underwriting risk

Underwriting risk is the risk of loss arising from the insurance underwriting activity, associated with both the perils covered and the processes followed in the conduct of the insurance business. Solvency II divides underwriting risk into three main business activities: life, non-life (or general insurance) and health.

The life underwriting risk category is subdivided into seven subcategories: mortality risk, longevity risk, disability/morbidity risk, lapse risk, expense risk, revision risk, and catastrophe risk.

The non-life underwriting risk category is subdivided into three subcategories: premium risk, reserve risk, and catastrophe risk.

2. International Actuarial Association, Insurer Solvency Assessment Working Party (2004). A Global Framework for Insurer Solvency Assessment. Retrieved December 27. 2024, from: https://www.actuaries.org/LIBRARY/Papers/Global_Framework_Insurer_Solvency_Assessment-public.pdf.

   CRO Forum (2024). Emerging Risks Initiative: Major Trends and Emerging Risk Radar, 2024. Retrieved December 27, 2024, from: https://thecroforum.org/wp-content/uploads/2024/08/ERI-Risk-Radar_2024.pdf.

3. Delegated Act 2015-35 & Directive 2009-138-EC (article 105).

4. International Association of Insurance Supervisors (July 2018). Risk-based Global Insurance Capital Standard Version 2.0. Public consultation document. Retrieved December 27, 2024, from: https://www.iaisweb.org/uploads/2022/01/180731-ICS-Version-2.0-Public-Consultation-Document.pdf.

The health underwriting risk category is split according to its technical nature: health insurance obligations pursued on a similar technical basis to that of life insurance (SLT health) and health insurance obligations not pursued on a similar technical basis to that of life insurance (non-SLT health). The distinction between SLT and non-SLT is the duration of the insurance contract. Non-SLT are short term (1 year or shorter) while SLT are longer term contracts.

Each subcategory aims to represent the main risk drivers of underwriting risk for an insurer.

Market risk

Market risk is the risk of loss arising from the level or volatility of market prices of financial instruments. The prevalent risk drivers are interest rates, stock prices, exchange rates, real estate prices, non-default spreads, and asset concentration. Regarding derivative prices, not only exposure to the movement of underlying asset prices but also the effect of other financial variables such as market-implied volatility are included in market risk. For market risks it is important to look at not only the impact of market risk drivers on assets but also the impact on liabilities. In practice, this means that companies might have to consider both upward and downward shocks to effectively measure the risk on the net asset liability position.

Counterparty default risk

Counterparty default risk is the risk of loss arising from an unexpected default, or deterioration of the credit quality, of the counterparty and debtors of the company. It includes exposures in relation to reinsurance arrangements, securitizations and derivatives, any other risk mitigation contracts, cash at bank, deposits and receivables from intermediaries, and policyholder debtors (including mortgage loans).

Spread risk and counterparty default risk for fixed-income instruments are inherently linked, and different regimes/companies can make choices about how to disaggregate and allocate the risks to risk categories. The same holds for concentration risk, which sometimes is part of market risk and sometimes is part of counterparty default risk.

Operational risk

Operational risk is the risk of loss arising from inadequate or failed internal processes, or from personnel and systems, or from external events.

The operational risk can be broadly categorized by two components:

- Operational failure risk: It arises from the potential for failure in the course of operating the business. Failure of people, processes, and technology used to develop the business plan can be included in this category.
- Operational strategic risk: It arises from environmental factors, such as a new competitor that changes the business paradigm; a major political, tax and regulatory regime change; or earthquake or other disasters that are outside the control of the company.

Operational risk under Solvency II focuses mainly on risks arising from operational failure and should include legal risks. It excludes risks arising from strategic decisions as well as reputational risks.

4.2 COMPONENTS OF RISK MODELING

In modeling those risks mentioned above, each risk type can be further decomposed into three key components:

- Volatility
- Uncertainty
- Extreme events/calamity

Volatility risk

Volatility is the risk of random fluctuations in either the frequency or severity of a contingent event. In fully efficient markets, idiosyncratic volatility risk is not market valued, since investors can reduce this volatility by diversifying their portfolio. However, because of the relatively inefficient markets for valuing insurance risks, the idiosyncratic volatility component of risk cannot be ignored, and a systematic risk component will always remain. An insurer can incur significant losses due to volatility risk. For example, even if the distribution of claim payment is modeled accurately (i.e., real claim distribution is the same as modeled), a company’s actual claim payment may largely differ from the average of the distribution, depending on the size of the business.

One good example is mortality risk for small companies. The law of large numbers works for mortality risk, which means that for large insurance companies volatility risk is likely small relative to its overall size. For smaller companies this may not be the case, and volatility risk can be a more dominant component of their risk profile.

Uncertainty risk

Uncertainty involves the risk of mis-specifying the model used to estimate the claims (frequency and severity). Uncertainty also involves the risk of misestimating the parameters within the models (parameter risks).

The latter can be further extended to the level and trend risks:

- Level risk is the risk of misestimation of the level of best estimate assumptions. Examples include the use of miscalibrated models for market value or interest rate movements, or a company's liability valuation based on an incorrect assumption of claim distribution.
- Trend risk is the risk of misestimation of the future trend in best estimate assumptions. Even if the model is correctly specified, the trend parameter maybe be incorrectly estimated.

Uncertainty risk is considered a systematic risk because it cannot be reduced by increasing the insured portfolio size.

As an example, it could be generally said that term insurance has less uncertainty risk compared to medical insurance, since cost of medical insurance would depend not only on pure incidence rates but also on government policy, improvement of medical technology, economic downturn, and other social problems that are difficult to predict.

Extreme events risk (calamity)

Extreme events include the risk of large common-cause events such as calamities: high-impact, low-frequency risks. Models may not capture all aspects of extreme risk, especially if no extreme events appear in the historical data used to develop models. Examples include catastrophes with multiple claims, market crashes, or extreme interest rate movements.

Extreme events are considered under Solvency II in the underwriting risk, through the "CAT" sub-category. In addition, a mass lapse event could be considered an extreme event too, which is captured in the underwriting risk through the "lapse" sub-category.

5. How should each of those risks be measured?

In the previous section we identified the different risk factors an insurance company may be exposed to. In this section we will discuss the different approaches to measuring risk and how they are applied to the different risk categories.

5.1 APPROACHES TO MEASURE RISK

There are several approaches to the measurement of losses, which have been listed with increasing flexibility and complexity level:

- **Factor-based model:** It aims to assess the sensitivity of capital to key risk factors, where factors are typically prescribed by the regulator. It is based on a linear combination of a static risk factor multiplied by a company-specific amount, which are typically accounting items such as the amount of premium income. An example of this is the U.S. regulatory framework, where the RBC requirement is primarily a factor-based model, with exceptions applied to market risks on specific products such as variable annuities, where reserves and capital are calculated under the principle-based reserving (PBR) framework.
- **Shock-based model:** Risk capital is calculated by measuring the impact of extreme events. It assesses the insurer's resilience under severe stress by applying one shock to specific risk drivers. The focus is more on the tail of the loss distribution and aims to find the insurer's breaking points. The shock scenario can be derived as a quantile of a probability distribution or can be based on historically observed scenarios. An example of this is the Standard Formula of Solvency II framework. For certain components, such as the lapse risk requirement, capital is calculated as the difference between best estimate liabilities calculated with a prescribed shock to the base lapse assumption, and the best estimate liabilities with the base assumptions.
- **Stochastic simulation approach:** Stochastic simulation approach simulates multiple scenarios rather than focusing on a pre-defined scenario or quantile of a distribution. It is better suited when there are multiple risk drivers with complicated dependency structures between the risk drivers. A stochastic factor model is processed in the following steps:
  - Identify relevant risk drivers.
  - Select the model for each risk driver and calibrate the underlying parameters. Back-testing and sensitivity analysis are usually performed as part of the validation process.
  - Model the joint distribution of risk drivers.
  - Aggregate the resulting loss across all risk types, leading to its stochastic distribution; risk capital is determined by applying a risk measure such as value at risk (VaR) or conditional tail expectation (CTE) to the company's total losses.

Under the principle-based components of the U.S. regulatory regime, capital is based on stochastic simulation results. For variable annuities, for example, the interest rate risk capital requirement is based on the deep tail of the loss distribution (i.e., TVaR 98).

