Discretionary Decisions in Capital Requirements under Solvency II

Nicolaus Grochola*, Sebastian Schlütter†

This version: June 2023‡

Abstract

The capital requirements of Solvency II allow insurers to make discretionary choices. Besides extensive possibilities regarding the choice of a risk model (ranging between a regulatory prescribed standard formula to a full self-developed internal model), insurers can make use of transitional measures and adjustments, which can have a substantial impact on their reported solvency level. The aim of this article is to study the effect of these long-term guarantee measures and to identify drivers of the discretionary decisions. For this purpose, we first assess the risk profile of 49 European insurers by estimating the sensitivities of their stock returns to movements in market risk drivers, such as interest rates and credit spreads. In a second step, we analyze to what extent insurers' risk profiles influence their discretionary decisions in the capital requirement calculation. We gather information on discretionary decisions based on hand-collected Solvency II data for the years 2016 to 2020. We find that insurers optimize their reported solvency situation by making discretionary decisions in such a way that capital requirements for material risk drivers are clearly reduced. For instance, we find that the usage of the volatility adjustment is positively related to the interest rate risk as perceived by financial markets, even when controlling for the portion of life insurance in technical provisions. Similarly, the matching adjustment is linked to significantly higher credit risk sensitivities. Our results point out that due to discretionary decisions Solvency II figures can substantially deviate from a market-oriented, risk-based view on insurance companies' risk situation.

Keywords: Solvency II, capital requirements, discretionary decisions

---

* Contacting Author. Goethe University Frankfurt, Faculty of Economics and Business, International Center for Insurance Regulation, House of Finance, Theodor-W.-Adorno-Platz 3, 60323 Frankfurt am Main, Germany; Phone: +49 69 798 33680; E-mail: grochola@finance.uni-frankfurt.de.

† Mainz University of Applied Sciences, School of Business, Lucy-Hillebrand-Str. 2, 55128 Mainz, Germany; Fellow of the International Center for Insurance Regulation, Goethe University Frankfurt; E-mail: sebastian.schluetter@hs-mainz.de.

‡ We are grateful for comments and suggestions by Till Förstemann, Fabian Regele, Felix Scheidl, Gregor Weiß, and participants at the 2019 ARIA, 2019 DGF, 2019 IME, 2019 Annual Meeting of the German Association for Insurance Studies (DVfVW) and the 2nd Frankfurt Insurance Research Workshop. This version supersedes the previously circulating version "Do Solvency II reports appropriately inform about European stock insurers' market risk exposures?". The working paper version has initially been published on June 7, 2023.

1 Introduction

Modern regulatory frameworks for financial institutions aim at providing a fair view on the risk and solvency situation of regulated entities. The first pillars of both, the Basel Capital Accord for banks and the Solvency II framework for insurance companies in the European Economic Area (EEA), define quantitative requirements for the assessment of major risks and capital needs. Both regulatory frameworks do not define a unique method for quantification, but allow companies to choose between options. For banks, an important option is to choose between the standardized approach and an Internal Rating Based (IRB) approach for credit risk. Under the IRB approach, banks choose a risk model to estimate the parameters for the risk assessment based on internal data. This set-up with two alternative approaches has been subject to substantial critique. Since the initial implementation of the IRB approach is costly to banks, only large financial institutions may effectively be able to select such an approach and thereby receive a competitive advantage. Thus, the option can induce moral hazard problems and increase the aggregate risk in the economy (cf. Hakenes and Schnabel (2011)). Moreover, empirical evidence suggests that banks intentionally choose and calibrate their risk models such that their reported risk situation brightens up (cf. Colliard (2019), Plosser and Santos (2014)).

