YE2021 COMPARATIVE STUDY ON MARKET AND CREDIT RISK MODELLING

EIOPA-BoS/23-113
03 April 2023

European Insurance and
Occupational Pensions Authority

CONTENTS

1. EXECUTIVE SUMMARY

Market and credit risk contribute significantly to the solvency capital requirement (SCR) of insurance undertakings[1] and are also of material importance for the majority of internal model undertakings. Consequently, the EIOPA Board of Supervisors at the beginning of 2018 decided[2] to perform annual European-wide comparative studies on the modelling of market and credit risks, to be run by a joint project group of National Competent Authorities (NCAs) and EIOPA. Undertakings with a significant exposure to assets denominated in Euro and an approved internal model covering market and credit risk shall take part in this annual study.

The objective is to ensure a consistent and regular collection of information in order to carry out such comparative studies on internal model outputs efficiently, and have an up-to-date overview of the modelling approaches, as well as to further develop supervisory tools and foster common supervisory practices, in complement to national supervision, and as foreseen in the Solvency II Directive[3].

This report summarises the key findings from the market and credit risk comparative study (MCRCS) undertaken in 2022 based on year-end 2021 data and provides an insight into the supervisory initiatives being taken following the conclusions of this study.

The study focuses on EUR denominated instruments, but also looks into selected GBP and USD denominated instruments as well as the corresponding foreign exchange rate indices. The 20 participants from 7 different Member States cover close to 100% of the EUR investments held by all undertakings with an approved internal model covering market and credit risk in the EEA.

It is important to note that the study focuses on drivers of the value of investments, but does not aim to cover the overall SCR. In particular, specific undertakings' risk profiles, the dependency effects between market & credit risk and other risks, tax impacts or matching adjustment are intentionally not considered – with the purpose of directly assessing the study's key subject. These other aspects should, however, be taken into account when judging the relevance of findings. Hence, no direct conclusion could be drawn with regard to a specific undertaking's solvency position or the overall appropriateness of the model with this comparative study.

---

[1] Cf. e.g. page 28 of the report on the EIOPA Insurance Stress Test 2021: the capital requirement for market risk accounts for 85.4% of the gross basic solvency capital requirement before diversification benefits.

[2] Decision of the Board of Supervisors on the annual market and credit risk modelling comparative study' (EIOPA-BoS 18/062)

[3] article 122.4 recommends the use of benchmark portfolios based on external data or assumptions for supervisory purposes

Nevertheless, as in previous editions, this study based on simplified asset-liability-portfolios also puts focus on the analysis of interest rate ‘down’ movements, more relevant for liabilities. Furthermore, to achieve a more holistic picture, effects from the undertakings’ approach to the volatility adjustment (VA) are taken into account in the analysis of those portfolios.

As in past editions, the overall results continue to show moderate to significant dispersion in some asset model outputs, which could be partly attributable to model and business specificities already known by the relevant NCAs, but also indicate a certain need for continuous supervisory scrutiny.

This report is part of an ongoing process of monitoring and comparing internal models for market and credit risk. Refinements and enhancements are a regular and important part of the studies and are expected to continue. The results, tools and experience are feeding into the Supervisory Review Process (SRP) on internal models and vice versa. For example, data in the MCRCS format is not only used for the MCRCS itself but also to assess model changes or models in pre-applications.

As a final introductory remark, internal models under Solvency II are governed by strong regulatory requirements on statistical quality, validation, documentation, justification of expert judgements, internal controls and model change governance as well as reporting to supervisors and the public. On-going compliance with these standards is safeguarded under the SRP. As a consequence of the variety of business models and risk profiles and the freedom of modelling, a variety of models are being used which contributes to mitigating potential herding behaviour. Another consequence is that national supervisors, participants and further stakeholders need tools, such as European comparative studies, to be provided with a necessary overview of model calibrations, although the results and statistical key figures in this report shall not be regarded as calibration targets.

Main qualitative results

There are two main approaches used by undertakings to model market and credit risk: integrated approaches and modular approaches (cf. section 4). Additionally, certain aspects of credit risk modelling are visible on portfolio level only. The approach taken in the study therefore enables comparison and ensures that reliable conclusions can be drawn. In that spirit, this report mainly presents results under combined market and credit risk at the level of benchmark portfolios, supplemented with a drill-down analysis of facets of market and credit risk. Although the sample achieves nearly full coverage from a statistical point of view, the sample size (with 20 participants) is not large – and will remain so in the short term at least. Furthermore, some benchmark assets are not relevant or not material for certain participants. This in part led to the consideration of model outcomes of lower quality, causing distortions in some of the results, which is mitigated by the use of ‘relevance scores’ provided by the participants.

As for the last edition, participants were also asked about the consideration of sustainability in their modelling approach. Of 20 participants in the study, only two explicitly use a taxonomy of sustainable economic activities for asset modelling within their models.

Main quantitative results

For the combined market and credit risk charge, i.e. relative loss in value at the level of benchmark portfolios, some results show a sizeable variation between undertakings. In that respect, as a regular practice, supervisors engage with the undertakings in feedback meetings and will continue evaluating results at European level (see also 5.3 and 6). Parts of the observed variations can be attributed to risk management preferences. Drilling down from the level of benchmark portfolios into facets of risk and asset types confirms this.

For the drill-down analyses in section 5.2, undertakings with no exposure on a particular financial instrument were excluded to a large extent. This makes the results more meaningful. As a consequence, the overall modelling quality underlying the results presented also becomes higher.

Credit risk charges for sovereign bonds across groups of modelling approaches show relatively low dispersion for bonds issued by Germany, Netherlands, Austria, Belgium, and France. The dispersion is greater for the bonds issued by Ireland, Portugal, Spain, and Italy. These results are influenced by firms which show zero or low credit risk shocks across the instruments.

Credit risk charges for corporate bonds are generally higher for bonds with lower credit ratings and the dispersion increases materially with worsening credit quality. The dispersion becomes substantial for BB-rated bonds. This demonstrates the variety of modelling assumptions being taken by firms, particularly for low rated bonds.

With respect to equity risk, undertakings in general show less dispersion in the risk charges for major equity indices compared to risk charges applied to the strategic equity participation. Risk charges applied to the five real estate investments differ to a larger extent compared to equity. However, for asset categories like real estate, model calibrations might place more emphasis on the risk profile of the undertakings' actual investment portfolio and less on publicly available indices.

The analysis of dependency structures also leads to observations which will be taken up in supervisory work; detailed analyses are explained in section 5.2.6.

Way forward: Regular studies and fostering the Supervisory Review Process ('SRP')

Finally, the findings highlighted by the study confirm the need for continuous supervisory scrutiny, including at the European level. Consequently, EIOPA will further develop supervisory tools and foster the consistency of supervisory approaches.

2. OBJECTIVES OF THE STUDY

Market and credit risks contribute significantly to the solvency capital requirement (SCR) of insurance undertakings and are also of material importance for the majority of internal model undertakings. Consequently, the EIOPA Board of Supervisors at the beginning of 2018 decided to perform annual European-wide comparative studies on the modelling of market and credit risks, to be run by a joint project group of National Competent Authorities (NCAs) and EIOPA. Undertakings with a significant exposure to assets denominated in Euro and an approved internal model covering market and credit risk shall take part in this annual study. In addition, the definition of market and credit risks in terms of the fluctuations in the level and in the volatility of market prices of financial instruments is to a large extent common to most undertakings (e.g. identification of similar risk factors, use of the same or similar historic data).

The objective is to ensure a consistent and regular collection of information in order to carry out such comparative studies on internal model outputs efficiently, and have an up-to-date overview of the modelling approaches, as well as to further develop supervisory tools and foster common supervisory practices.

The principal objective of the year-end 2021 market and credit risk modelling comparative study was to further develop and refine European comparative studies as a supervisory tool in the area of market and credit risk modelling. This should support the supervision of internal models and foster the convergence of supervisory approaches given the potential choices of mathematical, statistical and IT solutions to tailor models to the actual risk profiles. The use of synthetic instruments provides a stable comparison point over time which is combined with an assessment of the relevance of these assets in terms of exposure and modelling for the participants. The study should also allow supervisors to analyse models, model changes, approaches and calibrations over time and spot potential trends. In practice, the tool has already been used by NCAs, or supervisory colleges when relevant, and the conclusions of the study have provided input to the Supervisory Review Process (SRP), for example with regard to internal model changes.

Given the complexities of the overall market risk modelling process and the different risk profiles of firms, the data should facilitate reviews of the overall dispersion of model outcomes as well as analyses of single model components (e.g. risk factor model) more deeply in order to explain the overall behaviour. More concretely, the objectives were:

1. Comparing model outputs for a set of realistic asset portfolios that should reflect typical asset risk profiles of European insurance undertakings, e.g. by country.

Although the focus is on the asset side, the setup of the study should be flexible enough to analyse different exposures against different interest rate movements (e.g. interest rate ‘up’ and ‘down’ shocks).

The metric of this comparison is the ratio of the modelled Value at Risk (99.5%, one year horizon) and the provided market value of the portfolio (this metric is called ‘risk charge’).

2. Highlighting the causes of the presumed dispersion in the risk charges by analysing additional information such as individual risk charges (e.g. individual asset classes such as Fixed Income, Equity, etc.).

When assessing the relevance of variations, it is important to distinguish the metric chosen (the ‘risk charge’) from the SCR, as the latter especially considers both assets and liabilities, their interrelations, dynamics and potential mismatches. Furthermore, actual business and risk profiles as well as risk and investment strategies have to be taken into account in the judgment.

3. PROCESS AND SCOPE

Process

A project group operationalised the objectives, deriving concrete goals and updating the data request and questionnaire to undertakings, which was collected by the NCAs responsible ('participating NCAs') including first checks.

The project group processed the answers from the undertakings and performed thorough data quality and sense checks, with the aim of ensuring the reliability of results. This step included feedback loops with undertakings and resubmissions when necessary. This also holds true for the analysis and its successive refinements.

The project group developed dedicated tools to process the data submitted by undertakings and to carry out the analysis of the benchmark portfolios and individual instruments. These tools mainly consist of a programme written with the open source language R. This programme allows the data from different participants to be aggregated into a single database. This database can then be filtered to extract specific information in the form of tables, or to plot it for further analysis and visual exploration.

The overall results were discussed in the supervisory community and dedicated feedback packages were prepared to be discussed with undertakings, initiating follow-ups if deemed necessary. Where relevant, the results of these discussions were collated by the project group and fed into this report. The lessons learnt will feed the setup of the next study editions.

Last but not least, insights, methods and tools developed for analysis, comparison, data processing and data quality checks, as well as collaborative experience, will feed into the supervision of the on-going appropriateness of internal models under the SRP and enhance the consistency of supervisory approaches.

Scope of the study: Risks

The subject of this study is the modelling of the market and credit risks related to investment instruments. As a consequence, the conclusions of the study enable a comparison between participating undertakings of model outputs for some of these risks only, and not in terms of overall capital requirements. In particular, several effects which drive the overall SCR are not considered in the study, such as the dynamics of liabilities under changing financial market conditions or tax impacts.

While the main components of **market** risk are interest rate risk, equity risk, property risk and currency risk, **credit** risk could be split into three components, namely 'default risk', 'migration risk' and 'spread risk', where the first is defined in this study as the risk from the default of the issuer of securities, the second as the risk from spread movements related to rating migrations, and the third as the risk from spread movements within the same credit rating class in the one year horizon. Market risk models usually include other sub-risks such as implied volatilities for equity risk and implied volatilities for interest rate risk, which are not included in the standard formula.

The data collected are composed of market values for a number of synthetic market instruments, as well as a few benchmark portfolios composed of a selection of these synthetic instruments. For each instrument and portfolio, the participating undertakings were expected to send the complete set of values generated by their model (scenario-by-scenario data or selected percentiles depending on risk type and modelling approach), in addition to the initial market value of the instrument and the 'modelled Value-at-Risk' (mVaR) estimate. For some participants, the mVaR may differ from the 99.5% sample quantile on the simulated asset values, due to the statistical estimator and, for instance, to the inclusion of interpolation or smoothing schemes. Participants were expected to provide an assessment of the relevance of each instrument for their own exposure, as well as in terms of modelling quality. This was supplemented by data on their own asset portfolio, implied volatility for derivatives, inflation risk and qualitative information about the model and the approach to the study to support the quantitative analysis.

Concerning the concentration/accumulation of exposures, most participants address concentration implicitly through the correlation matrix used in Monte-Carlo simulations or, less commonly, through concentration thresholds defined by the company in a specific policy. Some undertakings add an explicit mark-up/penalisation for concentration calculated with standard formula or with a specific model.

Scope of the study: Undertakings

As market and credit risk models within groups are typically uniform, the 20 participants from 7 Member States are mainly international insurance groups with an approved internal model at group level, covering market and credit risk, and with significant EUR exposure. The EUR investments (excluding unit-linked assets) of participants amount to 100% of the total EUR investments[4] of EEA internal model undertakings fulfilling these criteria. The total assets of participants amount to 35.2% of total EEA assets.

[4] Based on data submitted by EEA undertakings as of year-end 2021.

4. MODELLING APPROACHES AND LIMITATIONS

Qualitative analysis of modelling approaches

Two aspects are crucial for the interpretation of the results: first, the characterisation of various structural model setups and second, the modelling of the one-year time horizon in the risk measure of Solvency II.