Each risk (e.g., equity risk or lapse risk) can be characterized by multiple risk drivers, i.e., factors or conditions that contribute to the existence of a risk or the underlying cause/reason why a risk might materialize. We underlined in Section 4.2 the three components for modeling the risk: volatility, uncertainty, and extreme events. In the application of the factor-based and shock-based approach, the distinction between different components is often not made. Either one of the components is considered (generally uncertainty and calamity) or the factor/shock is calibrated such that it in theory encompasses all components in terms of overall magnitude. In the stochastic simulation approach, it is more common to capture the multitude of risk drivers embedded in each single risk. However, each additional risk driver increases the dimension of the model and introduces more complexity. The selection of the risk drivers is therefore of paramount importance. In many regulatory frameworks a trade-off is made between accuracy through the granularity of the risk drivers and complexity of the calculation and reporting process. A good illustration of such trade-off consideration is the Standard Formula versus internal model under Solvency II.

Under Solvency II Standard Formula, the risk capital for certain risks is calculated as a single scenario, not specifying which components are captured by this single scenario. Internal models, however, often acknowledge more granular risk drivers than captured in the Standard Formula. For example, where the mortality/longevity shock in the Standard Formula is a single scenario, an internal model might recognize volatility risk separate from uncertainty, and split uncertainty further into a level and trend component. Internal models commonly make use of either shock-based model or stochastic simulation model.

The latter aims to better reflect the company's own view on its risk exposure and the amount of capital needed to cover long tail exposure given the complex interactions between the different risk drivers. Sometimes a stochastic simulation analysis based on granular risk drivers can be used to draw conclusions on whether all risk drivers need to be modeled. While internal models attempt to capture the risk drivers in a more granular way, companies with internal models do face challenges in complexity. A more granular approach to modeling risk might require more assumptions and subjective judgments, and lead to higher amount of computation time. Hence, companies need to carefully evaluate the materiality and dynamics of different risk drivers and utilize different methods to effectively reduce the number of risk drivers. Principal component analysis (PCA) is a common methodology used to reduce the amount of risk drivers and thereby the complexity underlying the risk measurement. Section 6.5 will discuss in more detail methods used by insurance companies to manage the computational complexity an internal model might introduce.

5.2 APPLICATION TO DIFFERENT RISKS

Since there is a wide variety of models to capture different types of risks, it is beyond the scope of this report to fully describe the measurement models for each risk type. In this section we cover the main considerations for the overarching risk categories.

Underwriting risk

For life insurance, the major types of underwriting risk are mortality, longevity, disability/morbidity, expenses, lapse, and other policyholder options such as guaranteed annuitization. For most underwriting risks, the volatility risk is relatively straightforward to estimate. However, estimating uncertainty risk poses some challenges. In this section we will describe some of the challenges faced in measuring mortality risk and lapse risk. While other risks are not discussed in depth, they face similar challenges to those described in this section.

Mortality/longevity risk

For mortality/longevity risk, uncertainty risk can be decomposed into trend and level risk:

- Trend risk refers to the trend of year-on-year improvement in mortality rates and its uncertainty. The trend is often based on national population observations and expectations.
- The level component captures the difference in insured mortality experience versus population mortality experience. This component captures the fact that the insured may lead a healthier lifestyle compared to the national population average.

The difficulty in measuring trend uncertainty is driven by the question of whether historical data captures all dynamics relevant to forecasting the risk toward the future. While the long-term improvements in mortality rates are dependent on developments in exogenous factors such as medical improvements and government spending, the best estimate models for long-term mortality rates are often endogenous models based on the historical mortality rates themselves. Capturing the long-term dependency between mortality rates and exogenous factors is deemed difficult for best estimate modeling given the potentially long time lag between mortality improvements and changes in exogenous factors. As it is difficult to use the true drivers of uncertainty, the exogenous factors, insurance companies tend to rely on endogenous models. However, these endogenous models may underestimate the risk going forward. Expert judgment is needed to determine whether statistical models calibrated to historical mortality rates adequately capture future uncertainty.

Catastrophe risk for mortality is another risk that should be explicitly considered. Following the COVID-19 pandemic, insurers and reinsurers have started to focus on new ways of estimating catastrophe risk for mortality. Global warming, including climate risk, has also started to be considered as a relevant component in the quantification/estimation of prospective mortality tables. Measuring catastrophe risk also poses issues with historical data. There is a limit to the amount of historical extreme scenarios. This makes it difficult to specify the risk in terms of a quantile of a probability distribution.

Lapse risk

Lapse rates can change as a result of economic conditions as well as non-economic movements. An example of economic drivers could be a rise in interest rates triggering rational behavior in policyholders to lapse and seek a more competitive offer. Non-economic movements could be driven by change in taxation of life insurance products and financial situation of the policyholders. For lapse risk, insurance companies usually distinguish between volatility risk, uncertainty risk, and mass lapse.

In case an insurance company assumes a relationship between market movements and lapse rates, this is typically referred to as dynamic lapse behavior and is commonly modeled consistently between the best estimate valuation and the risk quantification. Risks associated with a policyholder's options that are dependent on economic conditions can be more properly measured with stochastic analysis or a stress test.

Once an assumed interaction formula between economic assumptions and policyholder's behavioral decision is defined, the risk can be quantified by conducting simulations under a number of economic scenarios. The interaction formula can be developed by calibrating with historical company-specific or industry experiences. However, policyholder behavior is difficult to formulate, as it is affected by other factors than economic conditions such as downgrade of a major player in the industry and changes in tax policies, or is simply driven by a household's need for liquidity. As there are many potential interactions between lapse rates and other factors, it can be complicated to separate the economic-driven factors from other factors.

In case an insurance company models lapse rates as a function of interest rates, the impact of a change in lapse rates as a result of a change in interest rates can be captured in the interest rate risk module. Changes in lapse rates other than those assumed driven by interest rates are captured in the lapse risk model as part of underwriting risk.

Credit risk

Credit risk is often modeled in a way consistent with the banking standards. Default, credit migration, spread, and spread volatility risks are considered the main risk drivers:

- **Default risk:** The risk that a counterparty (e.g., borrower or the issuer of a security) is unable to meet its debt obligation, resulting in a default.
- **Migration risk:** The risk of credit rating deterioration/downgrade of a counterparty, also called credit rating transition risk.
- **Spread risk:** The risk from spread movements within the same credit rating class.
- **Spread volatility risk:** The risk from movements in (embedded) credit options due to changes in spread volatility.

Insurance companies are exposed to credit risk on the balance sheet through fixed-income instruments and through risk-mitigation contracts such as reinsurance and derivatives.

According to EIOPA,[5] credit risk modeling related to fixed-income instruments is grouped in two different approaches: an integrated approach and a modular approach. The integrated approach models all facets of credit risks (default, migration, and spread) as part of market or credit risk, while the modular approach isolates the different facets of credit between market risk (spread) and credit risk (default and migration).

The integrated approach can further use a bottom-up or top-down modeling choice. The bottom-up approach models default, migration, and spread separately, and it considers a correlation between each. However, in a top-down approach default, migration and spread are modeled as one. For both the bottom-up approach and the top-down approach, the modeling might be separated by maturity, credit rating, and market segment, leading to multiple risk drivers. The number of risk drivers in a top-down approach is likely lower than in a bottom-up approach, as the risk drivers are not separated further into default, migration, and spread risk. Even in a top-down approach, the dimensionality can still be high given the combination of maturity credit rating and market segment. To simplify this, insurance companies sometimes make use of PCA or a layered aggregation structure.

5. European Insurance and Occupational Pensions Authority (April 2024). YE2022 Comparative Study on Market and Credit Risk Modelling. Section 5.2.2, Credit Spreads on Corporates and Sovereign Bonds. Retrieved December 27, 2024, from: https://www.eiopa.europa.eu/document/download/bf3de359-c9f4-4d95-8e0f-d0c8c908c169_en?filename=YE 2022 Comparative Study on Market and Credit Risk Modelling.pdf.

Credit risk modeling is an inherently complicated topic due to the availability and reliability of data. This often requires the use of expert judgment for topics such as correlation structures or capturing migration effects. The granularity of the bottom-up approach makes this even more complicated compared to a top-down approach. Below are different models for modeling the default, migration, and spread risk.

- Structural models attempt to mimic the actual causes of default based on the economic fundamentals of the borrowing firm. They are descriptive models that provide insights into the nature of default by linking it to underlying structural variables related to the firm. The probability of default is endogenous to the model, as default normally occurs when the value of the firm's assets hits a barrier indicating a default. They are, however, generally difficult to calibrate since they require strong assumptions and complex analyses. Examples include Merton model or KMV model developed by KMV Corporation or Credit Metrics developed by JP Morgan.
- Reduced-form models, also called intensity models, attempt to mimic the behavior of a company credit rating over time, with the aim of establishing a distribution for the time of default. The default is treated as a random event driven by stochastic process or statistical models that make use of market statistics (micro and macro data) rather than firm's data (default is exogeneous). Reduced-form models are generally simpler and more data-driven. Examples include the CreditRisk+ model developed by Credit Suisse Financial Products.