Compared to the Basel Capital Accord, Solvency II allows insurance companies to choose between a much larger variety of implementation options. The first pillar of Solvency II defines a market-oriented balance sheet approach to measure insurers' own funds as well as a risk-based approach to determine their "solvency capital requirement" (SCR). The SCR shall reflect the loss in own funds over a one-year time horizon in a 1-in-200 year event due to various risks, including market risks, credit risks and insurance risks. To calculate the SCR, insurers can use an own full internal model, which covers the entire risk landscape, or a standard formula, which is defined by the regulator. As a further option, they can use a partial internal model, meaning that they choose risk categories which they model internally and use the standard formula for the others. Moreover, there are four non-mandatory long-term guarantees (LTG) measures which insurers can use or not (cf. Articles 43-54 European Commission (2015)): Matching adjustment, volatility adjustment, transitional measure on the risk-free interest rates, transitional measure on technical provision. These measures affect the discount rate that insurers use to calculate their technical provisions and hence directly impact the own funds. In addition, they influence the calculation of the SCR.

The central outcome of Pillar I of Solvency II is the solvency ratio, which divides the own funds by the SCR. It is frequently employed to state the insurer's financial soundness by a single figure. If the solvency ratio is at least 100%, insurers are said to comply with the SCR (cf. Article 100 European Commission (2009)).

There is a substantial variety in the way insurance companies choose to determine their own funds and SCR. In 2020, 651 out of 2458 insurance companies have used at least one LTG measure, 91 have employed a partial internal model and 56 a full internal model (cf. European Insurance and Occupational Pensions Authority (EIOPA) (2020)). Both LTG measures and the use of a (partial) internal model is positively linked to the size of insurer.[1] At the same time, the instruments have a substantial impact on the solvency ratio. For instance, the average solvency ratio of the companies using at least one of the transitionals, the matching adjustment or the volatility adjustment would decrease from 247% to 204% when removing that instrument (cf. EIOPA (2020)).

The purpose of this paper is to investigate the determinants of insurers' discretionary decisions in the implementation of Solvency II. Specifically, we want to shed light on the relation between information about the insurers' risk profiles and their implementation strategy. We suspect that insurers strategically make use of the leeway in the determination of the solvency ratio. When deciding on LTG measures and/or a (partial) internal model, they trade-off the improvement of the solvency ratio against possible drawbacks.[2] For instance, the use of the volatility adjustment becomes more valuable to an insurer, the higher its interest rate risk is.

Previous studies examining insurers' risk profiles find that market risks are typically the greatest threat to the solvency of life insurance companies, mainly because of the long duration of their liabilities and a high share of investments in government bonds (cf. Duverne and Hele (2016), Frey (2012), EIOPA (2017a)). Several empirical studies have measured how insurance companies are exposed to changes in long-term interest rates (e.g., Brewer et al. (2007), Carson et al. (2008) and Möhlmann (2021). For instance, Hartley et al. (2017) reveal that in the low interest rate environment following the recent financial crisis insurance companies benefit significantly from rising long-term interest rates. Moreover, Düll et al. (2017) reveal that insurers are significantly affected by changing credit default swap (CDS) spreads of

[1] For example, insurers using at least one LTG measure hold 80% of the technical provisions of all insurance companies subject to Solvency II (cf. EIOPA (2020)).
[2] In terms of LTG measures, these drawbacks include increased disclosure requirements and higher regulatory attention, since the local regulators closely monitors the use of the LTG measures. Establishing (partial) internal models requires substantial efforts for the implementation and maintenance.

government bonds. More recently, Grochola et al. (2021) point out that sovereign credit risk is of relatively high importance for European insurance companies in comparison with U.S. insurers, whose risk profile is dominated by interest rate risk.

To answer our research question, we proceed in two steps. Firstly, we analyze how the market capitalization of 49 listed insurance companies from 15 European countries react to long-term interest rate movements, CDS spread changes and an overall stock market index.[3] We perform firm-level multivariate regression analyses based on daily market data of the past few years. This step of analysis identifies insurance companies' interest rate risk, investment credit risk and stock market sensitivities (measured by the betas of the regression). Our findings show that between 2010 and 2019 the impact of daily changes in long-term interest rates on stock returns is significant for 41% of all insurers. In addition, 67% of firms are significantly impacted by daily movements of CDS spreads of domestic sovereign debt. The results of examining the risk profiles are largely consistent with other recent empirical studies. The estimated sensitivities also reveal a considerable heterogeneity in market risk exposures across European insurers which can be explained by the deviating width of duration gaps between the asset and liability sides of insurers' balance sheets, the use of legally binding guarantees for policyholders and the varying share of life insurance business.