Regarding the structural model setup, it is necessary to differentiate between 'integrated approaches' covering both market and credit risk in one sole simulation and 'modular approaches' covering most facets of market risk in one module while the remaining parts of market and credit risks are covered in another module. To simplify, we use the terms 'market module' and 'credit module' from this point forward. Also, the granularity of model outputs provided for this study varies along this dimension (for example, scenario-by-scenario data vs. aggregated data).

Twelve participants use integrated approaches while eight participants use modular approaches. Regarding the different sub-risks of credit risk, all undertakings using an integrated approach model pure credit spread risk, migration risk and default risk in the single market and credit risk module. Participants using modular approaches typically include credit spread modelling in the market risk module, except for two which include pure credit spread risk in the credit risk module and one which models all three components separately within the market risk module.

Therefore, in order to obtain meaningful comparisons, clusters of similar model approaches (integrated vs. modular) have been built for certain detailed analyses, reducing the sample size.

Furthermore, credit modules tend to use credit portfolio model approaches which tend to reveal the real risk charge only at the overall portfolio level and not at instrument level. For this reason, results are best compared and analysed at the combined market and credit risk level for portfolios.

With regard to the one-year time horizon required for Solvency II, two different approaches broadly exist. Fourteen participants apply 'instantaneous shock models' to their Solvency II balance sheets. Five[5] participants model their evolution of the balance sheets over the following year explicitly by taking into account 'ageing effects' for market and credit risk (for example, the remaining maturity of a bond is reduced by one year). One participant models a one-year evolution for credit risk but not for market risk.

[5] These five participants apply adjustments to their models for the purpose of the study to enable meaningful comparisons with 'instantaneous shock models'. This has to be taken into account in the use of these results with respect to the solvency capital requirement.

This needs to be appropriately considered in the definition of the respective risk measure, Value-at-Risk (VaR), underlying the solvency capital requirement (SCR) and it could deviate from a simple quantile estimator[6].

Regarding the use of the volatility adjustment (VA), eight participants do not use the VA, three participants keep the VA constant in the simulations and nine participants anticipate changes in the VA in line with the modelled credit spreads (‘Dynamic VA’, see also section 5.1.3).

Furthermore, the qualitative scores collected from undertakings to indicate exposure relevance showed that certain assets examined within the study were neither relevant to firms’ current or expected future exposures. Consequently, in certain detailed analyses, some undertakings which are not exposed to some instruments or which only provided rough proxies were excluded from the sample. This explains why the numbers of observations in the analyses, which are reported within graphs,vary and often do not cover the full set of participating undertakings.

Sustainability criteria

As for the previous editions, participants were asked about the consideration of sustainability[7] in their modelling approaches. Only two participants (of 20) indicated that they use a taxonomy of sustainable economic activities for asset modelling within their internal models. Although the remaining participants do not use a taxonomy for sustainable activities within their internal model, seven of them indicated they have developed or are in the process of developing such taxonomies[8] which are mainly for asset management purposes.

Moreover, participants were also asked about the consideration of physical risks from climate change[9] in their real estate modelling approaches. All participants stated that they do not explicitly consider this risk within their internal models.

---

[6] If modelling a one year evolution of the portfolio, the firms must take the expectation contained in their model approach into account. This can, for example, lead to the SCR being defined as the quantile of the distribution corrected by the mean.

[7] The concept of sustainability encompasses environmental issues that relate to the quality and functioning of the natural **E**nvironment and natural systems, **S**ocial issues that relate to the rights, well-being and interests of people and communities and **G**overnance issues that relate to the governance of companies. These are known as ‘ESG’ risks and factors.

[8] To define whether an economic activity substantially contributes to environmental or social objectives, and hence whether investing in the activity is sustainable, the European Commission is developing a taxonomy, i.e. a classification system for sustainable activities. Technical screening criteria will allow, for example, the definition of economic activities that can make a substantial contribution to climate change mitigation or adaptation, while avoiding significant harm to four other environmental objectives: sustainable use and protection of water and marine resources, transition to a circular economy, pollution prevention control, and protection and restoration of biodiversity and ecosystems. Other screening criteria will apply to define activities that contribute to social objectives. See: https://ec.europa.eu/info/business-economy-euro/banking-and-finance/sustainable-finance/eu-taxonomy-sustainable-activities_en#delegated

[9] Physical risks from climate change arise from a number of factors, and relate to specific weather events (such as heatwaves, floods, wildfires and storms) and longer-term shifts in the climate (such as changes in precipitation, extreme weather variability, sea level rise, and rising mean temperatures). Some examples of physical risks crystallising include: increased frequency, severity or volatility of

Limitations

Although the coverage of the study is very high in terms of exposure to EUR-denominated investments, from a statistical point of view the sample is not large, as it includes only 20 participants.

Regarding credit risk, the number of instruments and issuers could be considered low for exploring portfolio models, but this was deemed necessary for the sake of practicality for the participants and the analysis.

Additionally, because most of the analyses were performed considering only the asset side of the balance sheet, the risk charges presented in this report represent only capital charges for investments.

The study also includes an analysis that is extended to more realistic asset-liability exposures. Since the liability side is represented by a very simplified set of negative zero-coupon bonds, the risk charges should not be interpreted as or compared to Solvency II regulatory capital requirements which depend on the risk profile of each undertaking and take into account all features of the balance sheet.

Furthermore, the risk charges presented in this report take into account the diversification effects in the market and credit risk modules, but not the diversification effects with and among other risk modules. Similarly, the risk charges account for potential conservative margins attributed to specific risk factors (on the asset side) as used for the official SCR calculation; however, it does not account for potential margins added to the overall model outputs.

Taking into account the limitations described and given the differences between the business, investment, and risk profiles of the participants, the results of the study should not be considered as a calibration target.

extreme weather events impacting property and casualty insurance experience; and increased frequency and severity of flooding leading to physical damage household and commercial property, reducing its to the value as a financial asset or as a form of collateral held by banks.

5. RESULTS AND SUPERVISORY ACTIONS

General remarks

Aiming to cover integrated approaches as well as modular approaches, the key idea is to focus the analysis on the combined market and credit risk. The key metric chosen for comparison is the 'risk charge':

The **risk charge** corresponds to the relative reduction of the initial value based on the modelled Value-at-Risk on a one-year horizon ("mVaR"[10]) not taking into account effects from liabilities or tax, for instance. Therefore, it can be concluded that the findings of this report refer to the calibration of the models and not to the actual risk profiles of the undertakings.

Section 5.2 below contains information which is in some instances based on supplementary variables (e.g. interest rates and credit spreads). Here, the metric chosen for comparison is the 'shock':

The **shock** corresponds to a tail event of the underlying (marginal) risk factor distributions. For details on the derivation of the risk factor distributions from the value distributions please see footnotes 18 and 20.

More concretely, the absolute changes of a risk factor over a one-year time horizon are considered and depending on the type of risk factor the displayed shocks can either be two-sided (e.g. interest rates 'up/down') or one-sided (e.g. credit spreads 'up').

This metric takes into account the undertakings' individual risk measure definitions (in particular whether the mean of the distribution is taken into account or not) and is based on the 0.5% and 99.5% percentiles for two-sided risk factors and the 99.5% percentile for one-sided risk factors, respectively.

5.1. COMBINED MARKET AND CREDIT RISK, BENCHMARK PORTFOLIOS

[10] See above: the mVaR may differ from the 99.5% sample percentile on the simulated asset values, owing to the statistical estimator which can include, for example, interpolation or smoothing schemes.

5.1.1. BENCHMARK PORTFOLIO SETUP

For the purpose of the study a set of benchmark portfolios (‘BMPs’) was specified consisting of linear combinations of various synthetic fixed income, equity and real estate instruments (‘asset-BMPs’).

In order to extend the analysis to a more realistic asset-liability perspective, some of these asset-BMPs were combined with two very simplified portfolios of liabilities in form of risk-free zero coupon bond short positions (‘BMPLs’) with different durations. These asset-liability BMPs therefore contain both long and short positions and can be interpreted as a simplified representation of an insurer’s balance sheet (‘A-L-BMPs’). The different liability portfolio durations result in different hypothetical asset-liability duration gaps. Additionally the simplified liabilities were valued with and without Volatility Adjustment (VA) so as to give a first impression of the effect of using this measure on the risk charges. More concretely, the following steps were taken to construct the three BMP-types:

- **Asset-BMPs:** The BMPs were chosen in relation to real asset allocations of the insurance sector in the respective market. Therefore, the representative portfolios used by EIOPA to derive the volatility adjustment (VA), for year-end 2021 for EUR and seven country VAs, namely for BE, DE, ES, FR, IE, IT and NL, served as a basis for the target allocations[11]. The main criteria for the decomposition of fixed income instruments were sector (government, corporate), duration, maturity and credit quality step, using the usual mapping of ECAIs' credit assessments (‘ratings’) to credit quality steps (‘CQS’). To supplement these, two portfolios were constructed consisting purely of sovereign bonds in the first case and purely of corporate bonds in the second case, both with equal weights for all included instruments and leading in total to 10 asset-BMPs. Besides, only the most material and common financial instruments are used to construct these.
- **Liability-BMPs**: an extremely simplified representation of liabilities in terms of risk-free zero coupon bond short-positions. Two BMPs were set up in order to reflect different cash flow profiles. The maturity profile of these zero coupon bonds for BMP *L_D.long* was chosen in such a way to approximate the average cash flow profile of all European insurance undertakings (irrespective of segment: Life / Health and Property / Casualty) leading to a higher weighted average duration on the liability side compared to the fixed income assets (i.e. a ‘negative duration mismatch’). For BMP *L_D.short*, shorter dated zero coupon bonds were selected representing the average cash flow profile of the non-life liabilities of all European insurance undertakings, leading to a lower weighted duration on the liability side compared to the fixed income assets (i.e. a ‘positive duration mismatch’). It is important to note that the simplified

[11] The benchmark portfolios were constructed with the aim of mimicking the EIOPA VA representative portfolios. However, since the MCRCS portfolios are composed of a limited number of instruments the composition does not perfectly match the EIOPA VA representative portfolios.

liability portfolios do not capture potential asset-liability interactions, different kinds of products sold in the European market, loss-absorbing capacities of technical provisions or any other optionality.

- **Asset-Liability (A-L)-BMPs**: a subset of five asset-BMPs was combined with the two liability-BMPs and the liabilities were scaled in such a way that the net asset value of the A-L-BMPs reflected the average 'NAV to total assets' ratio across all European insurance undertakings (approx. 13%). This resulted in 10 A-L-BMP combinations which are shown in the following table. The suffix '*DG[-]*' and '*DG[+]*', respectively, indicates whether the A-L-BMP has a negative or positive duration gap when taking into account both asset and liability durations:

		Asset-BMP				
		A_EUR	A_DE	A_IT	A_SOV	A_CORP
Liability-BMP	L_D.long	EUR_DG[-]	DE_DG[-]	IT_DG[-]	SOV_DG[-]	CORP_DG[-]
	L_D.short	EUR_DG[+]	DE_DG[+]	IT_DG[+]	SOV_DG[+]	CORP_DG[+]

Table 1: A-L BMP combinations

Annexes 1 and 2 provide a detailed overview of the portfolio compositions.

From the graph below, it can be seen that the fixed income instruments of the BMPs have different maturity profiles and therefore lead to different portfolio durations:

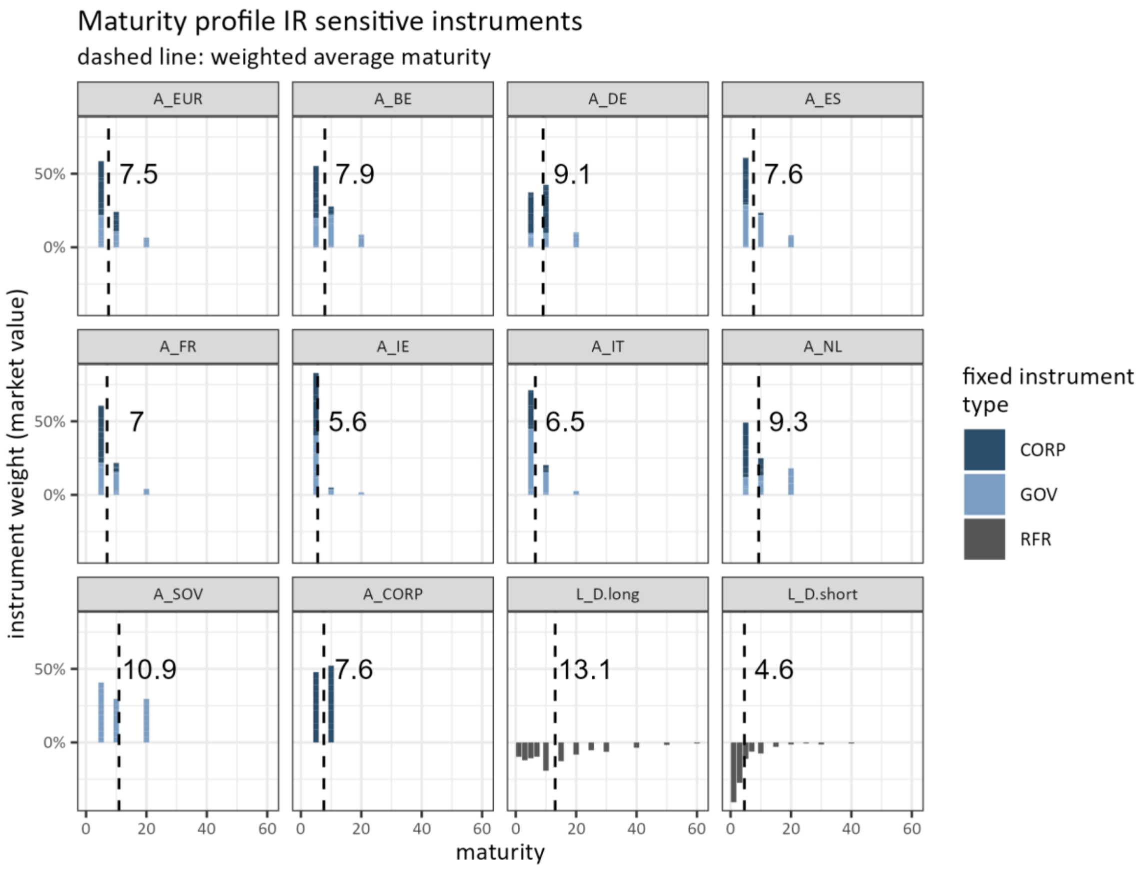

Figure 1: Maturity profiles of the asset-BMPs and the liability-BMPs

5.1.2. ASSET-LIABILITY BMPS

The following plot displays the risk charges for the A-L-BMPs in terms of loss in the net value compared to the total initial asset value. It shows the combined market and credit risk charges for the A-L-BMPs in the form of boxes ('boxplot'), bound by the 75% percentile at the top and by the 25% percentile at the bottom. This means that 75% and 25% of the risk charges in the sample are lower than the upper and lower line respectively. Additionally, the lines ('whiskers') at the bottom and the top indicate the 10% percentile and the 90% percentile, i.e. the plot covers 80% of the sample. Note that undertakings' results which fall outside of these 'boxes and whiskers' are not included in the chart. For reasons of interpretability and anonymization, boxplots in this report are only displayed if the sample size consists of at least four observations, otherwise only the sample size is displayed. The magenta coloured dot represents the BMP specific risk charge based on the currently applicable standard formula. The size of the sample is indicated in brackets underneath or above each box. The results presented in Figure 2 correspond to the approved internal model scopes regarding the treatment of the volatility adjustment (VA) and therefore offer the highest degree of comparability among the participants. More concretely, for undertakings using

- 'no VA' there is no VA-effect considered at all;
- 'constant VA', i.e. for the valuation of Technical Provisions but not modelling the VA explicitly in the internal model, a CVA-effect is considered;
- 'dynamic VA', i.e. for the valuation of Technical Provisions and also modelling the VA explicitly in the internal model, a DVA-effect is considered.

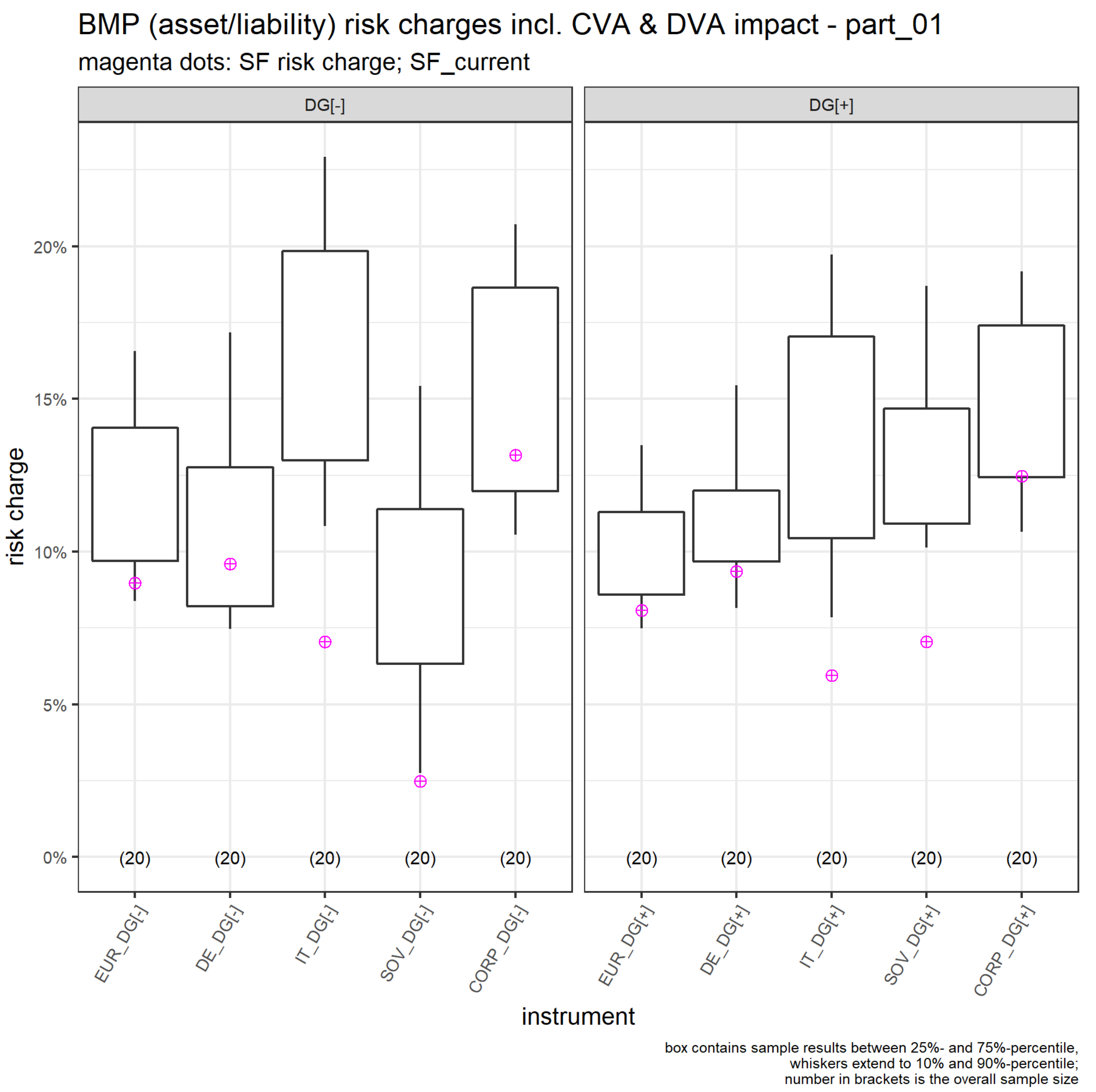

Figure 2: Combined market & credit risk charges for the asset-liability benchmark portfolios

Each of the boxes in Figure 2 covers a set of 11 out of 20 relevant participants[12]. Remaining participants are covered by the whiskers. The interquartile range (IQR), i.e. size of the boxes, for all A-L-BMPs ranges from 2.3% to 6.9%. This indicates a sizeable dispersion but at the same time there is no indication of risk charges using internal models being – globally speaking – systematically lower compared to risk charges using the standard formula. The dispersion is especially pronounced for *IT_DG[-]*, *CORP_DG[-]* and *IT_DG[+]* containing a large amount of sovereign exposure and in the case of *CORP_DG[-]* corporate exposure. The spread aspect will be explored further in section 5.2.2.

Due to the negative duration-mismatch, the A-L-BMPs ending with the suffix '*DG[-]*' are in general exposed to interest rate 'down' movements while those with the suffix '*DG[+]*' are exposed to interest rate 'up' movements, respectively. By and large, the dispersions are in a similar range irrespective of the duration gap, with exception of the *DE_DG[-]*/*DE_DG[+]* (Germany) where the IQR for the long liability duration is about twice as high as the short liability duration (4.6% and 2.3%, respectively).

Comparison to the Standard Formula

The standard formula is kept simple on purpose, in order to remain applicable for a broad range of companies. This means that some features can be captured only by internal models, e.g. for multi-currency portfolios and complex dependency structures between assets and liabilities. In addition, given that the interest rate environment remains low at the date of reference, the interest rate 'down' risk is not fully captured in the standard formula while all internal models take this into account. While the 2020 Solvency II Review proposal would increase the standard formula risk charges in Figure 2 (represented by dots), the general picture still would look similar, i.e. in most cases the standard formula risk charges would still be below or near the 25% percentiles. The selective comparison to standard formula does not imply that internal model companies could just switch to the standard formula, which can be inappropriate.

5.1.3. IMPACT OF THE DYNAMIC VOLATILITY ADJUSTMENT

The VA is applied to the risk-free interest rate curve under Solvency II. Application by undertakings is optional, and in some Member States its application is subject to approval. The value of the VA depends on the currency (and possibly the country) of the liabilities; and is set by EIOPA based on a

[12] This subset of participants can differ from BMP to BMP

formula using the average credit spread on reference portfolios of fixed-income instruments[13]. Given that the VA depends on credit spreads, some internal model undertakings dynamically model the VA using their market & credit risk model, i.e. letting the VA move in line with the modelled credit spreads – this is called the 'dynamic VA' (DVA) approach[14]. When an undertaking keeps the VA constant in its model, it is called a 'static' or 'constant' VA approach[15] (CVA).

In order to disentangle this DVA effect in the results from Figure 2, the following graph splits the results into the subsets of 'DVA-users' and 'Non-DVA-users', the latter including CVA-users. The vertical axis displays again the 'risk charge'. For comparison, the risk charge given by the standard formula is shown as a purple dashed line.

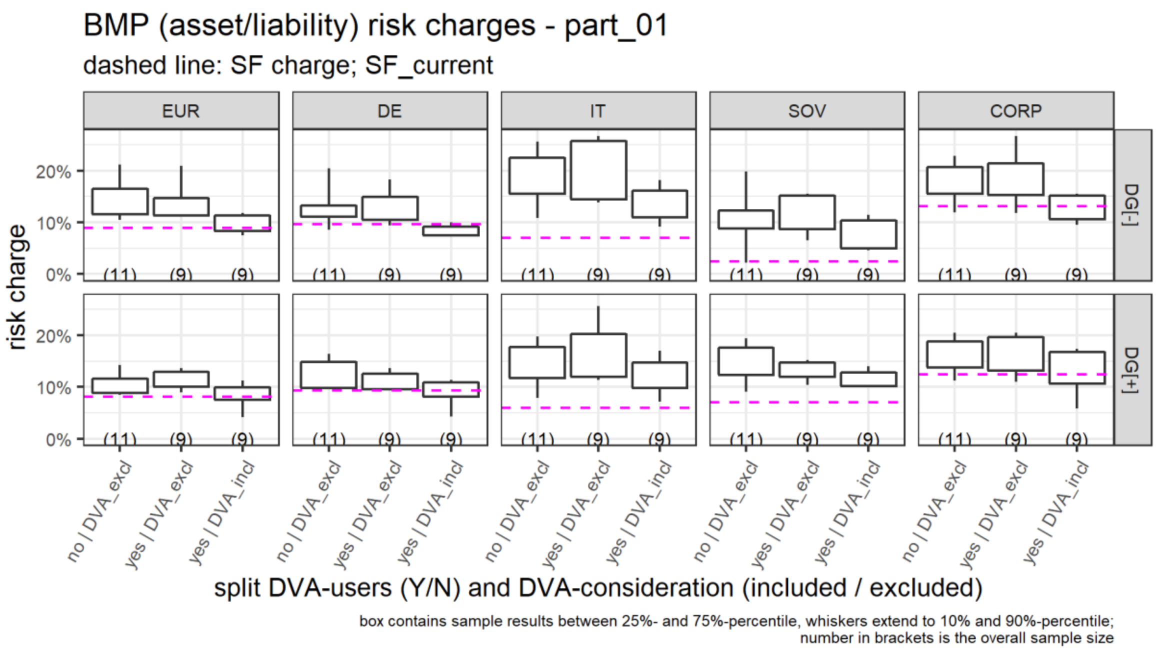

Figure 3: Risk charge for simplified asset-liability portfolios separately for non-dynamic VA users and for dynamic VA users (for these without ('excl') and with ('incl') dynamic VA impact); the upper row contains A-L-BMPs with negative duration gaps (*DG[-]*) while the lower row contains those with positive duration gaps (*DG[+]*).

The box on the left-hand side of each plot shows the risk charge for 11 models not using a DVA in their model setup (three of those including a CVA effect). The boxes on the right-hand side convey

[13] Please refer to section 8.A of the RFR Technical Documentation https://www.eiopa.europa.eu/sites/default/files/eiopa-bos-21-475-technical-documentation.pdf

[14] Please refer to EIOPA Opinion on the supervisory assessment of internal models including a dynamic volatility adjustment https://www.eiopa.europa.eu/sites/default/files/publications/opinions/2017-12-20_eiopa-bos-17-366_internal_model_dva_opinion.pdf

[15] Among the undertakings covered by this study, eight do not use any VA in their internal model calculations, nine use a dynamic VA, and 3 use a constant VA.

the impact of activating the dynamic VA mechanism (for those models including a DVA). While for the A-L-BMPs with negative duration gaps the dispersion seems to decrease, the opposite seems to be the case for some of the A-L-BMPs with positive duration gaps.

As mentioned above, the various A-L-BMPs show different levels of dispersion. Excluding the DVA-effect for the DVA-users would increase this dispersion and significantly increase the risk charges.

5.1.4. ASSET-BMPS

The following graph displays the risk charges for the different asset-BMPs.