Exposure at default (EAD) and loss given default (LGD) are typical inputs needed by those models to determine credit risk. EAD represents the total amount of loss an insurer is exposed to in case of default. LGD represents the loss due to default as a percentage of the exposure and reflects recovery rates and collateral value.

The choice between reduced-form and structural approaches often depends on the objective, application, available data, and the level of understanding sought. Structural models are often used for corporate credit risk analysis while reduced-form models are commonly used for pricing credit derivatives and assessing credit risk in markets where detailed firm-specific data may not be available. Both types of models are used to determine economic capital related to counterparty default risk.

On top of the aspects discussed above, counterparty default risk for reinsurance contracts has two additional aspects. In the event of a default, the protection provided by the reinsurance contract is lost and needs to be replaced. This can result in replacement costs and uncovered losses until replacement is in place. This is referred to as "replacement risk." Another element of risk modeling for reinsurance is the interdependency between counterparty default risk and the volatility of the underlying collateral value. If these two move independently in opposite directions, this is referred to as "wrong way risk."

In Section 3, we introduced the concept of adjustment to the risk-free yield curve for non-default spreads present in SII, ICS, and other regulatory frameworks. When modeling non-default spread risk for assets, an insurance company must also decide how to reflect this on the liability side. Depending on how the adjustment for non-default spreads on liabilities is determined and how the insurance company reflects this in the risk model, it can lead to a loss exposure to downward shock in non-default spreads as opposed to an upward shock in spreads. As a result, the 2020 Solvency II Review explicitly sets a cap in the risk model on the benefit of non-default spread related adjustments on the liabilities.[6].

Market risk

For life insurance, the major drivers of market risk are interest rate, equity, inflation, non-default spread, currency, real estate, and asset concentration.

While market risk often focuses on assets, it is not meaningful for insurers without evaluating the impact on liabilities. This is sometimes referred to as asset-liability management (ALM) risk. The interaction between market risks and liabilities can take different forms:

- Changing asset yields could affect the market value of liabilities through the discount rate that is implicitly or explicitly derived.
- Changing asset yields could affect the amount and/or timing of future liability cash flows. Performance-linked bonus such as profit sharing is one of the examples.

6. Council of the European Union (January 2024). Proposal for a Directive of the European Parliament and of the Council amending Directive 2009/138/EC as regards proportionality, quality of supervision, reporting, long-term guarantee measures, macro-prudential tools, sustainability risks, group and cross-border supervision and amending Directives 2002/87/EC and 2013/34/E, p. 37. Retrieved December 27, 2024, from: https://data.consilium.europa.eu/doc/document/ST-5481-2024-INIT/en/pdf

- Changes in asset returns in the competing market may affect the amount and/or timing of future liability cash flows through changes in policyholder behavior such as excessive surrenders due to higher return in the competing market or additional premium payment to the existing products guaranteeing higher return compared to the competing market (cf. temporary lapses).

While measuring market risk faces fewer challenges than underwriting risk in terms of usability of historical data, it does have its own challenges. One aspect is the potential high dimensionality of market risk. For example, for equity risk, one needs to determine how many risk drivers are appropriate. Does one consider one risk driver appropriate for all individual equity risk exposures? Or does one differentiate by geographical segmentation or market segment? When dealing with a high dimension of potential risk drivers, an insurance company can make use of principle component analysis to reduce the dimensionality.

Another dimension that complicates measuring overall market risk is the dependency structure between the different market risks. It is widely accepted that correlations between market risk drivers are not linear, particularly in the tail. Copulas, described in more detail in section 6.2, can be used to deal with the nonlinear nature of the dependency between market risks. However, the choice and calibration of copulas is not straightforward and can be further complicated by high dimensionality.

Operational risk

Operational risk is an area still in development. It is difficult to quantify historical losses as a result of operational risk. As such, it is inherently difficult to measure operational risk. Regulatory regimes have taken different approaches to operational risk. Some take a quantitative approach while others are based on a qualitative assessment that may or may not lead to a capital charge. Modeling approaches currently in use are consistent with those from the banking industry and financial institutions, more specifically from the Basel II framework. They are classified as follows:

- **Standardized approach (or simple add-on model):** The model aggregates operational risk by combining the anticipated costs for the various identified operational risks. In order to apply an aggregation method to these risks, one must assume a certain degree of correlation and a certain confidence level. This factor-based approach is commonly applied by a regulator based on specified factors.
- **Advanced measurement approach (or stochastic frequency-severity model):** The main operational risks are captured in each business unit through scenario analysis with experienced staffs and risk managers. The scenario analysis process includes defining the story behind each risk scenario and determining frequency and severity parameters. These processes require a wide range of experience, information, and expert judgment.

The Standard Formula of Solvency II provides a standardized approach to quantify the operational risk, based on the amount of earned premium, best estimate liabilities, and incurred expenses. Insurers can also use their internal model to quantify the risk; however, given the difficulty of measurement, it is not uncommon for a company to rely on the Standard Formula approach. A qualitative assessment of governance, process, and data quality is also required under the second pillar (i.e., ORSA) as an indirect means of addressing operational risk.

The Swiss Solvency Test (SST) differs from the Solvency II framework for operational risk because the approach is qualitative in nature, with operational risk capital required only on a case-by-case basis.

The U.S. uses a factor-based approach based on premium or assets under management. This approach is close to the Standard Formula of Solvency II.

6. What modeling decisions should inform the analysis?

As seen in the previous section, there are a variety of models to calculate economic capital, and it is necessary to make a number of decisions for what type of models, techniques, and parameters should be adopted. This section goes through some of those issues typically relevant for economic capital calculation.

6.1 RISK MEASURES

The main risk measures that have generally been viewed as most suitable fall into two categories:

- Loss at a given quantile of a distribution: This is usually referred to as value at risk (VaR).
- Probability weighted loss beyond a given quantile of a distribution: This is often referred to as tail value at risk (TVaR), expected shortfall (ES), or conditional tail expectation (CTE). In this paper TVaR is used.

Other measures are also possible, such as the standard deviation of the losses that a company may suffer. All these measures are based on a view of the possible outcomes for the future level of solvency as a probability distribution. Even under a stress test approach, the stress on a particular risk component can be calibrated to correspond to a certain probability of occurring based on the underlying assumed distribution of that risk component.

VaR assesses the probability of ruin at a given quantile of the probability distribution over a specific period. An amount corresponding to a VaR with a 95% confidence level means that statistically we would be 95% confident that the loss would not exceed that amount. The VaR does not provide information about the magnitude of losses beyond the quantile.

TVaR considers both the probability and severity of losses that exceed a given quantile and is defined as the arithmetic average of losses exceeding a given quantile. For a 95% confidence level, the TVaR is the average loss in the worst 5% of cases. TVaR is adopted for market risk capital calculation is the United States.

Note that the definition of required economic capital provided in the opening section was effectively based on VaR. However, TVaR is also discussed as a possible measure for solvency capital and is used by some companies as a measure to assess economic capital. A limitation of VaR is that it is not subadditive under all conditions. Subadditivity is a desirable property for risk measures, and it means that a portfolio's risk exposure should be at most the sum of the risk exposures of its individual positions. For most stakeholders, a VaR approach may be considered sufficient, as most insurance companies hold a capital buffer in excess of the VaR. From a regulatory point of view, however, the magnitude of losses beyond the quantile used to determine the VaR could be significant because it will determine the losses to a policyholder if an insurance company is not adequately capitalized to bear the loss and has no means to attract more capital. Hence, losses beyond a certain quantile can damage the reputation of the insurance industry and the regulator. Regimes like Solvency II, which are VaR based, are designed in concept to intervene before the adverse scenario occurs. While the formal trigger for intervention may be 100% solvency ratio, most supervisors would start tightening supervision when the ratio is declining toward 100% solvency.

6.2 AGGREGATION OF RISKS

It is widely recognized that the total capital requirement could be less than the sum of the capital required for individual risks because of the potential correlations among individual risks. There are two main aggregation approaches:

- Calculation of capital requirements based on aggregation of the loss amounts for each risk stressed individually. Often these loss amounts are aggregated using a correlation matrix, in which case the calculation is a straightforward matrix multiplication.
- Calculation of capital requirements using an aggregated loss amount at the level of all risks combined. Under this approach, dependencies are applied between the risks themselves, rather than to the loss amounts. The capital requirement is then based on the loss for an extreme scenario. In practice, this entails creating a very large number of all-risk scenarios (such as hundreds of thousands) for each of which the loss amount is calculated. These loss amounts can then be ranked, and the appropriate extreme scenario can then be determined.