In the second step, we systematically gather information about the insurers' discretionary decisions and risk management approaches from the Solvency and Financial Condition Reports" (SFCRs) which European insurers are obliged to create and publish annually. The SFCRs provide detailed information about the business and performance, the system of governance, the risk profile, the valuation for solvency purposes and capital management of insurance companies (cf. Articles 292-298 European Commission (2015)). We obtain data on the solvency ratio, the impact of the LTG measures as well as qualitative information on the composition of internal models. For this purpose, we examine all reports after the introduction of Solvency II in 2016 of the 49 companies in the sample. We then investigate which market risk sensitivities and which other firm-specific characteristics such as size and the portion of life insurance business are most helpful to explain the insurers' choices regarding the extent of the use of LTG measures and internal models.

The idea behind the SFCRs is that the insurers' stakeholders gain transparency about the companies' risk profiles and that their potential punishment provides the insurers with an

[3] Obtaining market risk sensitivities by performing regressions on a firm level by using stock returns as the dependent variable is an approach that has been done by Berends et al. (2013) for insurers and by Campbell et al. (2001) and Da et al. (2012) for a broader sample of firms.

incentive to seek a sound risk and solvency position. From a stakeholder perspective it is important to have empirical evidence on whether the reported solvency ratio is informative and whether this regulatory tool works. Gatzert and Heidinger (2020) and Mukhtarov et al. (2022) demonstrate that the published quantitative data on risk characteristics in the SFCRs lead to a significant abnormal stock return indicating that shareholders react to “good news” or “bad news” provided by the SFCRs. Nevertheless, it remains an open question how much the reported solvency ratios reflect the actual solvency position of an insurer.

For the insurers in our sample, the results demonstrate that the solvency ratios are strongly affected by the LTG measures. The matching adjustment, which has the highest impact, increases the solvency ratio by 59 percentage points (ppt) in absolute terms on average. Firms with an otherwise low solvency ratio can gradually adjust the reported figure upwards. Particularly, the impact of the volatility adjustment on the solvency ratio is significantly larger for less solvent insurers. Considering that the volatility adjustment is applied by 67% of the stock listed insurers in our sample, this finding shows that the reported solvency ratio is rather uninformative without taking into account how it has been adjusted by the use of LTG measures.

The subsequent parts of the paper are structured as follows. The methodology for the estimation of market risk sensitivities based on market data is outlined in chapter 2. Our approach and the empirical results addressing the research question on the drivers of discretionary decisions under Solvency II is revealed in chapter 3. Chapter 4 concludes.

2 Estimation of market risk sensitivities based on market data

2.1 Dependent variable

Our sample consists of European insurers that are publicly listed and for which daily stock data can be obtained from Thomson Reuters Eikon. Additionally, we restrict our analysis to insurers that have published at least one Solvency and Financial Condition Report (SFCR) on the group level. We exclude five micro-cap firms with total assets below $250 million as of year-end 2020 from the sample due to lower liquidity and potentially abnormal risk-return profiles compared with larger firms (cf. Lins et al. (2017)).[4] In addition, we exclude three insurers due to low data frequencies (less than 100 stock price observations per year) as the estimated firm level coefficients can be biased by missing, more volatile or inaccurately timed observations. Hence,

[4] Typically, micro-cap firms are associated with higher risk and potential for higher returns due to factors such as higher volatility, liquidity risk, and growth prospects. We thus underline that the findings of this paper are limited to larger stock listed insurance companies.