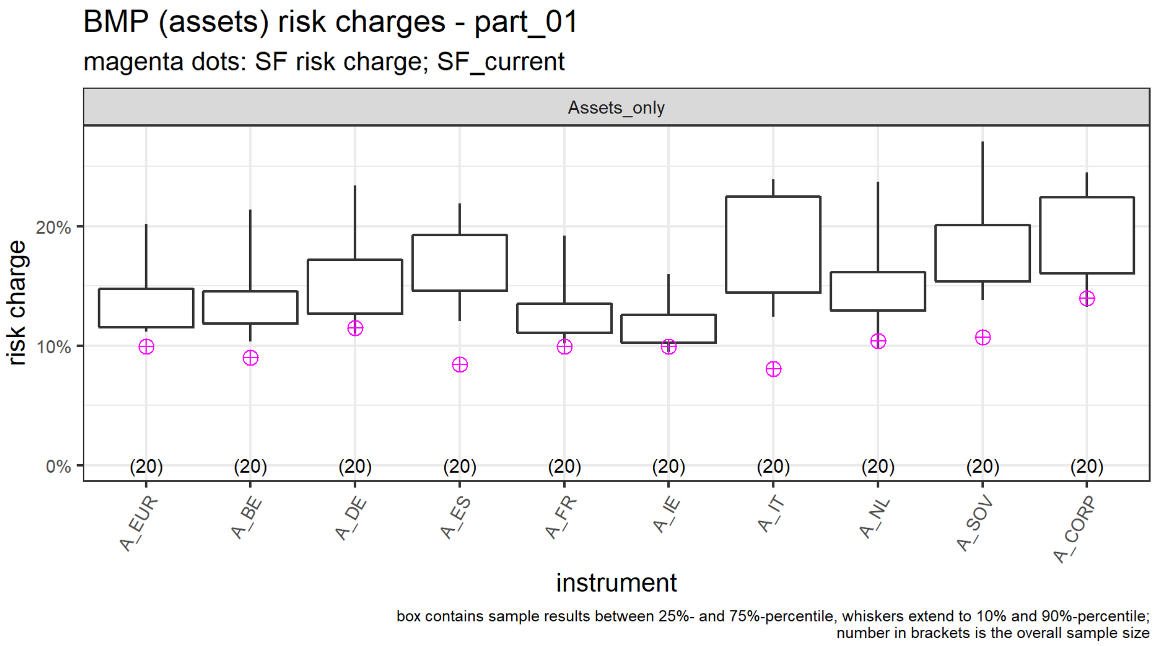

Figure 4: Combined market & credit risk charges for asset benchmark portfolios

Figure 4 shows moderate dispersions for most BMPs and a slightly higher dispersion for BMP *A_IT* which is consistent to the A-L-BMP results in section 5.1.2 and the government credit spread dispersions shown in Figure 8. At the same time the risk charges give no indication of internal models producing – globally speaking – systematically lower risk charges compared to the standard formula. The IQR ranges from 2.3% to 8.0% (with a mean of 4.2%). The highest IQR (8.0%) is observed for BMP *A_IT* , the lowest IQR (2.3%) for BMP *A_IE*. Almost all asset-BMP risk charges are higher compared to the standard formula. This holds especially for BMPs with a dominant weight of sovereign bonds (e.g. BMPs *A_ES*, *A_IT* and *A_SOV*) and is explained by the fact that for sovereign bonds credit risks are generally reflected in internal models, in contrast to the standard formula[16].

5.1.5. LIABILITY-BMP (BMPL)

Two BMPLs were introduced particularly to analyse interest rate 'down' movements, also in the combination of different maturities and different portfolio durations (e.g. in combination with the asset BMPs resulting in positive and negative asset-liability 'duration gaps'). Stand-alone results for the BMPLs and plots are presented in section 5.2.

5.2. DRILLING DOWN

Despite the limitations in model comparison due to differences in model types (see section 4), certain facets of market & credit risk were analysed, especially interest rate risk, spread risk, equity and property risk, to support the analysis of benchmark portfolios (BMP) and their individual calibration. Additionally, analyses performed on currencies other than the EUR as well as on derivatives and intra-market risk dependency are presented in this section.

5.2.1. INTEREST RATES – RISK FREE

Unlike the standard formula, interest rate risk in internal models does not only comprise two scenarios, 'up' and 'down', but a large set of simulated variations (including a change in slope and curvature of the interest rate curve). Internal models are also in general able to adapt more rapidly to market changes.

For Euro risk free rates, the starting curves for these simulations in the liquid part are essentially identical across participants, but differ in two cases. In these two cases there are slight differences in the liquid part of the curve, while main differences lie in the extrapolated part, for which there is no convergence to the EIOPA UFR. For one participant the extrapolation appears to be essentially flat[17], while the other uses a different UFR. Although the EIOPA risk free rate curve is used by all undertakings for the valuation of technical provisions, for these undertakings, the derivation of 'shocked curves' does not start from the EIOPA curve. Such a modelling choice is not considered to be critical per se: for certain assets and liabilities exposures to only the liquid part of the curve might be relevant for calculating the risk, in other cases the modelled variations are independent from the

[16] All internal model results in this sub-section are purely related to the asset side, i.e. they do not include the risk-mitigating effect of the 'dynamic volatility adjustment' which is applied by some undertakings. For details see previous sub-section.

[17] I.e. essentially constant spot or forward rate after the last liquid point.

base curve or the same base curve is used for assets and liabilities, based on market information, consistent with the classification of risk in the risk management system.

Unlike the standard formula, all models allow for negative interest rates and also allow for shocks to negative rates.

When restricting the comparison to single maturities, some dispersion in shocks can be observed. But as interest curve movements in general are more complex, this observation will partly require re-assessment (see analysis on the liability portfolios below).

The following graph illustrates the observed spectrum of marginal downward and upward shocks per term node in the sample for a EUR risk free rate:

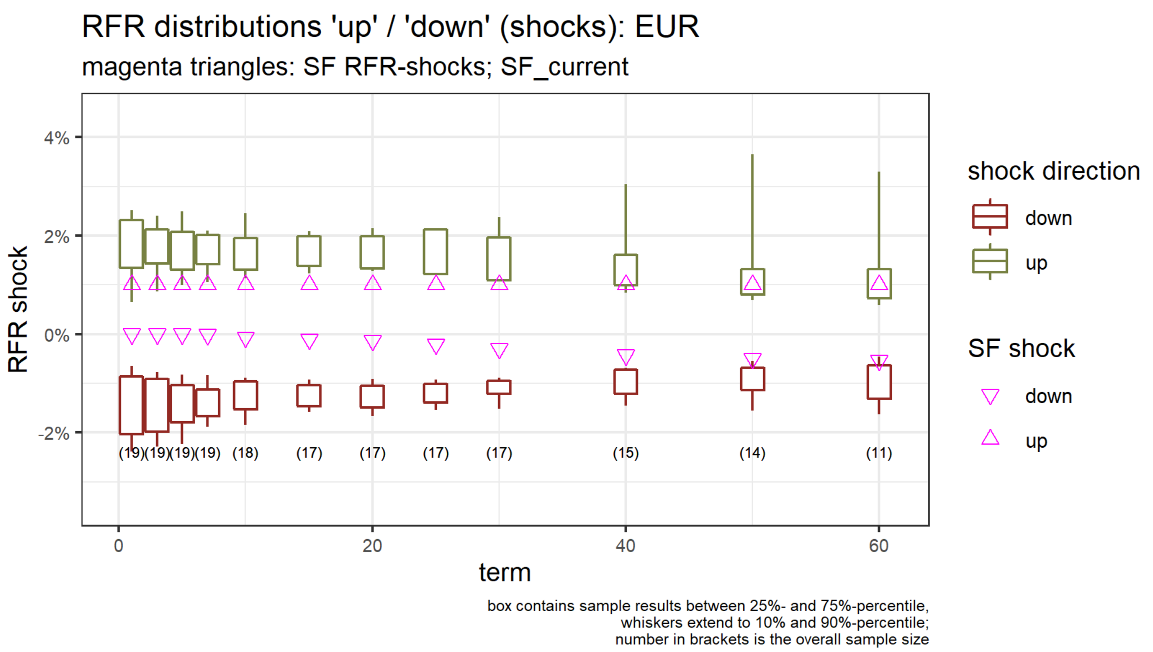

Figure 5: Downward and upward shocks on the spot rates for EUR risk free rates for single maturities (i.e. 'marginal' shocks on single nodes, not shocked curves) restricted to firms reporting an exposure

Figure 5 displays shocks on the initial spot rate[18] for selected maturities from the sample of participants. But note that these shocks are marginal, i.e. in only one dimension. This differs from the shocks underlying the risk charges for BMPLs presented below.

Figure 5 only depicts the results of those participants that stated at least some exposure for the underlying zero coupon bond for the respective maturity. This means that the graph is based on the

[18] Spot rates are derived from risk free zero coupon bonds by discrete compounding, e.g. for maturity T and currency ccy: $spot\ rate(ZCB^{rf}(T,ccy)) = \sqrt[T]{\frac{notional(ZCB^{rf}(T,ccy))}{value(ZCB^{rf}(T,ccy))}} - 1$. For the 'shock'-definition see the beginning of section 5.

input for a varying numbers of participants (11 – 19) for the different maturities, also leading to a varying number of participants included in the boxes and whiskers. It can be observed that the longer the underlying maturities the fewer the participants reporting exposure. In comparison to year end 2020 some participants show a higher shock which leads to a higher dispersion in the sample.

A similar analysis has been carried out for GBP and USD, which is presented in section 5.2.4.

Considering the proposal for interest rate shocks in the 2020 Solvency II Review, the plot changes slightly: the marginal up-shocks proposed as for the Standard Formula, especially for short terms, and the down shocks for most of the terms, increase.

As stated above, movements of yield curves are more complex than variations in single maturities. To further explore these aspects, the study also comprises two simplified portfolios of short positions in risk free instruments. One portfolio was derived from the cash flow profile and duration of the combined liabilities of all European insurers ("BMP *L_D.long*"). The second one has a shorter duration (4.6 years compared to 13.1) and was derived from combined non-life and Non-SLT-health[19] liabilities only ("BMP *L_D.short*"). They can be thought of as simplified and deterministic liability portfolios (cf. also section 5.1.2, Asset-Liability BMP). Evaluating these portfolios is a first step in analysing the characteristics of interest rate modelling beyond parallel shifts, although it only provides a global picture of the aggregated impact of the modelled rate curve shapes.

The following graph shows, similar to BMPs, the relative risk charge:

[19] Health business written on a similar technical basis as non-life insurance (i.e. short term business)

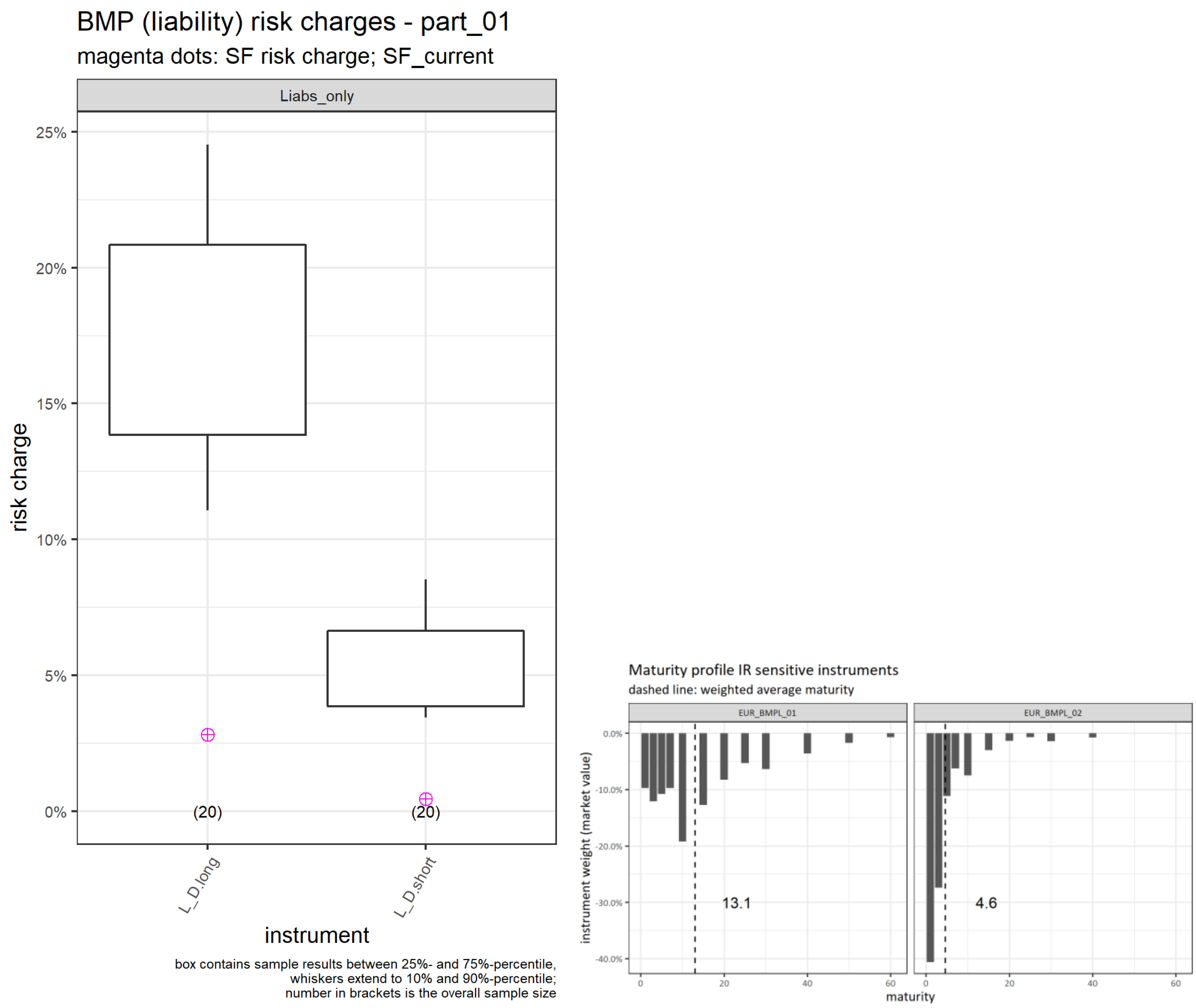

Figure 6: Risk charges and maturity profiles for the simplified liability portfolios (short position in risk free rates, no options and guarantees)

The boxes show that for 50% of this sample (comprised by the box, excluding the whiskers) the risk charges for BMP *L_D.long* lie between 13.8% and 20.8% and for BMP *L_D.short* between 3.8% and 6.6%, i.e. a dispersion of 7% for BMP L_D.long and a dispersion of 2.8% for BMP *L_D.short*. 80% of the sample (represented by the box and the whiskers) show dispersions of 13.5% for BMP *L_D.long* and 5.1% for BMP *L_D.short*. The portfolio with the longer duration exhibits higher risk charges as well as a larger dispersion, which is primarily driven by the fact that from a fixed income valuation perspective a higher duration implies higher absolute value changes and therefore variations at longer maturities are amplified. The risk charges for both BMPLs are significantly higher compared to the standard formula. Indeed, the interest rate environment remains at a low level despite the recent increase, and internal models reflect this more appropriately. It should also be noted that looking solely at an asset or liability portfolio does not capture the impact of rate curve movements on the combination of assets and liabilities, as encountered in an undertaking's balance sheet.