The first option is often referred to as the covariance approach. It is operationally attractive and usually provides intuitive results. Dependent on the correlations between the risks, significant diversification effects can be observed. Diversification effects exist at different levels in insurance groups: between subrisks (for instance mortality, longevity, expense, lapse) between main risks (market and insurance risks), and between entities. The determination of the correlations can be difficult and require a substantial amount of data. Stability of correlations over time and the level of the correlations are closely monitored by supervisors. The example in Section 7 (illustrative examples) shows the aggregation mechanism with the covariance approach.

A limitation of the covariance approach is that it assumes a linear correlation structure between the different risks. The second "all-risks" approach gives a more realistic view of the risk exposures in the capital requirement, particularly where other dynamics are at play (such as hedging strategies), or where correlation structures are non-linear. We have seen from our work that risk correlations can behave differently in extreme scenarios than they do across most of the probability distribution. For example, a limited movement in mortality may be largely uncorrelated to economic factors driving market risks, but large movements in mortality would be more likely to be correlated to market risks. A big earthquake or terrorist attack could cause a mortality/morbidity surge and a huge drop in asset market prices simultaneously.

Copula is a function used to describe the dependence structure between random variables. Mathematically speaking, a copula is a multivariate probability distribution function with uniform marginal distributions. Copulas can be applied to any kind of risk. A good example of the use of copulas is for default risk modeling, since it is convenient to use copulas to model clear historical evidence that more defaults occur when the market is bear than it is bull. This effect cannot be captured by a simple multivariate normal distribution with correlation matrix. Popular types of copulas are:

1. **Gaussian copula**: This copula is used due to its simplicity and ease of implementation. It assumes a multivariate normal distribution and is suitable for modeling linear dependencies. However, it may not capture tail dependencies accurately.
2. **t-copula**: Similar to the Gaussian copula but with heavier tails, the t-copula is useful for modeling dependencies in extreme events. It is particularly helpful in capturing tail dependence, which is crucial for assessing the risk of extreme losses.
3. **Archimedean copulas**: This family includes several copulas such as the Clayton, Gumbel, and Frank copulas. They are popular due to their flexibility and ability to model different types of dependencies, including asymmetric dependencies and tail dependencies. Each member of the Archimedean family has distinct properties:
   - **Clayton copula**: Good for modeling lower tail dependence.
   - **Gumbel copula**: Suitable for upper tail dependence.
   - **Frank copula**: Does not exhibit tail dependence but can model a wide range of dependencies.
4. **Vine copulas**: These are a flexible class of copulas constructed from a sequence of bivariate copulas. Vine copulas, including regular vines (R-vines) and canonical vines (C-vines), allow for capturing complex dependencies among multiple variables and are particularly useful in high-dimensional settings.

Each type of copula has its strengths and is chosen based on the specific characteristics of the dependencies being modeled and the nature of the risks involved. The choice of copula can significantly impact the accuracy of risk assessments. Companies leverage economic capital software tools that support the more sophisticated copulas.

While a copula function has such an appealing feature, there are sometimes difficulties when applying it to actual practices:

- There is no unique way to determine what kind of copulas should be used.
- There are multiple methods to assess goodness of fit of copulas to sample data points. Those methods include comparisons of likelihood functions and graphical comparisons of Monte Carlo simulation results with copulas to the sample data points.

Given that copulas have both benefits and drawbacks, an insurance company must make a conscientious choice based on the necessity to capture certain dynamics between risks. The following three effects can be motivation to opt for a copula-based dependency structure.

- **Tail dynamics:** Correlation in the tail can be different from correlation around the mean, leading to non-linear correlation.
- **Non-normal distributions:** In case of distributions with a heavy focus on the tail, such as those used for catastrophe risk, a simple covariance matrix-based aggregation of the individual shock amounts can lead to a misestimation of the joint shock.
- **Cross terms:** A cross term refers to a situation where the combined effect of a change in multiple underlying risk drivers is different than the sum of the marginal impacts of the individual changes. For example, if interest rates go down, the lower discount rate increases the present value of the expected cash flows. In a similar way, lower discount rates will increase the present value of the expected cash flows under a longevity shock scenario. As such, there is a cross term between interest rates and longevity risk.

In addition to the diversification effect of different independent risks within an insurance company, insurance groups with diverse businesses will benefit from group diversification benefits by the extent to which their different businesses have non-correlated risks. While such benefits are commonly recognized at an insurance group level, it is not self-evident that an insurance company within an insurance group benefits from group diversification. Depending on the purpose of the calculation, an insurance company may or may not recognize group diversification:

- For purposes of regulatory required capital, subsidiary insurance companies that are part of an insurance group are usually not allowed to recognize group diversification benefits unless they have a capital guarantee by the insurance group.
- For purposes of pricing insurance products, insurance companies may recognize that they are part of a larger group that benefits from group diversification. At the same time, the risks from entities in the group may need to be considered in the pricing.

6.3 TIME HORIZON TO CONSIDER

The approaches to modeling economic capital have tended to follow one of two methods in measuring risks and required capital:

- One-year time horizon
- Full portfolio run-off

Under the first method, the insurer could involve testing the solvency for a short-term shock such as a sudden movement in equity market or interest rates. The shock is calibrated to represent a specific quantile such as a one-in-every-200-year event. Hence, the amount of capital required to survive the shock is the amount needed to ensure continued solvency with this level of probability. It should be noted that a one-year change in certain risk factors can have an impact on cash flows beyond that one year. An example is the lapse rate. The lapse rate can change due to new information coming in over the year, such as market forecasts, which in turn affect the anticipated future lapse rates that underlie the liability value at the end of that year.

A full run-off approach can either be structured such that there is adequate capital throughout a certain percentage of these scenarios or only at the end of a certain percentage of these scenarios, which is specifically discussed in the following section. A multi-year time horizon can give deeper understanding of the long-term risk exposures. Given the longer projection horizon, there is the possibility of including some degree of management actions, such as asset rebalancing in the event of market falls or lowering dividend payments. However, it may be hard to allow realistically for the full range of possible regulatory and management actions on questions such as capital raising and hedging of risks.

Most jurisdictions that rely on a one-year time horizon have also moved toward a market-consistent approach for valuing the balance sheet and measuring risk. Combining the facts that: a) in a market-consistent approach, the balance sheet can be volatile due to market movements and b) these approaches tend to measure only a one-year risk horizon, it is important that the solvency position is monitored regularly. In such jurisdictions it is not uncommon for companies to calculate their economic capital on a quarterly basis, and some at an even higher frequency.

When modeling economic capital over a longer horizon, a decision needs to be made whether to ensure non-negative cumulative surplus only at the end of the time horizon, or at any time in the time horizon. Not allowing for a negative cumulative surplus in the middle of the time horizon is a stricter requirement and as such will yield a higher required capital. If a negative cumulative surplus in the middle of a time horizon is not allowed, one might consider relevant management actions as part of the risk assessment (discussed in the next section). Neither approach is necessarily superior to the other, as the approach needs to be considered in conjunction with the other choices made. In the case of a one-year approach, this aspect is often not explicitly considered, given the short time horizon. Instead, the focus is on frequent monitoring of the solvency position.

6.4 MANAGEMENT ACTIONS AND POLICIES

There are several management actions and policies that can have a material impact on economic capital. In this section we will describe the impact of management actions and policies related to some of the more impactful topics:

- New business
- Capital management actions and investment policies
- Loss compensating measures

New business

New-business-related assumptions can influence economic capital in multiple ways. For example:

- They can generate profits that can compensate for losses from in-force business.
- They can alter the diversification profile of an insurance company over time.
- They can provide capacity to carry future expenses.

Most regulatory regimes aim to assess the required capital of insurance companies based on the existing contractual obligation to policyholders without the inflow of new business. While the exclusion of new business is not typically in line with real-world expectations, the projection of new business requires subjective assumptions, i.e., how much new business is sold and the profitability of the new business. Such assumptions would introduce new risk in itself. For existing contracts, it is important to decide up until which point to project premiums and corresponding liabilities. This is often referred to as the "contract boundary." For example, if a contract has the option to be renewed after five years but the terms and conditions can be renegotiated, a decision needs to be made whether to stop projecting at this point or continue the projection of premiums and claims. In the case of the latter, decisions need to be made as to how the new terms and conditions will be set and how likely the policyholder will accept them. Regimes like Solvency II set the contract boundary at the point where:

- The premiums or contract can be terminated unilaterally, or
- The terms and conditions can be altered to the point that the premium can fully cover the risk at the portfolio level.