in total, eight insurers are excluded, out of which none has used an LTG measure or an internal model between 2016 and 2020.[5] To conduct the empirical analysis on market risk sensitivities, we gather daily stock prices of 49 insurance companies across 15 European countries, spanning from March 20th, 2006 to December 30th 2019, using Thomson Reuters Eikon as our data source. We choose this time frame to adequately reflect insurers' risk profiles as their choice of LTG measures is a long-term decision. Our analysis encompasses a time span of 3,775 trading days, during which we observe daily returns. The dependent variable in our regression model is the relative daily change of the total return index r_t, which captures stock price changes accounting for dividend payments and fluctuations in the number of outstanding shares. We use this as a measure for the stock return:

$$r_t = \frac{TRI_t}{TRI_{t_{previous}}} - 1 \tag{1}$$

If the TRI remains unchanged for at least three consecutive days, we assume a lack of data and exclude the TRI observation starting from the second day. Table 1 presents the descriptive statistics for the sum of all remaining stock price and stock return observations. The statistics of collected stock returns r_t at the insurer level are shown in Table A1 in Appendix I, revealing that the mean of daily stock returns at the level of insurers ranges from -0.01% to 0.22%, and the standard deviation from 1.21% to 4.05%. Outliers with absolute daily returns exceeding 50% are removed from the regressions. As of 2020, the total assets held by all companies in our sample amount to 7.606 trillion € (5.274 trillion € after excluding U.K. insurers), accounting for approximately 57% of all insurers' assets in the EEA based on data from the EIOPA Insurance Statistics.

2.2 Independent variables

We utilize 10-year interest rates from the European Central Bank (ECB) for our regression analyses to assess interest rate risk. The data is sourced from daily estimates of the euro yield curve, and the term structure is derived using the Svensson model applied to government bonds in the Eurozone with an AAA-rating. The resulting annual interest rates represent those of a 10-year zero-coupon bond.

Following the methodology of Brewer et al. (2007) and Grochola et al. (2021), we employ the holding period return (hpr) of long-term interest rates as the independent variable for measuring interest rate risk. This return corresponds to the yield obtained by purchasing a zero-coupon

[5] The excluded firms are mostly from smaller European insurance markets: Cyprus (two insurers), Croatia (one), Hungary (one), Iceland (one), Malta (one). One insurer each comes from Norway and the U.K.

bond with the prevailing interest rate and selling it the following day. If the 10-year interest rate (denoted as $y10$) were to increase during this period, the market value of the bond would decrease, resulting in a negative hpr within one trading day. As such, a positive hpr would only be observed after a decline in the interest rate. The calculation for the hpr on day t is as follows:

$$r_{y10,t} = \left(\frac{1 + y10_{t_{previous}}}{1 + y10_t}\right)^{10} - 1 \tag{2}$$

Given that European insurers allocate a significant portion of their assets to sovereign bonds, as evidenced by EIOPA (2016a), we utilize CDS spreads of government debt as a proxy for credit risk. The data for CDS spreads are sourced from IHS Markit. Following the approach of Düll et al. (2017), we specifically select CDS spreads denominated in USD with a maturity of 5 years. These spreads reflect the estimated probability of a country defaulting on its payment obligations within the 5-year period following the issue date, serving as an indicator of credit risk.

We gather sovereign CDS data for all countries where insurers in our sample are headquartered. Each insurer is assigned to the domestic CDS quotes based on its country of origin (denoted as c). Hence, we employ country-specific data as a measure for credit risk, distinguishing it from the other independent variables. We adopt this approach because insurers' sensitivities are significantly influenced by domestic CDS spreads, as evidenced by Düll et al. (2017). For each day t, we compute the relative daily change of each government bond's CDS spread. Thus, the following formula is applicable:

$$r_{CDS,c,t} = \frac{CDS_{c,t}}{CDS_{c,t_{previous}}} - 1 \tag{3}$$

To assess sensitivities to stock markets, we collect daily data on the index prices of Euro Stoxx 50 from Thomson Reuters Eikon. The Euro Stoxx 50 index comprises the stock prices of 50 major corporations with liquid stocks from Eurozone countries, and is widely acknowledged as a reliable indicator for the overall growth of the European economy, as documented by Brechmann and Czado (2013). In an empirical model, the market index returns $r_{m,t}$ account for macroeconomic shocks that influence all insurers simultaneously (cf. Hartley et al. (2017)). Analogously to CAPM betas, we estimate company-level sensitivities to stock market movements, the latter being defined as:

$$r_{m,t} = \frac{Euro\ Stoxx\ 50_t}{Euro\ Stoxx\ 50_{t_{previous}}} - 1 \tag{4}$$