5.2.2. CREDIT SPREADS ON CORPORATES AND SOVEREIGN BONDS

The study required participating undertakings to submit values on the modelled credit risk associated with a selection of synthetic corporate and sovereign bonds. Unlike the standard formula, credit risk for sovereign bonds is, in general, modelled by the participants.

The values of corporate bonds and sovereign bonds are driven by the overall risk-free interest rate level and by the instrument-specific credit risk. The study has been structured to enable these aspects to be differentiated.

However, analysis of the observed credit risk charges is complicated by the different model types encountered. In particular, model outputs for the integrated models have generally covered all facets of credit risk while model outputs for modular approaches do not provide data on migration risk or default risk at the single instrument level.

The analysis of credit risk modelling focused on credit spread information which was derived from the data submissions[20]. Analyses have been grouped as follows:

Participating undertakings were combined into two groups: undertakings using an integrated modelling approach, for which instrument-level data on credit spread risk, migration risk and default risk is covered in one simulation; and undertakings using a modular approach, for which the market module was used to provide instrument-level data, covering, in general, only credit spread risk.

Corporate bonds were split into three groups: financial, non-financial and supranational.

In the following analysis we have, as previously mentioned, excluded the subset of participants in the plots who reported no exposure to the underlying bonds. Therefore, the number of participants captured in the figures will once again vary and be smaller than the whole sample.

Corporate bonds

Data submitted by firms reveal certain risk factors which are important drivers of modelled credit risk charges and others which are not. Significant variations in firms' sensitivity to certain risk

[20] Credit spreads are calculated from the credit risky zero coupon bond values analogously to spot rates but subtracting the risk free portion from the yield.
For example, for maturity T and currency ccy:

$$credit\ spread(ZCB^{risky}(T,ccy)) = \sqrt[T]{\frac{notional(ZCB^{risky}(T,ccy))}{value(ZCB^{risky}(T,ccy))}} - spot\ rate\big(ZCB^{rf}(T,ccy)\big) - 1.$$

As, in general, quantiles from risk-free and risky instruments do not coincide, spreads are calculated on scenario-by-scenario data. This data includes market and credit risk for integrated modelling approaches and market risk for modular approaches. For the definition of 'shock' see the beginning of section 5.

factors, such as bond credit ratings, were observed. Mixed treatments of bond durations and bond seniority (covered or unsecured) were evident from the results.

At the highest level, a variety of expected features was observed in the submitted data. Comparing across the groups of modelling approaches, credit risk charges at an instrument level were generally higher for those firms using an integrated approach ('case A', covering all facets of credit risk in an integrated simulation) versus those using a modular approach ('non-case A', for which only credit spread risk can be analysed at an instrument level). Credit risk charges were also generally higher for bonds with lower credit ratings.

Moreover, there may be differences in the credit quality used for corporate bond modelling, e.g. based on the issuer, based on the issuance or based on the current market spread. It is also evident that different views on default and recovery rates (for sovereigns and corporates) do and should exist.

Furthermore, deviations in results could also be caused by an undertaking specific elasticity of risk charges over the due dates. This is basically attributable to the understanding and the implementation of main principles like "through the cycle" / "point in time" in models and calibrations.

The following graph demonstrates the dispersion of modelled credit risk charges depending on the type and credit quality of 5-year financial corporate bonds. The dispersion increases materially as the credit rating underlying the bond decreases and becomes substantial for BB-rated bonds. This demonstrates the variety of modelling assumptions being taken by firms, particularly for low rated bonds.

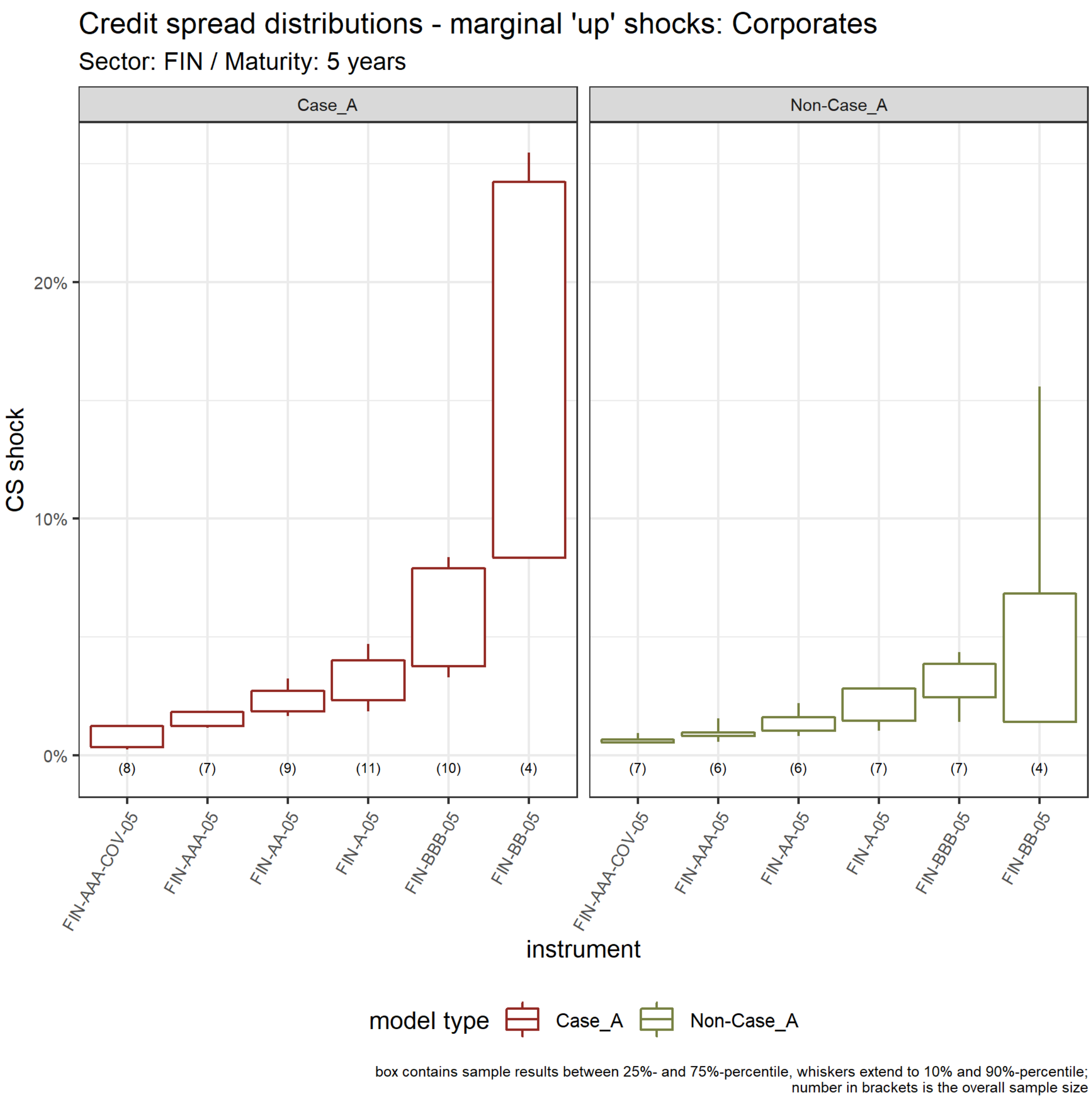

Figure 7: Credit spread marginal 'up' shocks for financial corporates on instrument level: integrated approaches ('case A') with all facets of credit risk, modular approaches ('non-case A') without migration & default restricted to firms that reported exposure

Other notable features observed:

- Comparing 5Y and 10Y bonds, the differences in modelled credit spread shocks generally depend on the modelling approach and the bond's credit rating:
  - For firms using a modular modelling approach, for which, in general, only credit spread risk was analysed, modelled credit spread shocks were similar for 5Y and 10Y bonds across all credit ratings.

  - For firms with an integrated modelling approach, for which all facets of credit risk were analysed, modelled credit spread shocks were, on average, lower for 10Y bonds than for 5Y bonds. The difference was seen to become larger as the credit rating declined, especially for those attributed to the financial sector.

- For approximately half of firms, models consistently produced higher credit risk charges for financial bonds than for the equivalent non-financial bonds. For the other firms, no appreciable difference was observed.
- For approximately half of firms, models produced a lower credit risk charge for covered bonds than for the equivalent unsecured bond, while no appreciable difference was observed for the remaining firms.
- Regarding the higher dispersion in risk charges for lower rated bonds, we point out that the high-yield market is very segmented, similar as for real estate, and the internal model calibration of companies may depend on the targeted high-yield segment. This might explain the dispersion in the calibration for BB-rated bonds.

Finally, the study specified a benchmark portfolio, BMP 10, which comprised all the 23 specified corporate bonds. The portfolio had a weighted average duration of 7.6 years.

Sovereign bonds

Credit risk charges showed relatively low dispersion for the bonds issued by Germany, Netherlands, Austria, France, and Belgium. Greater dispersion was observed for the bonds issued by Ireland, Portugal, Spain, and Italy. Nevertheless, globally the dispersion has increased compared to the previous year. The following graph demonstrates this finding for 10 year bonds[21].

In contrast, the standard formula does not include a credit risk charge for sovereigns[22] which are examined in this study. We therefore omit any comparison with the standard formula in the analysis.

[21] For Portugal, only a 5 year bond was specified as part of the exercise and the modelling output for that issuer is not shown in the graph. A similar pattern was observed for 5 year bonds, with Portuguese bonds showing a similar dispersion to Irish, Spanish and Italian bonds.

[22] Note also that the standard formula keeps the volatility adjustment constant.

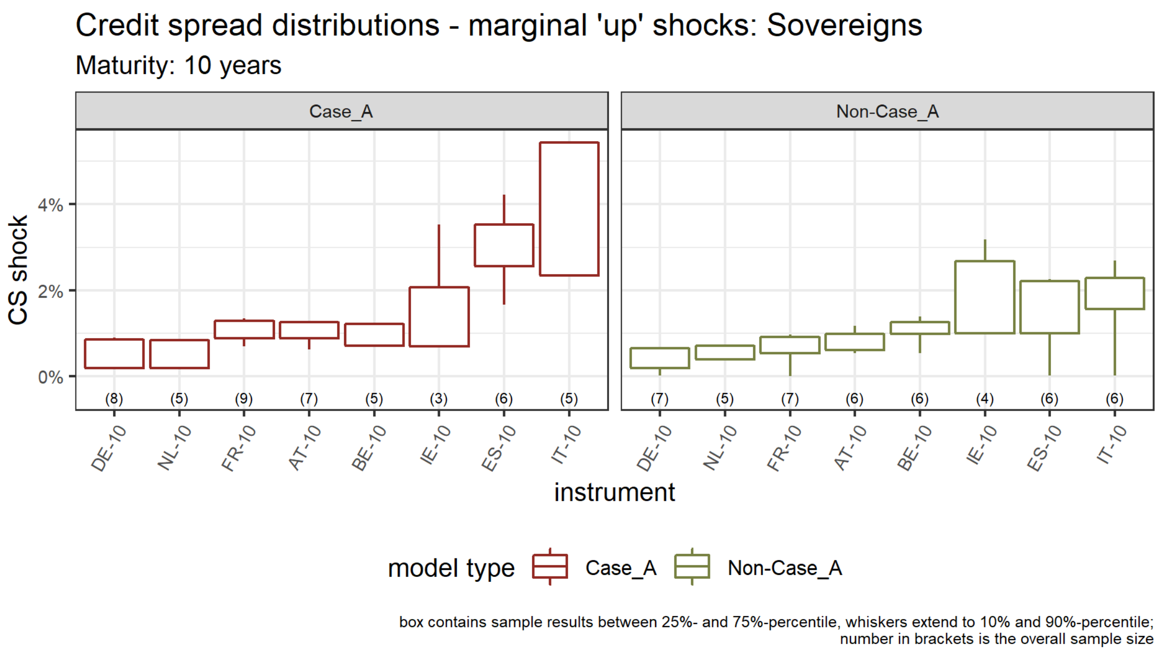

Figure 8: Credit spread marginal 'up' shocks at instrument level for 10 year sovereign bonds across modelling approaches restricted to firms that reported exposure

The analysis of individual cases also reveals the following information:

- Three integrated models and one modular approach show a near-zero risk charge for all sovereign instruments. Another participant shows a near-zero risk charge for the German sovereign instrument.
- Three groups apply a different calibration at local level (for the individual SCR calculation) for some domestic sovereign bonds held by these local entities.