This definition of the contract boundary limits the ability of losses on in-force business to be compensated by future business.

While the recognition of profits stemming from new business may not be allowed by most jurisdictions, that does not mean that economic capital should be calculated assuming the insurance company is a closed-book business. For example, the assumption of going concern can affect expense assumptions. Without the inflow of new business, an insurance company would eventually be forced to reduce its operating expenses in line with the decline of the in-force business to stay operationally competitive. Such a decline in expenses may be deemed unrealistic if the in-force policies run off quickly. In case of a going concern, the incoming new business can carry expenses, leading to a situation where the reduction in expenses may be less severe or not needed and is therefore more realistic. A comparable situation exists for par business and the dividend payments.

Another area affected by a going-concern assumption is the diversification benefits. The more balanced the exposure of an insurance company to different products and risk types, the higher the diversification benefit between risks. However, not every product and its corresponding risks have the same duration. In a closed-book assumption, some products would run off faster than others, leading to a shift in the risk profile. This in turn would affect the diversification benefit over time. Such considerations can be relevant when modeling the risk over longer periods of time.

Investment policies are often modeled based on a going-concern assumption. When the current business runs off, assets would need to be liquidated in order to pay insurance claims, changing the asset mix, but with inflow of premiums from new business the investment activity would be different.

Capital management actions and investment policies

In case of a stressed scenario, companies can take several actions to protect the solvency position. They can increase their available capital by issuing new shares or subordinated loans. Alternatively, they can reduce their required capital through de-risking. De-risking can be done by changing the asset allocation to safer investments with a lower capital charge, hedging market risks, or reinsuring their insurance liabilities. Such measures do take time in practice and as such are usually not considered in regulatory capital calculations in jurisdictions where the required capital is determined on a one-year time horizon. When simulating the risk over a longer time horizon, the consideration of such action to be done with a certain time lag may be more valuable and realistic. From a modeling perspective, it is challenging to model an action that has yet to be formulated or implemented. It is, however, possible to model a future action/decision corresponding to an existing policy/guideline. While capital management actions may not be considered in the required capital calculation, they are usually considered when performing their ORSA or recovery/resolution planning.

Loss-compensating measures

There are some management actions in response to losses that are commonly considered in the calculation of the required capital. In the case of discretionary profit-sharing schemes, management may decide to pay out less profit sharing than they would in a best estimate scenario. Another consideration is that, depending on the jurisdiction, taxable losses may generate tax benefits in a shocked scenario. In the Solvency II regime, these measures are referred to as loss-absorbing capacity and are explicitly calculated as part of the required capital. The use of such measures does require documentation and evidence that these benefits can be realized. For example, a tax benefit in a loss scenario may only be utilized if post-shock an insurance company can generate enough taxable profits to utilize the tax benefit.

6.5 METHODS TO REDUCE COMPUTATIONAL COMPLEXITY

As discussed in Chapter 5, the most elaborate way to measure risk is through a full stochastic Monte Carlo simulation. Many insurance companies have recognized that modeling market risks can require capturing complicated dependency structures through copulas and thus have moved to (partial) stochastic Monte Carlo simulations for their economic capital models. Monte Carlo simulations are, broadly speaking, a three-step approach:

1. Generate scenarios
2. Value an asset/liability in each scenario
3. Analyze results from all scenarios focusing on either the mean or some type of tail metrics

The computational complexity of the Monte Carlo simulation is driven by:

- The number of risk drivers
- The number of scenarios required
- The complexity of the valuation process

As mentioned earlier in this paper, principal component analysis is a popular approach to reduce the number of risk drivers. For example, when modeling interest rate risk, it is important to consider the full-term structure of interest rates. Given the long nature of some life insurance products, this could mean projecting over 100 maturities of interest rates. Through the use of PCA instead, this high-dimensional data can be significantly reduced in dimensions while retaining trends and patterns. The method does this by transforming the original variables (i.e., time series per tenor) into a new set of variables called principal components. These components are orthogonal (i.e., uncorrelated) and are ordered so that the first few retain most of the variation present in the original dataset. These principal components are then modeled and projected and can in theory be translated back into the full-term structure of interest rates. This technique can be applied to a wide variety of high-dimensional data. The process works best on linear data of a similar scale with underlying distributions that are symmetric. PCA may also not perform well in case of heavy tail distributions. In case the data does not fit the optimal criteria, it is common practice to transform the data before applying a PCA.

A Monte Carlo simulation can require more than 100,000 scenarios. While there are techniques to reduce the number of scenarios, in practice this can be difficult because the full range of scenarios is needed given the potentially complex interactions between the risk drivers and the relevant percentile for the economic capital. Instead, most insurance companies have focused on simplifying the valuation process in each Monte Carlo simulation through approximations.

In general, the number of scenarios needed for the determination of the time value of options and guarantees can be less because the focus of that calculation is not on the tail of the distribution.

A common method used to simplify the valuation process in a given scenario is the use of curve fitting. The outcome of the curve fitting process are proxy functions, i.e. simplified mathematical models or functions that approximate more complex functions or processes. As an example, an insurance company can use this process to simplify the valuation of liabilities using the following steps:

1. Generate a number of scenarios of risk drivers (e.g., interest rates, equity prices, etc.).
2. Calculate the value of the liabilities in each of these scenarios using the full valuation method.
3. They can then fit a simple proxy function that approximates as a function of the risk drivers the value of liabilities.
4. The proxy function can then be used to calculate the value of liabilities quickly in each scenario of the Monte Carlo simulation to determine the economic capital.

Choices can be made in several aspects when executing the curve fitting process:

- How many scenarios to use for calibration, and how they are selected
- The choice of proxy function
- Whether to fit the present value or the expected cash flows
- Univariate fitting or multi-variate fitting

While calibrating on expected cash flows increases the complexity of the calibration due to the increased number of variables that need to be fitted, it has the advantage that the cross term between the cash-flow projection and the discounting is explicitly captured.

For options and guarantees, it is common practice to apply stochastic risk-neutral valuation procedures to determine the best estimate value. In this case, a least square Monte Carlo approach is typically used instead of curve fitting because it allows for more efficient use of calibration scenarios. For options and guarantees, the calibration scenarios require a nested Monte Carlo simulation, which is a Monte Carlo simulation where within each scenario another Monte Carlo simulation is performed. The first step of generating scenarios is referred to as the "outer scenario," and the scenarios simulated within each outer scenario are referred to as the risk-neutral or "inner scenarios." The least square Monte Carlo method is specifically designed to calibrate proxy functions for nested Monte Carlo simulations. It is essentially a curve-fitting process with considerably more outer scenarios and a very limited number of inner scenarios per outer scenario. A least squares regression is used to fit the proxy functions to the simulated data. The fit per outer scenario may be poor, but by generating a lot of outer scenarios, a proper calibration can be ensured. When applying curve fitting and least square Monte Carlo to the measurement of TVaR/CTE, extra attention needs to be paid to the calibration and fit. Compared to the application to a VaR measurement, significantly more calibration points may be needed to ensure a proper fit.

Other commonly used approaches are replicating portfolios and model point reduction.

- In this method the insurance liabilities are replicated using standard financial instruments such as zero-coupon bonds, call options and swaptions[7]. It is conceptually a curve-fitting process or least square Monte Carlo where the commonly used polynomial proxy functions are replaced with asset valuation functions. The main advantage of this method is that it gives a more intuitive understanding of the market sensitivities of the insurance liabilities and thus can also be used for other purposes, such as asset-liability management. The downside is that it only works for market risks and not for underwriting risk. For a complicated insurance product such as one with a combination of market and insurance options and guarantees, it can be challenging to find an appropriate asset-replicating portfolio.
- In the model point reduction approach a clustered file of contracts is constructed which is generally less 10% of the original volume of the portfolio. The reduced file is used to run the models for a limited scenario set to determine confidence levels. The already compressed set of contracts and outcomes can be used to further compress the set of contracts. With the last set of contracts, a full run of scenarios can be performed.

7. A swaption is an option that grants the right but not the obligation to enter into a predetermined swap contract (commonly for the purpose of replicating portfolios, European interest rate swaptions are used).

7. Illustrative examples

This section goes through some illustrative examples of capital requirement calculations:

- Capital requirement under Solvency II, i.e., the solvency capital requirement (SCR) calculation.
- Required capital using a copula for individual risk aggregation.
- Capital under U.S. statutory requirements (U.S. Stat).