Table 1 below presents the summary statistics of the variables used for measuring interest rate risk, credit risk, and the stock market sensitivity over the entire time period from 2006 to 2019. Sovereign CDS spreads are reported for each relevant country. In terms of absolute values, the daily CDS spreads with a five-year maturity vary from 0.0108% (the lowest value, observed in Finnish government bonds in June 2007) to 232% (the highest value, observed in Greek sovereign debt in January 2013). In a robustness test, we use national stock indices instead of the Euro Stoxx 50 for measuring insurers' sensitivities to stock markets. The summary statistics for national stock indices are shown in Table A2 in Appendix I.

	N	Mean	Median	SD	p1	p5	p95	p99
Insurer characteristics (insurer-day level in ppt)								
$\mathrm{TRI}_{i,t}$ (stock price level)	157,491	4,828	495	15,178	-17.5	-44.2	18,286	99,350
$\mathrm{r}_{i,t}$ (stock return)	157,434	0.04	0.00	2.30	-6.24	-3.14	3.23	6.61
Interest rate risk variables (day level in ppt)								
$\mathrm{y10}_t$ (10-year interest level)	3,519	2.09	2.00	1.58	-0.52	-0.12	4.34	4.59
$\mathrm{r}_{y10,t}$ (10-year hpr)	3,519	0.011	0.018	0.37	-0.97	-0.60	0.59	0.91
Credit risk variables (country-day level in ppt)								
$\mathrm{CDS}_{c,t}$ (CDS level, all countr.)	52,783	2.57	0.36	5.03	0.014	0.021	4.46	23.32
$\mathrm{r}_{CDS,c,t}$ (CDS return, all c.)	52,781	0.13	0.00	3.98	-9.57	-4.92	5.67	12.84
$\mathrm{CDS}_{Austria,t}$ (CDS level)	3,519	0.45	0.26	0.50	0.016	0.018	1.64	2.10
$\mathrm{CDS}_{Belgium,t}$ (CDS level)	3,519	0.62	0.38	0.72	0.021	0.024	2.40	3.09
$\mathrm{CDS}_{Denmark,t}$ (CDS level)	3,519	0.30	0.20	0.33	0.013	0.021	1.17	1.36
$\mathrm{CDS}_{Finland,t}$ (CDS level)	3,519	0.24	0.22	0.19	0.012	0.015	0.68	0.85
$\mathrm{CDS}_{France,t}$ (CDS level)	3,519	0.47	0.31	0.49	0.015	0.017	1.73	2.14
$\mathrm{CDS}_{Germany,t}$ (CDS level)	3,519	0.25	0.18	0.24	0.015	0.017	0.84	1.02
$\mathrm{CDS}_{Greece,t}$ (CDS level)	3,519	28.97	4.85	65.94	0.053	0.079	231.89	231.89
$\mathrm{CDS}_{Ireland,t}$ (CDS level)	3,519	1.59	0.54	2.22	0.018	0.023	7.00	8.56
$\mathrm{CDS}_{Italy,t}$ (CDS level)	3,519	1.43	1.18	1.17	0.061	0.086	4.37	5.35
$\mathrm{CDS}_{Netherlands,t}$ (CDS level)	3,519	0.32	0.24	0.29	0.012	0.018	1.02	1.24
$\mathrm{CDS}_{Norway,t}$ (CDS level)	3,519	0.16	0.14	0.10	0.013	0.016	0.39	0.50
$\mathrm{CDS}_{Poland,t}$ (CDS level)	3,518	0.95	0.73	0.68	0.085	0.135	2.45	3.10
$\mathrm{CDS}_{Slovenia,t}$ (CDS level)	3,518	1.20	0.82	1.08	0.036	0.044	3.73	4.31
$\mathrm{CDS}_{Spain,t}$ (CDS level)	3,519	1.25	0.76	1.29	0.026	0.030	3.97	5.55
$\mathrm{CDS}_{UK,t}$ (CDS level)	3,519	0.37	0.27	0.29	0.013	0.016	0.91	1.27
Equity risk variables (day level in ppt)								
Euro Stoxx 50_t (market index)	3,519	3,165	3,141	559	2,092	2,269	4,242	4,470
$\mathrm{r}_{m,t}$ (market return)	3,519	0.009	0.028	1.38	-3.87	-2.14	2.10	3.47