Finally, the study specified a benchmark portfolio, BMP 09, which was comprised entirely of the 27 specified sovereign bonds with uniform weights. The portfolio had a weighted average duration of 10.9 years.

5.2.3. EQUITY AND PROPERTY

The study indicates that internal model firms apply a wider variation of risk charges for property risks when compared to listed equity risks. In contrast, risk charges for undertakings' insurance participations exhibit significant dispersion. The study also indicates that the undertakings' listed equity and property risk exposure tends to be in line with the standard formula shock. Further, for most undertakings, equity risk modelling is more sophisticated when compared to the property risk modelling.

Some degree of caution needs to be taken when interpreting the risk charge that is applied by an undertaking in its capital calculation (for example at the 99.5th percentile) and whether it appropriately reflects any adjustments firms might make for expected return. The following analysis for equity risk and property risk is based on the 'Modelled Value-at-Risk (mVaR)' information provided by the undertakings.

Equity risk

The study indicates that the sample of undertakings shows less dispersion in risk charges for the major equity indices such as EuroStoxx 50, MSCI Europe, FTSE100 and S&P500, when compared to the risk charges applied to the instrument 'strategic insurance equity participation' (INSUR_PARTIC)[23].

As compared to last years' results, the risk charge for the standard formula has increased due to the higher symetric adjustment term[24]. Thereby the standard formula risk charges now lie within the 25% and 75% percentiles of the internal model sample for listed equity indices.

For the UK market, the sample for medium and high exposure[25] is more concentrated than the full sample whereas for the US market this feature is reverted. For the other indices there is no significant difference in the dispersion of risk charges between all undertakings and those with higher equity exposures.

The boxplots below compare percentiles for each equity index for all the undertakings (on the left) and only for the undertakings that have higher exposure to a given synthetic equity risk (on the right).

[23] Strategic equity participation in a non-listed insurance entity.

[24] Due to an increase in the Global Equity Index

[25] Higher exposure is assumed for those undertakings that have reported an exposure relevance score of 3 (medium exposure) or 4 (high exposure). Lower exposure is assumed for those undertakings that have reported an exposure relevance score of 1 (not relevant) or 2 (immaterial). Please note that these categories were intentionally not defined by concrete thresholds and thus will also reflect the participants' materiality concepts.

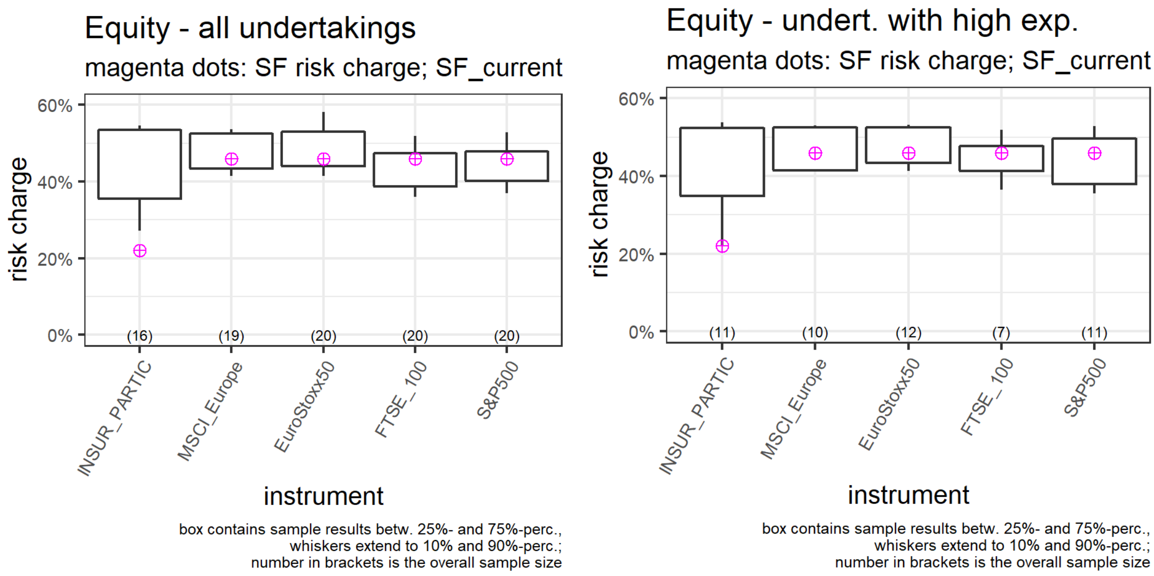

Figure 9: Risk charges for equity indices and participations for the overall sample (on the left) and for undertakings with higher exposure (on the right)

Property risk

For the four commercial property risk metrics, highest risk charges within the full sample are applied to UK instruments. The 25% standard formula shock constitutes the lower quartile for this market and lies well within the box of 25% to 75% percentiles for the other locations. Residential property instruments, represented in the study by the NL market, tend to be calibrated with lower risk charges.

The study indicates some differences in the level of the risk charges that are applied by the participants with higher[26] exposure, when compared to the risk charges applied by all participants (i.e. including the undertakings with low exposures). In particular for residential properties (NL) the risk charges applied by participants with higher exposure tend to be lower than those applied by all participants. For the UK commercial property instrument this effect is reversed, as the sample of higher exposure only contains one undertaking with a significantly higher risk charge (not displayed for confidentiality reasons). Both effects could be the result of a more granular modelling and calibration approach for undertakings with significant exposures to the respective markets.

[26] Higher exposure is defined as the undertakings that have reported an exposure relevance score of 3 (medium exposure) or 4 (high exposure). Lower exposure is defined as the undertakings that have reported an exposure relevance score of 1 (not relevant) or 2 (immaterial). Please note that these categories were intentionally not defined by concrete thresholds and thus will also reflect the participants' materiality concepts.

The boxplots below compare percentiles for each property risk metric for all the undertakings (on the left) and only for the undertakings that have higher exposure (on the right) in a given synthetic property risk.

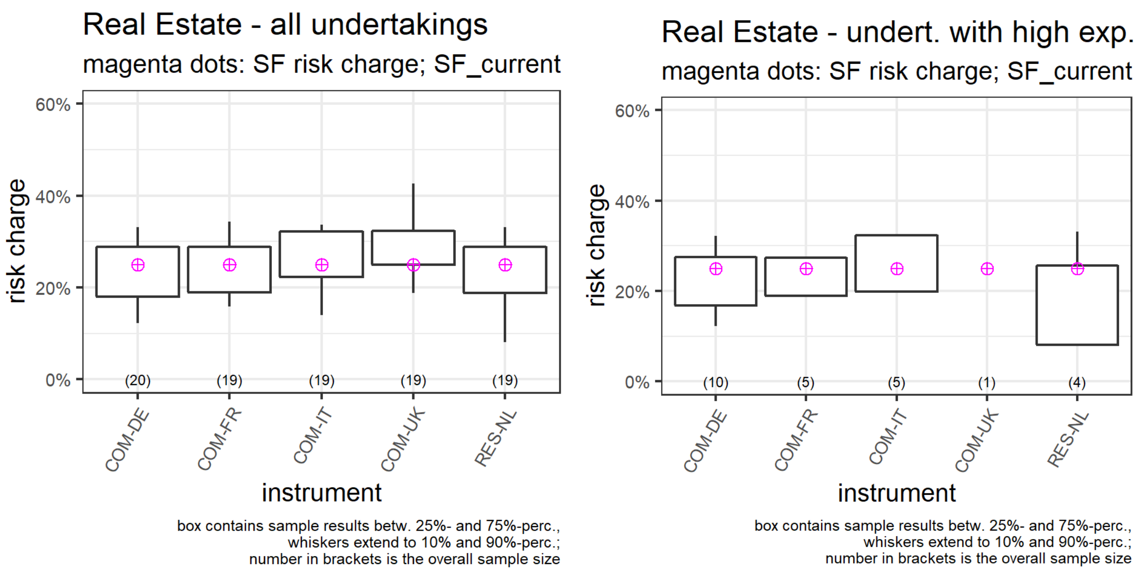

Figure 10: Risk charges for real estate for the overall sample (on the left) and for undertakings with higher exposure (on the right)

For certain asset categories, such as real estate, model calibrations might place more emphasis on the valuation methods and the risk profile of the undertakings' actual investment portfolio than referring to publicly available indices. Lower stresses compared to other participants or standard formula results can therefore also be an indication for a more defensive investment strategy of an undertaking in a particular asset type.

5.2.4. OTHER CURRENCIES

Although the BMPs do not include material parts of non-EUR currencies, an inspection of the respective modelling still is of general interest. As the most material foreign currencies, the GBP and USD are included in the scope of this study. The following plots only include data from those firms that claim to have exposure to these risk free rates or the respective exchange rates.

Regarding the risk free rate, the dispersion of the marginal shocks term-wise is in general more pronounced than for EUR especially for long term maturities:

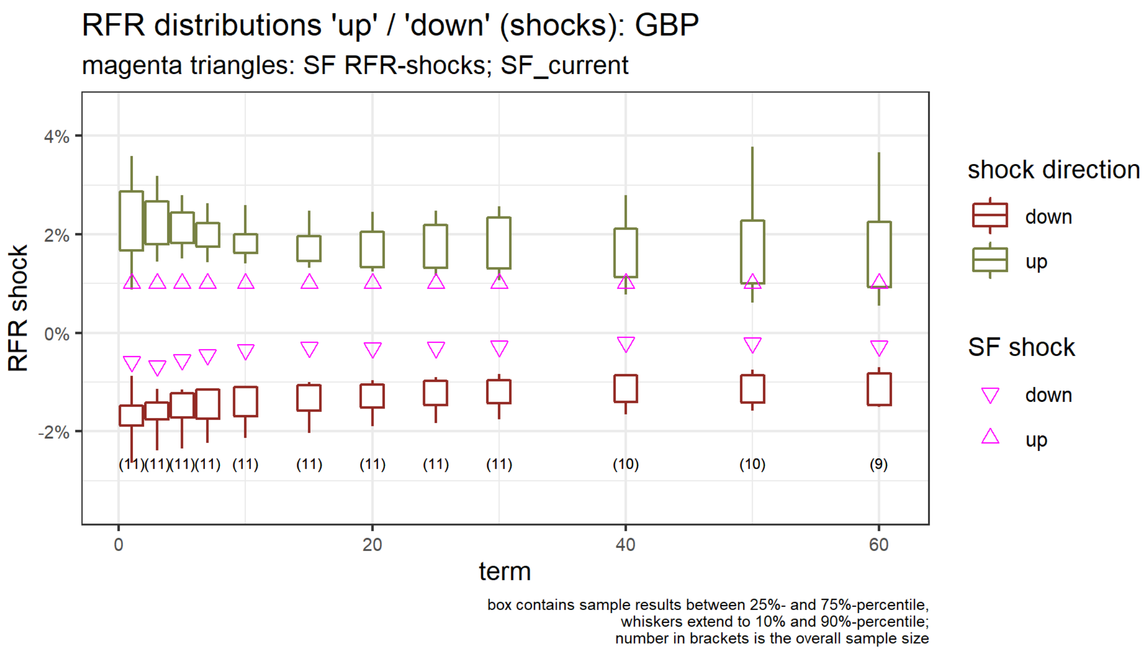

Figure 11: Downward and upward shocks on the spot rates for GBP risk free rates for single maturities (i.e. 'marginal' shocks on single nodes, not shocked curves) restricted to firms that reported exposure

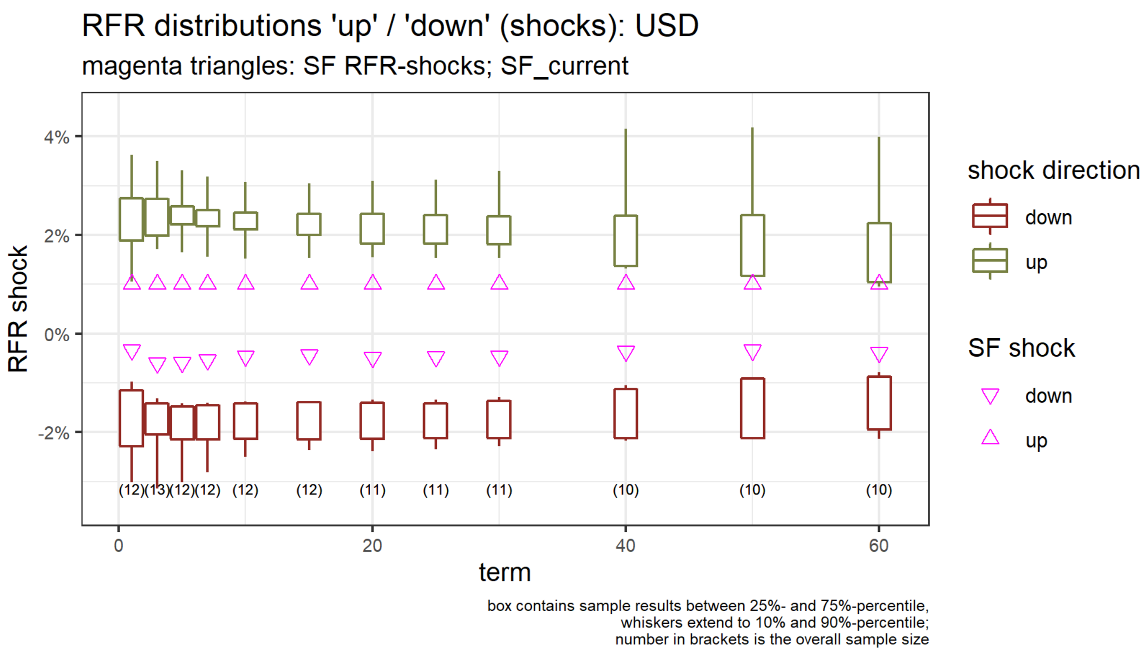

Figure 12: Downward and upward shocks on the spot rates for USD risk free rates for single maturities (i.e. 'marginal' shocks on single nodes, not shocked curves) restricted to firms that reported exposure

As for the Euro RFR, a general increase in RFR shocks can be observed for both USD and GBP.