7.1 CAPITAL REQUIREMENT UNDER SOLVENCY II - SCR CALCULATION

This section illustrates how European insurance companies would typically determine the SCR under Solvency II, using the Standard Formula. The example underlines the different steps, including determining the economic balance sheet, the calculation of individual risks, the aggregation process, the own funds estimation, and finally the Solvency II ratio.

Some simplifications and assumptions have been adopted (e.g., zero risk margin and no taxes) in order to focus on the main principles of capital requirement estimation rather than the technical aspects of the Solvency II framework.

Overview of the company in scope

Let's assume an insurance company based in Europe, ABC Life, operating in the lifetime annuity business. For regulatory purposes, the company has to determine the amount of capital requirement under Solvency II (SCR), the amount of own funds and its solvency ratio. The premiums collected are invested in bonds and equities.

At the valuation date, the economic balance sheet is as follows:

ASSETS (IN € BILLIONS)		LIABILITIES (IN € BILLIONS)	
Equity shares	7.5	Own Funds	10.0
Bonds	92.5	Technical Provisions	90.0
Total	**100.0**	**Total**	**100.0**

The technical provisions under Solvency II correspond to the sum of the best estimate of liabilities and the risk margin. A best estimate of liabilities of €90 billion has been calculated for the annuity portfolio. In this example and for simplicity, we assumed a risk margin of zero and corporate tax of zero.

The company is invested in bonds and equity shares. As these financial instruments are publicly traded, they are accounted for at their market value on the balance sheet (bonds at €92.5 billion and equity shares at €7.5 billion).

The own funds (or available capital) is €10 billion, corresponding to the difference between the total assets and the technical provisions.

Capital requirement (SCR shocks)

For simplicity, we assume that the company assets are invested in the European market to avoid the currency risk exposure. Bonds are 50% government issued and 50% corporate issued with AAA rating, and will be held until maturity.

The company would be exposed to the underwriting risk (longevity risk) due to selling annuity products and to the market risk due to its investments (interest rate risk, equity risk, and spread risk).

The Standard Formula of Solvency II provides the shocks to be applied for each of the risks identified that the company is exposed to as well as the correlation matrices to be applied to aggregate these risks in order to obtain the amount of total capital requirement.

SCR - Individual risks

The individual amounts of capital requirement correspond to the impact on the net asset value (NAV or own funds) resulting from the shocks. The table below present the results of each shock.

RISK-MODULE	SHOCK TO BE APPLIED	ASSETS AFTER SHOCK (€ BILLIONS)	LIABILITIES AFTER SHOCK (€ BILLIONS)	SCR AMOUNT (€ BILLIONS)
Market Risk				4.67
Interest rate risk	Non-linear shock (up and down) on the EIOPA yield curve [1]	Up: 87.62 Down: 96.85	Up: 85.96 Down: 93.59	0.84
Equity risk	39% drop of equity value [2]	Equity 4.57 Total 97.07		2.93
Spread risk	Drop of bond market value [3]	Total 98.03		1.97
Diversification Benefit				-1.07 [5]
Underwriting Risk	20% drop in the mortality rates [4]		Down: 91.17	1.17

1. For interest rate risk, both assets and liabilities are shocked in an up scenario and a down scenario. The amount of SCR corresponds to the maximum value (i.e., baseline versus shocked value), which is up in our example. The duration of assets and liabilities is very close. However, since it is not a perfect match, there remains a loss in an upward interest rate shock scenario, leading to an SCR for interest rate risk of 0.84.
2. The value of the equity shock depends on the equity category: (a) “global equity” for listed in regulated markets in the countries which are members of the EEA or the OECD, (b) “other equity” for equity listed only in emerging markets, non-listed equity, hedge funds, and any other investments not included elsewhere in the Solvency II market risk module. The shock applied in this example assumes that the equities invested into fall into the “global equity” category. The symmetric adjustment, a correction to the equity shock to account for cyclical movements in equity markets, is ignored for simplicity.
3. The value of the spread shock of bonds depends on the duration and a spread risk factor, which is function of the rating class of the bonds. The values are calibrated to deliver a shock consistent with a VaR 99.5% following a widening of credit spreads. For an “AAA” bond rating, which makes up of 50% of the bond investments, with a duration of 4.74, the spread risk factor is 0.9%. The instantaneous decrease of values in bonds due to the widening of their credit spreads corresponds to 4.27% of that portfolio.
4. As the insurance company focus is whole of life annuities in payment, its primary insurance risk is longevity risk. A downward shock on mortality rates of 20% increases the life expectancy of policyholders, meaning that the insurance company has to pay policyholders longer than expected.
5. The sum of the individual component of the market risk, i.e., interest rate risk, equity risk, and spread risk, corresponds to the undiversified risk amount (5.74). The amount of market risk (4.67), i.e., diversified risk amount, is calculated via a correlation matrix to allow for a diversification effect. In the Standard Formula the correlation matrix is dependent on whether the up or down interest rate shock is applicable. The difference between undiversified and diversified risk gives the amount of diversification effect (1.07). The company asset allocation strategy (7.5% of assets in equity and 92.5% in bonds – 50/50 between governments and corporates) is translated into a relatively large amount of capital requirement for the market risk. However, investing in various asset classes brings about diversification, which benefits the company through the diversification effect.

Correlation Matrix: Market “Up”

	INTEREST RATES	EQUITY	SPREAD
Interest Rates	1.00	0.00	0.00
Equity	0.00	1.00	0.75
Spread	0.00	0.75	1.00

The covariance approach determines the amount of capital requirement for the market risk using the market “up” correlation matrix for aggregating the individual risks.

$$SCR_{Market} = \sqrt{\sum_{i=1}^{3}\sum_{j=1}^{3} corr_{i,j} \times SCR_{risk\ i} \times SCR_{risk\ j}}$$

For simplicity, we assume only the company’s longevity risk exposure under the underwriting risk and have therefore neglected other risks such as lapses and expenses.

The individual risk results underline a large exposure to the market risk compared to the underwriting risk.

SCR - Individual risks aggregation

The overall capital requirement corresponds to the aggregation of the individual risks. It should be interpreted as the loss amount that the company is exposed to over a one-year time horizon with a 99.5% quantile.

For simplicity, we assume no operational risk and no loss absorbing capacity of technical provision/deferred taxes.

The Standard Formula provides the correlation matrix to be used to aggregate the individual risks.

Correlation Matrix: SCR

	MARKET RISK	UNDERWRITING RISK
Market Risk	1.00	0.25
Underwriting Risk	0.25	1.00

The covariance approach determines the amount of capital requirement using a correlation matrix for aggregating the individual risks.

$$SCR = \sqrt{\sum_{i=1}^{2}\sum_{j=1}^{2} corr_{i,j} \times SCR_{risk\ i} \times SCR_{risk\ j}}$$

The table below present the results of the individual risks aggregation.

	SCR AMOUNT (€ BILLIONS)
Market Risk	4.67
Underwriting risk	1.17
Diversification Benefit	-0.75
SCR – Capital Requirement	**5.09**

The SCR consists of predominately market risk, followed by life underwriting risk. The combined risks are offset by diversification benefits.

Own funds

The own funds (or available capital) of €10 billion corresponds to the difference between the total assets (€100 billion) and the technical provisions (€90 billion) whose values are calculated based on economic assumptions.

Under Solvency II, own funds exist out of three tier levels based on quality: Tier 1 capital is the highest ranking of quality, such as retained earnings and share capital, Tier 2 funds are composed of hybrid debt and Tier 3 comprises deferred tax assets. For simplicity, we assume that ABC Life's own funds are made of Tier 1 capital only.

	VALUE (€ BILLIONS)
Total Assets	100.00
Technical Provisions	90.00
Own Funds	**10.00**

Solvency II ratio

The Solvency II ratio corresponds to the ratio of the own funds to the SCR.

Own Funds	**€ 10.00bln**
SCR	€ 5.09bln
Solvency II ratio	196.7%

The Solvency II ratio of 196.7% shows that the company holds a capital buffer in excess of the SCR.

7.2 REQUIRED CAPITAL USING A COPULA FOR INDIVIDUAL RISK AGGREGATION

In this section we show that the choice of aggregation method has an impact on the SCR. Section 7.1 used the Standard Formula to calculate the required capital. The Standard Formula relies on the covariance method to aggregate risk. In Section 6.26.2 we discussed that copulas are a popular alternative method to the covariance method. This section focuses on the amount of required capital (RC) using a student's *t* copula to aggregate the company's risks. A comparison with the use of a covariance structure will be presented to underline the impact of using a copula. To make a relevant comparison between the copula and the covariance method, we consider one layer of aggregation instead of a multi-layered aggregation approach.