Note: The stock price and stock return are at insurer-day level and retrieved from Refinitiv. Insurers' sensitivities to interest rates are measured by the hpr of 10-year interest rates collected from the ECB at day level. Credit risk variables are at country-day level and retrieved from S&P Global Markit. For estimating insurers' sensitivities to stock markets, we use the return of the Euro Stoxx 50 index at day level retrieved from Refinitiv. While returns are used for the regression analyses, the table also displays the levels of the corresponding variables for information purposes. The sample starts in March 20th, 2006 and ends in December 30th, 2019 and includes 49 European insurers.

Table 1: Descriptive statistics (stage one)

The Pearson correlation matrix of the previously mentioned independent variables is shown in Table 2 below. Here, $r_{CDS,c,t}$ refers to changes in average CDS spreads across all 15 countries. Notably, the correlation between the interest rate hpr and CDS spread returns are relatively low (0.18). The augmented Dickey-Fuller test and the variance inflation factor suggests that the independent variables are stationary and no multicollinearity is detected. In the empirical model, the variables are used to estimate a measure for each insurers' interest rate risk, credit risk and stock market sensitivities.

Correlation coefficients	$r_{y10,t}$	$r_{CDS,c,t}$	$r_{m,t}$
$r_{y10,t}$	1		
$r_{CDS,c,t}$	0.18	1	
$r_{m,t}$	−0.31	−0.33	1

Table 2: Correlation matrix of independent variables

2.3 Regression model

In the empirical model for the first stage of our regression analyses, we account for the effects of interest rate risk, credit risk, and stock market sensitivities on insurers' stock performance during the period from 2006 to 2019. Considering these three market risk factors in a joint model mitigates the risk of omitted variable bias that could arise when analyzing the market risk factors separately. Similarly, in line with Solvency II requirements, European insurers are mandated to consider all market risks and their interdependencies, as stipulated in Article 164 of the European Commission (2015). In line with previous studies that have performed firm level regressions with stock returns to obtain individual betas (cf. Berends et al. (2013), Campbell et al. (2001) and Da et al. (2012)), we analyze market risk sensitivities at the insurer level using time series data. This approach allows us to investigate the heterogeneity in market risk exposures among insurers, as highlighted by Berends et al. (2013) and Möhlmann (2021). Following the approach of Düll et al. (2017), we apply logarithmic transformations to all variables, allowing us to interpret the beta coefficients as elasticities.

For determining insurers' market risk sensitivities, we use rolling time windows. Thereby, we account for changes in the insurers' risk profiles. The time windows cover a time frame of 10 years each, which results in five periods p: 2006 to 2015, 2007 to 2016, 2008 to 2017, 2009 to 2018 and 2010 to 2019. The motivation behind choosing revolving time frames of ten years, is that our empirical analyses focuses on LTG measures. The decision whether to implement an LTG measure should, in theory, be based on an insurer's long-term risk profile of a firm, which we measure by the sensitivities of stock performance over several years. For each period p, we perform one OLS regression for each of the 49 insurers i in the sample, assuming stock data is available. Thereby, we obtain insurer and period specific measures for interest rate risk, credit risk and stock market sensitivities. This approach provides individual risk profiles of insurance companies based on stock market reactions. The aforementioned periods are also chosen because they include times of crisis such as the global financial crisis (2007-2009) and the European sovereign debt crisis (2010-2013). In these times of crisis, market risk sensitivities of individual companies become more visible on capital markets. By using rolling time windows, we ensure to take into account that insurers' market risk profiles can change over time. The linear regressions for each insurer i in the sample and for each period p are based on the following model:

$$ln(r_{i,t}+1) = \alpha + \beta_{y10,i,p} ln(r_{y10,t}+1) + \beta_{CDS,i,p} ln(r_{CDS,c(i),t}+1) + \beta_{m,i,p} ln(r_{m,t}+1) + \varepsilon_{i,t,p} \quad (5)$$