FX rates

Another risk stemming from investment in different currencies comes from potential changes in exchange rates. Figure 13 shows upwards and downwards shocks on the EUR/GBP and EUR/USD exchange rates collected in the study.

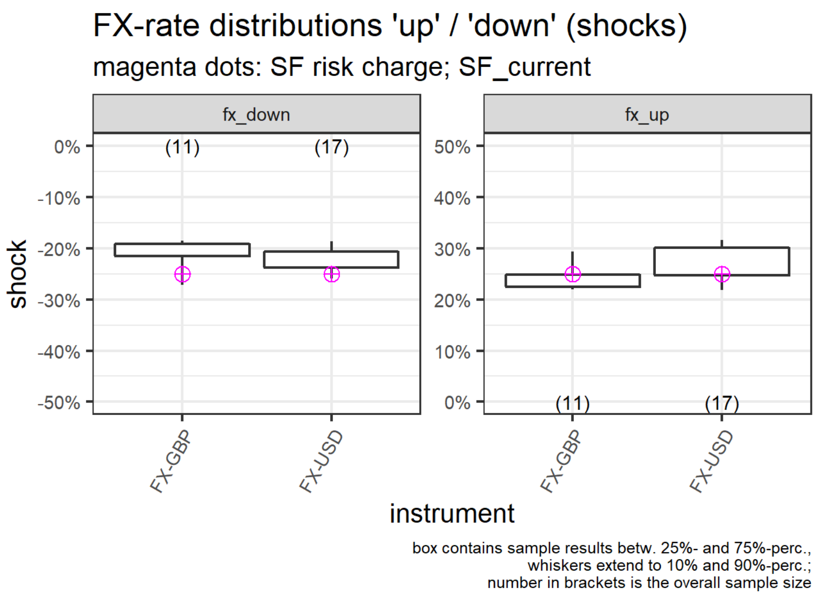

Figure 13: Risk charge for exchange rates for firms that reported exposure

Similarly to interest rate risk, currency risk is a two-sided risk. Therefore, exposure to the shocks is not clear per se, but depends on the exposure in the balance sheet. For example, a firm reporting in Euro that has a large exposure of assets denoted in USD (or GBP respectively) on the asset side without any exposure on the liability side is exposed to an increase in the EUR/USD exchange rate (or the EUR/GBP rate respectively).

It can be observed in Figure 13 that the dispersion of the shocks on modelled foreign exchange rates across undertakings is limited and in a similar range to that of the standard formula (+/-25%). The dispersion of shocks are similar to YE2020. However, it is worth noting that upward shocks on FX rates (shocks corresponding to an appreciation of the EUR against the GBP and USD) have a slightly greater amplitude than downward shocks (shocks corresponding to a depreciation of the EUR against the GBP and USD) for all the undertakings in the sample. In other words, the modelled probability of a +25% upward shock is higher than the probability of a -25% downward shock for most of the undertakings. This may be explained to some extent by the way some undertakings factor the 1Y forward FX rates observable on the OTC market in their modelled distributions of FX rates as forward rates were higher than spot rates at YE2021[27].

5.2.5. DERIVATIVES

Overview

The data request also comprised four standardised derivative instruments: one 5 year at-the-money European equity put (EuroStoxx 50) and three European at-the-money EUR-receiver swaptions with term-/tenor-combinations of 1/10, 10/10 and 20/20 years.[28]

The chosen derivative instruments can be considered as fairly standard products and almost all participants apply common market-standard valuation models in their internal models (e.g. Black-Scholes for the equity put). Regarding the implied volatility convention/pricing model for the swaptions a large majority of undertakings adopt a 'Normal/Bachelier'-approach.

5 participants assigned an exposure relevance score of 2 or higher (immaterial to high)to the European equity put and 8 respectively for each of the swaption instruments. From the point of view of 'invested assets' these exposures are of limited materiality compared to the other asset classes and they are therefore not included in the benchmark portfolios (although it should be noted that equity put options are a common instrument for hedging the downside risk of equity exposures on an undertaking's balance sheet).

However, the relevance of these instruments also needs to be assessed in the context of valuing the Technical Provisions of the traditional life business, in particular their embedded options and guarantees. Life insurance products often contain embedded options in the form of profit sharing and guaranteed returns on premiums deposited by the customer. From a market-consistent valuation perspective, the costs of these options and guarantees depend, among other things, on the level of 'implied volatility'[29]. A significant part of the undertakings' exposure to the risk category 'implied volatility' relates to these embedded options and guarantees. Internal models aim to capture the dynamics of this valuation parameter over a one-year horizon and this section provides some insights about these dynamics.

Regarding the initial valuation of the instruments (t=0), most of the values provided by undertakings are in a comparable range and close to mark-to-model prices observed at a third party market data

[27] For more details on this subject, see the MCRCS YE2019 report.

[28] A receiver swaption gives the holder of the swaption the right but not the obligation to enter into an interest rate swap where he/she receives the fixed leg and pays the floating leg.

[29] In contrast to other pricing-relevant parameters this is not directly observable but implicit in the observed market price of the option and usually derived via market-standard pricing models.

provider. This does not completely hold for the 20/20-swaption where undertakings have applied different valuation approaches. This is most likely due to the fact that the relevant part of the yield curve for this swaption is in the extrapolated part of the EIOPA risk free rate where deviations in the market-curve (swap) are more pronounced.

Results of the 'implied volatility' risk factor

The valuation of derivatives depends on several variables entering simultaneously in the pricing functions. Some of them have already been covered in other sections of this report (cf. sections 5.2.1 and 5.2.4) and therefore the following results are not based on 'risk charges'. Instead, the focus is on the dynamics of the 'implied volatility' risk factor over a one-year horizon in the internal models.

Depending on the direction of the derivative's exposure - i.e. 'long' vs. 'short' - an undertaking can be exposed to either an increase or decrease of the implied volatility risk factor. Therefore, the following graphs display the 0.5%-down and 99.5%-up percentiles of absolute changes in implied volatility. Considering the overall sample size for the 10/10-swaption, only the results from the subset of participants using a 'normal implied volatility' convention are displayed. It is worth noting that implied volatility is not part of the Standard Formula risk framework and therefore no comparison with the Standard Formula is provided here. By and large, the extreme percentiles for this risk factor are in a comparable range for both instruments (the observed implied volatilities at year-end 2021 were approx. 19% for the EQ-Put and 60 bps for the 10/10-swaption).

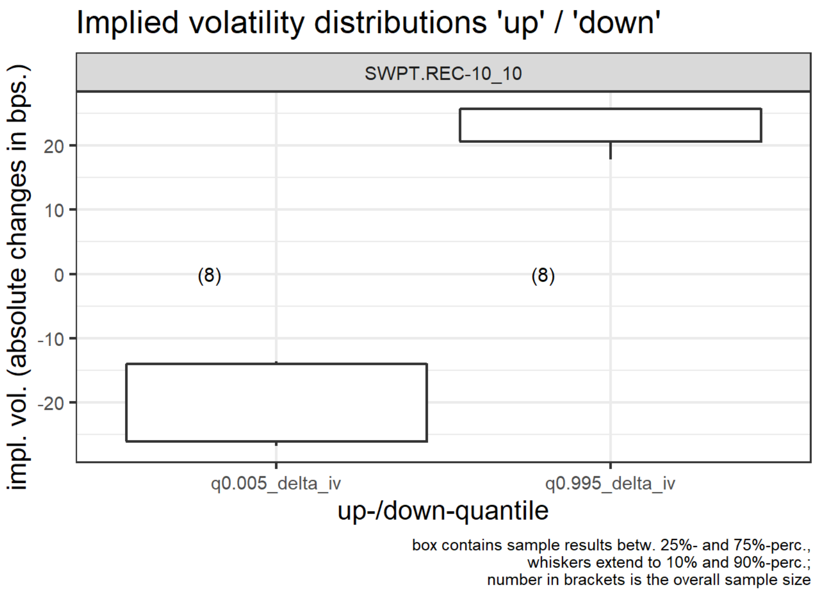

Figure 14: Risk factor 10/10-swaption implied volatility absolute changes 'down' (0.5%-percentile) and 'up' (99.5%-percentile) for participants using a 'normal implied volatility'

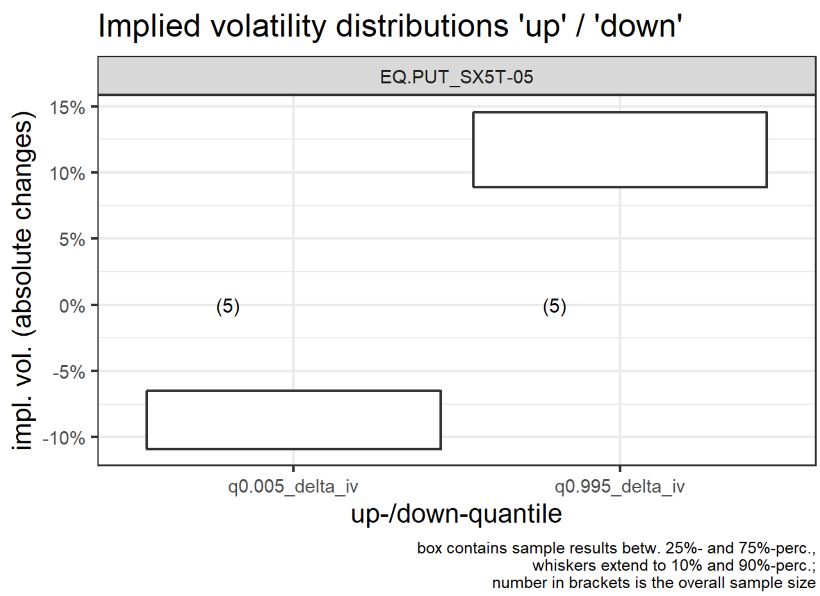

Figure 15: Risk factor equity implied volatility absolute changes 'down' (0.5%-percentile) and 'up' (99.5%-percentile) for participants with an exposure relevance score higher than 1 (not relevant)

5.2.6. INTRA-MARKET RISK DEPENDENCY

While the focus of the study is the combined market and credit risk, the other part of the analysis involved drilling down to the level of single instruments. To close the 'gap' between these levels, the MCRCS includes an analysis of dependency structures within market risk, i.e. excluding migration and default of credit risk (technically speaking this refers to the part-02b data of the MCRCS-questionnaire) and the dynamic volatility adjustment.

To allow for a direct comparison of dependency structures across model types, participants with integrated models were asked to deliver data from which the migration and default risk component was removed[30]. This allowed for a similar scope of risks. Another key requirement was the full consistency of simulation data for benchmark portfolios and single instruments.

Multivariate dependencies: Empirical copula

Under these conditions, it was possible to derive the implied dependency structure in form of the empirical copula of the undertaking from the simulation data across all synthetic instruments, representing the underlying risk factors for the purpose of the MCRCS. Such an exercise could be performed for almost all undertakings. The marginal distributions (derived from simulated data for the single instruments) of a given undertaking *A* could then be combined with the empirical copula

[30] As a possible approach to eliminate migration and default the undertakings could perform a simulation but hold all ratings constant, i.e. not allowing for either migration or default.

of another undertaking *B*[31]. This would give rise to a hypothetical joint distribution which would, for instance, allow a hypothetical mVaR to be calculated for the value of benchmark portfolios for undertaking *A*. By repeating this exercise for the dependency structures of all other undertakings, sets of hypothetical mVaRs based on the dependency structure of other participants in the study could be generated. Comparing the mVaRs based on the undertaking's own dependency structure with these sets of hypothetical mVaRs could give an indication for possible model uncertainty (variation/shape of the resulting boxplot) related to the dependency structure for a given benchmark portfolio and allows to compare the effects of dependency structures at an aggregated level across undertakings (relative position of the undertaking compared to the boxplot). Here it should be noted that the own portfolio typically differs from the benchmark portfolios and that conclusions should be taken in this light. Also the individual choice for marginal distributions influences the consequential choice of dependency structures.

Bivariate dependencies: Joint Quantile Exceedance probabilities

In addition, an analysis of dependencies was performed on the individual instrument data. This data allowed risk factor information to be derived, e.g. for corporate bonds: to determine the spreads as described in section 5.2.2. On a risk factor level, it was then possible to construct bivariate Joint Quantile Exceedance probability (JQE) as the joint probability that both risk factors will simultaneously surpass the same quantile. For this exercise, a quantile of 80% was used on the one hand to allow for enough data to have significance and on the other hand to focus on the tail of the distribution. This estimator is a more relevant measure of tail dependencies than correlations, which take the whole distribution into account.