Required capital using a copula

Starting with the amount of RC for each individual risk estimated in section 7.1:

	SCR AMOUNT (€ BILLIONS)
Interest Rate Risk	0.84
Equity risk	2.93
Spread Risk	1.97
Underwriting (Longevity) Risk	1.17

We aggregate these individual risks using a student's t copula with the following assumptions:

- All risks listed above are normally distributed (with mean 0 and standard deviation of 1)
- Degree of freedom = 3
- Correlation matrix (consistent with section 7.1):

	INTEREST RATE RISK	EQUITY RISK	SPREAD RISK	UNDERWRITING RISK
Interest Rate Risk	1.00	0.00	0.00	0.25
Equity Risk	0.00	1.00	0.75	0.25
Spread Risk	0.00	0.75	1.00	0.25
Underwriting Risk	0.25	0.25	0.25	1.00

<u>T copula principle</u>

Let $\theta = \{(v, \Sigma) : v \in (1, \infty), \Sigma \in R^{m \times m}\}$ and let t_v be a univariate *t* distribution with v degrees of freedom.

The student's *t* copula can be written as $C_\theta(u_1, u_2, \dots, u_m) = t_{v,\Sigma}\left(t_v^{-1}(u_1), t_v^{-1}(u_2), \dots, t_v^{-1}(u_m)\right)$

Where $t_{v,\Sigma}$ is the multivariate student's *t* distribution with a correlation matrix Σ with v degrees of freedom, and the $u_i \in [0,1]$.

<u>T copula simulation process</u>

The input parameters for the simulation are (v, Σ). The *t* copula can be simulated by the following two steps:

1. Generate a multivariate vector $X \sim t_m(v, 0, \Sigma)$ following the centered *t* distribution with v degrees of freedom and correlation matrix Σ.
2. Transform the vector X into joint probabilities $U = \left(t_v(X_1), \dots, t_v(X_m)\right)^T$ where t_v is the distribution function of univariate *t* distribution with v degrees of freedom.

To simulate centered multivariate *t* random variables, we use the property that $X \sim t_m(v, 0, \Sigma)$ if $X = \sqrt{v/s}\, Z$ where $Z \sim N(0, \Sigma)$ and the univariate random variable $s \sim \chi_v^2$.

The simulation process begins with the Cholesky decomposition of the correlation matrix Σ. This decomposition transforms the correlation matrix into a lower triangular matrix, with zeros above the diagonal. Applying a Cholesky decomposition to a sample of independent normally distributed random variables creates a sample of normally distributed random variables that is correlated according to the original correlation matrix.

Required capital calculation

The total amount of economic capital is calculated using 100,000 simulations as follows:

1. Simulate the joint outcomes (i.e., probabilities) using the student *t* copula for each individual risk following the steps specified in "*t* copula simulation process"
2. Transform back to the marginal distributions per risk, which is a standard normal distribution in our case
3. Multiply by individual risks capital
4. Aggregate individual risks per scenario
5. Order the 100,000 simulations and take the VaR 99.5%

The step-by-step calculation is presented in the appendix of this document.

Result

We calculate an aggregate amount of required capital (RC) of €5.53 billion using a *t* copula and a solvency ratio of 180.8% that remains above the 100% threshold. The solvency ratio corresponds to the ratio of the own funds to the RC.

IN € BILLION	RC AMOUNT	OWN FUNDS	SOLVENCY RATIO
RC with the use of copula	5.53	10	180.8%

Comparison with the Covar structure

The covariance approach relies on the assumption of linear relationships and normal distribution of risks, which simplifies the aggregation of risk by focusing on variance and covariance. In contrast, a copula simulation approach can combine complex, non-linear dependent risks by using, for example, curve fitting or least square Monte Carlo. Additionally, non-normal copulas such as the *t* copula provide more flexibility in capturing joint distributions, particularly in the tails.

In this example we consider only one layer of aggregation to calculate the total amount of RC using the covariance structure instead of a multi-layered aggregation approach such as in example 7.1 (i.e., a first layer of aggregation to get the market risk [interest rates, equity, and spread] with a first correlation matrix and then we used a second layer of aggregation [and a second correlation matrix] to get the total SCR [market and underwriting]).

We calculated a total amount of RC of €5.15 billion using the covariance structure and €5.53 billion using a *t* copula. The aggregation of individual risks using a student's *t* copula increases the amount of required capital by 7.3%. This results in a decrease in the solvency ratio by 13.3%.

METHOD OF RISKS AGGREGATION IN € BILLION	RC AMOUNT	OWN FUNDS	SOLVENCY RATIO
Covariance	5.15	10	194.1%
Copula	5.53	10	180.8%

7.3 U.S. STAT

This section focuses on capital treatment in the U.S. market under the statutory regime. Although U.S. regulatory capital is largely formulaic and only parts "economic" in nature, the following section helps to illustrate some of the techniques and concepts used in U.S. RBC that also applies to economic capital modeling in general.

Some simplifications and assumptions have been adopted in order to focus on the main principles of capital requirement modeling rather than the technical aspects of the RBC and PBR framework.

Overview of the company in scope

Our European insurance company has decided to cede its entire block of annuity liabilities to a U.S. reinsurer, XYZ Re, on a 100% coinsurance basis. XYZ Re focuses on annuity liabilities, and has a book of variable annuity (VA) and fixed deferred annuity (FDA) business from a number of different cedants.

At the valuation date, XYZ Re's statutory balance sheet is as follows:

ASSETS (IN US$ BILLIONS)		LIABILITIES (IN US$ BILLIONS)	
Cash	40.0	Statutory Reserves	200.5
Common Equities	10.0	IMR	20.0
		Other Liabilities	49.5
Bonds	100.0	**Total Liabilities**	**270.0**
Mortgages	150.0	Surplus	30.0
Total Assets	**300.0**	**Total Liabilities and surplus**	**300.0**

Balance sheet overview

The U.S. statutory system is a book-value regime.

On the asset side of the balance sheet, where XYZ Re primarily holds a fixed income portfolio, asset valuation is done on a book-value basis.

On the liability side of the balance sheet, XYZ Re has the following components:

- Statutory reserves
  - Fixed Deferred Annuities (FDA)
    - As of 2024, FDA reserves are calculated with the Commissioners Annuity Reserve Valuation Method (CARVM) under the U.S. statutory regime. CARVM is set as the highest present value of benefits among possible policyholder behaviors, using the guaranteed interest rate. A prescribed discount rate is used in the present value calculation.
  - Variable Annuities (VA)
    - For VAs, VM-21 applies for statutory reserves and capital calculations.
    - Reserve and capital requirements are based on a stochastic valuation approach, calibrated at different levels for reserve and capital calculations, and an additional buffer amount calculated based on prescribed assumptions.
    - The stochastic reserve is calculated by taking the TVaR of the greatest present value of accumulated deficiencies in the projection across a set of real-world scenarios. In general, companies may use up to 10,000 equity and interest rate scenarios from a prescribed generator with prescribed parameters.
    - For simplicity, the buffer will not be calculated in this example.
- Interest maintenance reserves (IMR)
  - The IMR is a statutory reserve balance that is designed to amortize realized capital gains and losses from interest rate movement. The intent is to create a matching of assets and liabilities accounting treatment, recognizing that liabilities reflect a locked-in valuation interest rate appropriate at time of policy issue; the supporting assets should likewise have a locked-in book yield.

In this example, we have the following calculation results for the FDA and VA business:

CALCULATION	AMOUNT (US$ BILLION)
CARVM Reserve – FDA	100
TVaR 70(reflecting only existing hedges) – VA	105
TVaR 98(reflecting only existing hedges) – VA	120

However, for XYZ Re, which has a hedging strategy that meets regulatory requirements, the benefits of hedging can also be reflected in the reserves.

CALCULATION	AMOUNT (US$ BILLION)
TVaR 70 (with future hedging reflected) – VA	100
TVaR 98 (with future hedging reflected) – VA	110

Under VM-21, the stochastic reserve for VAs is calculated as follows:

$$Stochastic\ Reserve = TVaR\ 70\ (Best\ Efforts) + E\ \times Max(0, TVaR\ 70\ (Adjusted) - TVaR\ 70\ (Best\ Efforts))$$

where E is the “error factor” and reflects how the hedging strategy captures future risks. The better the hedging strategy is, the lower the error factor is.

For XYZ Re, with a well-managed hedging strategy that results in an error factor of 10%, the stochastic reserve held for the VA business is $100.5 billion.