In the table below, the values of the JQE measure are compared with theoretical correlation coefficients in a Gaussian copula framework. Different use cases are shown based on different thresholds (i.e. 80%, 90% and 95% percentiles).

In the case of perfect negative dependence, we observe that the JQE equals zero. Indeed, a strong upward movement for one risk factor would be accompanied by an equally strong downward movement for the other risk factor.

Correlation Coefficient	**Joint Quantile Exceedance probabilities**		
	80%	**90%**	**95%**

[31] It is important to keep in mind that marginal distributions, joint distributions and dependency structures for an internal market risk model are in general not chosen independently but are part of the general model specification process and therefore the respective choices and decisions are somewhat interlinked. Also it should be noted that if two of those variables are chosen the third is fixed, e.g. defining marginal distributions and the dependency structure determines the joint distribution.

-100%	0.00%	0.00%	0.00%
-75%	0.09%	0.001%	0.00001%
-50%	0.84%	0.07%	0.01%
-25%	2.22%	0.39%	0.07%
0%	4.00%	1.00%	0.25%
25%	6.14%	1.93%	0.61%
50%	8.72%	3.24%	1.22%
75%	12.06%	5.12%	2.20%
100%	20.00%	10.00%	5.00%

Table 2: Comparison of Joint Quantile Exceedance probabilities and correlations for a Gaussian copula and for thresholds of 80%, 90% and 95%

In the case of perfect positive dependence, the JQE would depend on the value of the threshold. All upward movements above a certain threshold for one risk factor would also lead to a movement above the same threshold for the other risk factor (comonotonicity). The JQE would then equal the number of observations above this threshold (e.g. 20% in the case of an 80% threshold).

In the case of independence, the probabilities of surpassing the threshold can simply be multiplied to obtain the joint probability of surpassing the threshold, e.g. 20% times 20% (= 4%) for an 80% threshold.

In the graph below we give an overview of the different JQEs across a selection of risk factors (including two risk free rate maturities, two corporate and sovereign spreads as well as an equity index). For instance, we focus on the specific example of the boxplot between AA and BBB Non-Financial corporate bonds at 5 years. Here, we can see that the box lies between 9.6% and 16.4%, indicating a high dispersion of JQEs. The JQE assuming full independence of the risk factors is also shown as a red dotted line for comparison purposes. For interpretation of the scale, the JQE values contained in

Table 2: (column '80%') can also be used as a reference for the specific case of a Gaussian copula. The JQEs show that both corporate spreads are positively dependent for all participants.

The whole matrix of JQEs presents a boxplot for all pairs of selected risk factors. Since the JQE is symmetric, the boxplots shown in the upper and lower triangles are the same. If we compare the JQE across risk factors for the undertakings in the sample, we observe that the range of JQEs between DE and IT sovereign spreads is wider than for other risk factors.

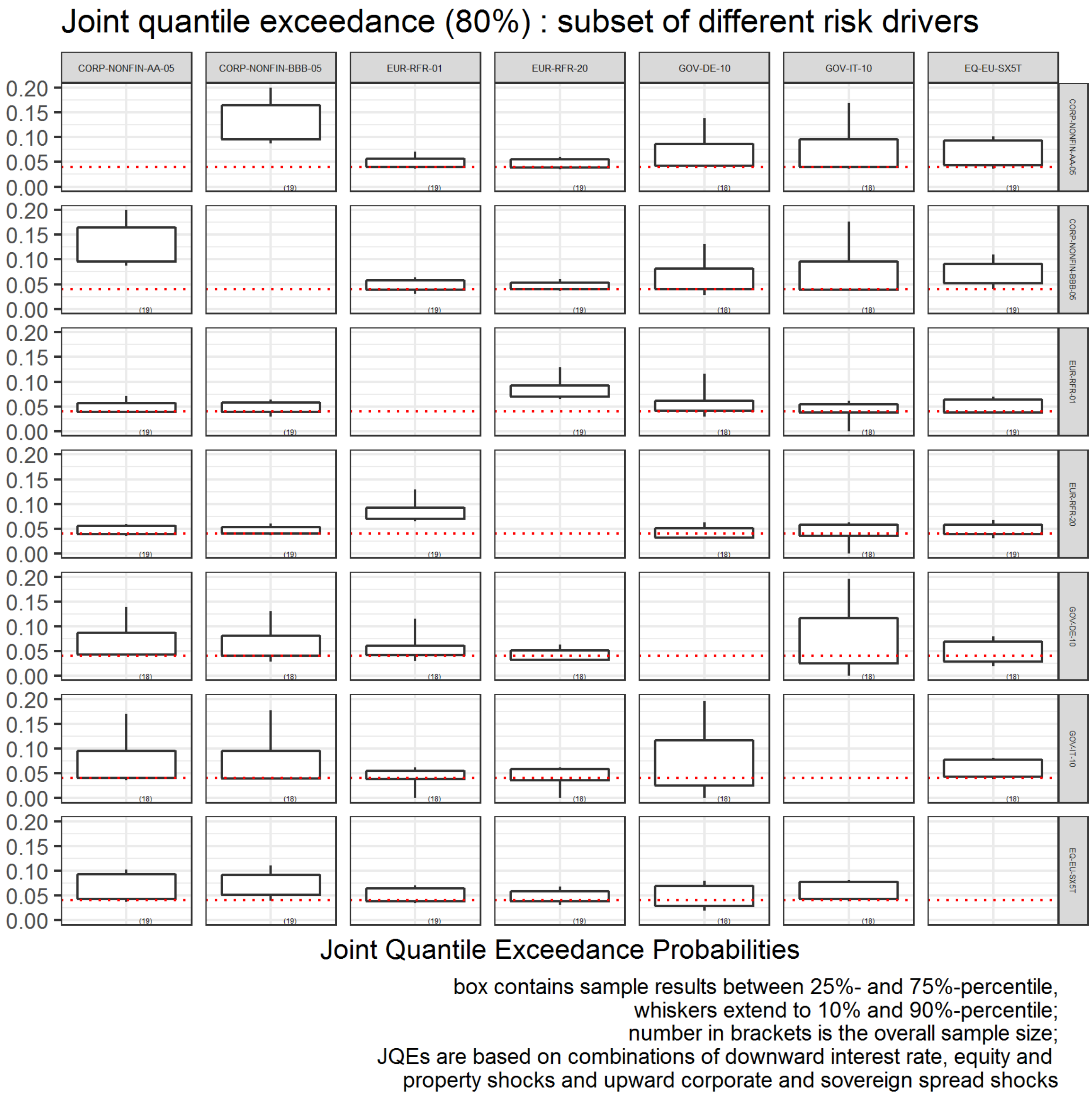

Figure 16: Joint Quantile Exceedances based on an 80% quantile for a range of risk factors

5.3. SUPERVISORY FOLLOW-UP AND OUTLOOK

The Market and Credit Risk Comparative Study (MCRCS) is not a stand-alone exercise but one important element in the EEA-supervisory tool-kit for monitoring the on-going appropriateness of internal market and credit risk models. Parts of it have been and are being used in other supervisory processes and especially the assessment of model changes and initial applications.

After each edition of the MCRCS, participating NCAs are provided with tailored feedback packages going beyond the global view outlined in this report and enabling them to discuss with and challenge the participating undertakings. In some instances the MCRCS results also feed into the respective regular validation processes and specific validation exercises performed by undertakings, which sometimes led to model changes. It is also expected to occur in the future and EIOPA will follow up on NCAs' activities.

Specific topics discussed and challenged in this edition include the following:

1. Two participants don't have a risk charge for sovereign bonds. They perform regular liquidity analysis in Pillar II instead, assessing whether liquidity would trigger the sale of bonds.
2. Two participants model only the pure credit spread risk. For both participants, major model changes have been submitted in 2022. EIOPA is kept informed of the developments in a timely manner. These participants have set up conservative margins to mitigate this model deficiency.

Also, the interactions with the undertakings comprise aspects of data quality and improvements of single submissions. The undertakings were additionally asked to provide written feedback on the results and their evaluation of these. Furthermore, the NCAs' feedback on the setup of the study itself and potential future improvements was collected.

In the case of insurance groups, group supervisors are encouraged to inform the college about the study and discuss relevant insights with the supervisory authorities concerned.

Following EIOPA's decision to perform the MCRCS annually there will be a study based on year-end 2022 data. The data requested will remain close to the scope and extent of the last data request. Nevertheless, some extensions are being discussed by the Project Group and potential changes will be highlighted in the YE2022 data request.

ANNEX 1: COMPOSITION OF THE ASSET BENCHMARK PORTFOLIOS

Benchmark portfolios /	**A_EUR**	**A_BE**	**A_DE**	**A_ES**	**A_FR**	**A_IE**	**A_IT**	**A_NL**	**A_SOV**	**A_CORP**
\ Type of instrument	**EUR_BMP_01**	**EUR_BMP_02**	**EUR_BMP_03**	**EUR_BMP_04**	**EUR_BMP_05**	**EUR_BMP_06**	**EUR_BMP_07**	**EUR_BMP_08**	**EUR_BMP_09**	**EUR_BMP_10**
Fixed income instrum.	89.3%	91.7%	90.1%	92.6%	86.5%	89.5%	94.0%	92.1%	100.0%	100.0%
CORPORATES	49.6%	40.8%	60.3%	33.1%	44.8%	43.5%	31.3%	48.7%	0.0%	100.0%
ESM	2.4%	0.5%	3.7%	1.0%	2.4%	0.4%	0.6%	2.6%	0.0%	4.3%
Other CORP	47.2%	40.3%	56.6%	32.2%	42.5%	43.1%	30.7%	46.0%	0.0%	95.7%
AAA	7.6%	6.9%	19.5%	1.9%	4.2%	6.2%	0.5%	5.8%	0.0%	26.1%
AA	9.4%	7.6%	11.7%	4.1%	8.7%	8.9%	2.4%	7.7%	0.0%	17.4%
A	15.3%	12.2%	13.4%	9.3%	16.2%	14.2%	6.0%	15.6%	0.0%	17.4%
BBB	13.3%	12.9%	9.3%	15.1%	12.2%	11.6%	19.2%	16.1%	0.0%	17.4%
BB	1.6%	0.7%	2.7%	1.6%	1.1%	2.2%	2.6%	0.9%	0.0%	17.4%
GOVERNMENTS	39.7%	50.9%	29.8%	59.5%	41.7%	46.0%	62.7%	43.5%	100.0%	0.0%
AT	1.6%	2.1%	2.6%	0.3%	1.6%	1.5%	0.2%	3.2%	11.1%	0.0%
BE	3.2%	33.2%	2.2%	0.6%	2.4%	2.0%	0.4%	3.0%	11.1%	0.0%
DE	5.5%	2.1%	14.0%	0.5%	0.9%	4.7%	0.9%	11.9%	11.1%	0.0%
ES	4.0%	1.9%	1.8%	52.1%	2.4%	2.9%	3.0%	1.4%	11.1%	0.0%
FR	12.0%	6.2%	4.0%	0.6%	29.2%	5.1%	0.9%	6.2%	11.1%	0.0%
IE	0.4%	1.1%	0.5%	0.3%	0.6%	4.5%	0.4%	0.9%	11.1%	0.0%
IT	9.6%	3.2%	1.8%	4.1%	4.0%	11.6%	56.0%	1.3%	11.1%	0.0%
NL	2.0%	0.5%	1.1%	0.2%	0.4%	1.5%	0.3%	15.0%	11.1%	0.0%
PT	0.4%	0.2%	0.1%	0.6%	0.2%	0.5%	0.1%	0.0%	3.7%	0.0%
UK	0.3%	0.0%	0.5%	0.0%	0.1%	6.0%	0.1%	0.3%	3.7%	0.0%
US	0.6%	0.4%	1.3%	0.2%	0.1%	5.8%	0.4%	0.3%	3.7%	0.0%
Equity	6.7%	4.3%	6.4%	3.4%	9.0%	6.5%	3.5%	4.3%	0.0%	0.0%
Real Estate	4.0%	4.0%	3.5%	4.0%	4.5%	4.0%	2.5%	3.6%	0.0%	0.0%
Commercial	3.2%	3.2%	2.8%	3.2%	3.6%	3.2%	2.2%	2.0%	0.0%	0.0%
Residential	0.8%	0.8%	0.7%	0.8%	0.9%	0.8%	0.3%	1.6%	0.0%	0.0%
Total Assets	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

ANNEX 2: COMPOSITION OF THE LIABILITY BENCHMARK PORTFOLIOS

Benchmark portfolios	L_D.long	L_D.short
Risk free rates (maturity)	EUR_BMPL_01	EUR_BMPL_02
1	9.7%	40.6%
3	12.1%	27.4%
5	10.8%	11.1%
7	9.7%	6.2%
10	19.2%	7.5%
15	12.7%	3.0%
20	8.2%	1.3%
25	5.3%	0.7%
30	6.3%	1.4%
40	3.6%	0.8%
50	1.7%	0.0%
60	0.7%	0.0%
Total Liabilities	100.0%	100.0%

EIOPA

Westhafen Tower, Westhafenplatz 1
60327 Frankfurt – Germany
Tel. + 49 69-951119-20
info@eiopa.europa.eu
https://www.eiopa.europa.eu