Capital requirement (RBC)

The U.S. RBC framework is almost entirely factor-based, with the exception being the interest rate risk components (C-3) for selected products. For this illustrative example, only C-3 calculations for the VA block are shown.

Prescribed capital factors are applied onto book value asset balances, as well as reserve amounts, to calculate the four components of the RBC framework:

- Asset risk (C-1)
  - C-1o risk for fixed-income assets, C-1s risk for equities
- Insurance risk (C-2)
  - Not applicable for annuities (except payout annuities)
- Interest rate risk (C-3)
- Business risk (C-4)

For C-1 risk component, the factor-based calculation is as follows, based on asset balances and prescribed capital factors:

ASSET CLASS	AMOUNT (US$ BILLION)	RBC FACTOR (POST TAX)	RBC C-1 CAPITAL (US$ BILLION)
Bond – AA	25	0.35%	0.09
Bond - A	25	0.68%	0.17
Bond – BBB	50	1.27%	0.63
Commercial Mortgage Loan - CM1	150	0.76%	1.14
Total C-1o	250	0.81%	2.03
Total C-1s (Common Shares)	10	23.70%	2.37

For simplification purposes, the C-3 Phase I result for the FDA block is assumed to be 1.0% of statutory reserves.

For the VA block, the C-3 requirement is calculated as follows:

$$C - 3 = 25\%\ \times \big((CTE98\ (w\ Error\ Factor) - Statutory\ Reserve(w\ Error\ Factor)) \times (1 - Federal\ Income\ Tax) - (Statutory\ Reserve(w\ Error\ Factor) - Tax\ Reserve(w\ Error\ Factor)) * Federal\ Income\ Tax\big),$$

$$where\ Federal\ Income\ Tax = 21\%, and\ for\ this\ simplified\ example, Tax\ Reserve\ is\ assumed\ to\ be\ 92.81\%\ of\ Statutory\ Reserve$$

The C-4 risk component, also known as business risk, is comprised of prescribed factors applied on various balances such as life insurance premium, annuity considerations, and separate account liabilities. For simplicity, C-4 is assumed to be 0 for XYZ Re.

Therefore, we arrive at the following RBC risk charges.

RBC COMPONENTS	AMOUNT (US$ BILLION)
C1o	2.03
C1s	2.37
C2	-
C3	3.24
C4	-

The final capital requirement then includes diversification of the above components, through the following formula:

$$CAL\ RBC = C4 + \sqrt{(C1o + C3)^2 + C1s^2 + C2^2} = 5.78$$

RBC capital ratio

The RBC capital ratio is then calculated as follows:

Statutory Surplus	30
RBC CAL	5.78
CAL RBC Ratio	519%

Ultimately, the RBC ratio for XYZ Re is well above the regulatory intervention level of 200% RBC, is consistent with levels that would be deemed the target for a highly rated company, and overall looks to be in a very healthy position.

Internal capital

As part of its annual ORSA exercise, XYZ Re would also like to do its own assessment of its risks through an internal lens of capital.

Based on its internal analysis, XYZ Re’s view is that a different set of capital factors should be applied onto assets, and that insurance risk is best reflected by applying a lapse assumption shock onto its FDA block. Therefore, the intermediate capital calculations are as follows:

ASSET MIX	BOOK VALUE (US $BILLION)	INTERNAL CAPITAL FACTOR	INTERNAL C-1 CAPITAL (US$ BILLION)
Bond - AA	25	0.35%	0.09
Bond - A	25	0. 70%	0.18
Bond - BBB	50	1.30%	0.65
Commercial Mortgage Loan - CM1	150	0.77%	1.16
Total Fixed Income Capital	250	0.83%	2.07
Common Shares	10	25.00%	2.50

CALCULATION	AMOUNT (US$ BILLION)
PV of FDA Cash Flows at rfr[8] - Base Lapse Assumption	80
PV of FDA Cash Flows at rfr - Lapse Assumption + 20%	83.5

Therefore, the overall internal capital, with XYZ Re taking the same aggregation and diversification approach, is as follows:

INTERNAL CAPITAL	AMOUNT (US$ BILLION)
C1o	2.07
C1s	2.50
C2	3.50
C3	3.24
C4	-
Surplus	30
Internal Capital	6.83
Internal Capital Ratio	439%

[8] rfr = risk free rate

8. Appendix - Example 7.2 – Copula: Step by step

In this appendix, we present the step-by-step calculation of the required capital illustrated in Section 7.2 with an extract of 10 simulations.

8.1 INPUTS

We use the same inputs as specified in section 7.2.

RISK FACTOR	EC	TYPE RISK	DEGREES OF FREEDOM
Interest rate risk	0.84	Normal	3
Equity risk	2.93	Normal	3
Spread risk	1.97	Normal	3
Longevity risk	1.17	Normal	3

Correlation matrix

	INTEREST RATE RISK	EQUITY RISK	SPREAD RISK	UNDERWRITING RISK
Interest Rate Risk	1.00	0.00	0.00	0.25
Equity Risk	0.00	1.00	0.75	0.25
Spread Risk	0.00	0.75	1.00	0.25
Underwriting Risk	0.25	0.25	0.25	1.00

8.2 REQUIRED CAPITAL CALCULATION

The total amount of economic capital is calculated as follows:

1. **Simulate the joint outcomes (i.e., probabilities)**

   We simulate a student *t* copula for each individual risk following the steps specified in "*t* copula simulation process" of Section 7.2.

	INTEREST RATE RISK	EQUITY RISK	SPREAD RISK	LONGEVITY RISK
Simulation_1	0.45	0.37	0.59	0.43
Simulation_2	0.49	0.28	0.29	0.54
Simulation_3	0.90	0.48	0.32	0.53
Simulation_4	0.64	0.91	0.76	0.74
Simulation_5	0.35	0.69	0.54	0.24
Simulation_6	0.47	0.39	0.50	0.39
Simulation_7	0.19	0.75	0.60	0.32
Simulation_8	0.86	0.12	0.20	0.62
Simulation_9	0.31	0.73	0.77	0.23
Simulation_10	0.50	0.15	0.17	0.30

2. **Transform back to normal distributions**

We transform the probabilities into percentiles of a standard normal distribution for each of our risk.

	INTEREST RATE RISK	EQUITY RISK	SPREAD RISK	LONGEVITY RISK
Simulation_1	-0.12	-0.33	0.22	-0.16
Simulation_2	-0.03	-0.58	-0.57	0.09
Simulation_3	1.27	-0.05	-0.46	0.08
Simulation_4	0.35	1.33	0.70	0.65
Simulation_5	-0.39	0.51	0.11	-0.72
Simulation_6	-0.07	-0.28	-0.01	-0.27
Simulation_7	-0.88	0.67	0.27	-0.48
Simulation_8	1.08	-1.17	-0.85	0.30
Simulation_9	-0.51	0.62	0.75	-0.75
Simulation_10	0.00	-1.04	-0.95	-0.52

3. **Multiply by individual risks capital**

We multiply results from the previous step by its relevant economic capital (EC) to get the individual amount of required capital, considering the dependency with the other risks.

Since the individual EC represents the 99.5 quantile, we should also apply a factor to appropriately reflect it (i.e., divide our result by the 99.5 quantile of the normal distribution [≈2.576]).

	INTEREST RATE RISK	EQUITY RISK	SPREAD RISK	LONGEVITY RISK
Simulation_1	-0.04	-0.37	0.17	-0.07
Simulation_2	-0.01	-0.66	-0.43	0.04
Simulation_3	0.41	-0.06	-0.35	0.03
Simulation_4	0.11	1.51	0.54	0.30
Simulation_5	-0.13	0.58	0.08	-0.33
Simulation_6	-0.02	-0.32	-0.01	-0.12
Simulation_7	-0.29	0.76	0.20	-0.22
Simulation_8	0.35	-1.33	-0.65	0.14
Simulation_9	-0.17	0.71	0.57	-0.34
Simulation_10	0.00	-1.18	-0.73	-0.24

4. **Aggregate individual risks per scenario**

We aggregate each risk to obtain the total amount of RC by simulation.

	TOTAL RC
Simulation_1	-0.31
Simulation_2	-1.07
Simulation_3	0.04
Simulation_4	2.46
Simulation_5	0.21
Simulation_6	-0.48
Simulation_7	0.46
Simulation_8	-1.49
Simulation_9	0.78
Simulation_10	-2.14

5. **Order the simulations and take the VaR 99.5%**

In this final step, we order our simulations and take the 99.5 quantile.

The 99.5% quantile based on this sample of 10 is 2.14. Please note that for illustration purposes we have limited the number of simulations to 10. To estimate the 99.5% quantile accurately a significantly larger sample is needed.

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