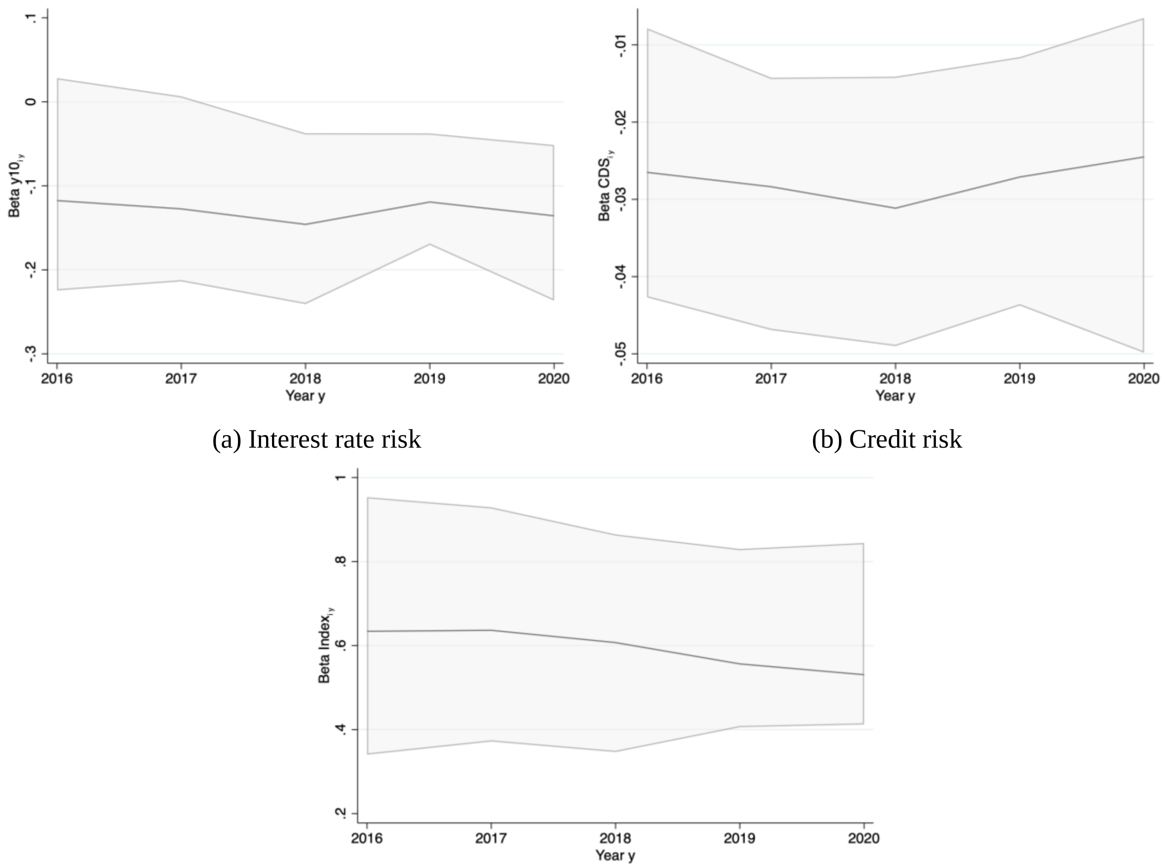
In Equation (5), $c(i)$ reflects the country in which insurer i is headquartered. An insurer's daily stock return, denoted by r_t for each day t, serves as the dependent variable. The first independent variable is $r_{y10,t}$, which indicates the 1-day hpr of an AAA-rated zero coupon bond with 10-year maturity. The second independent variable, $r_{CDS,c,t}$, measures changes in the CDS spreads of domestic sovereign debt, based on an insurer's country of headquarters. The last independent variable, $r_{m,t}$, reflects daily changes in the Euro Stoxx 50 index. The residual term in the regression model is denoted by ε_t. We store the estimated beta coefficients and t-values for each insurer i, period p, and independent variables from all 232 regressions as the ingredients for our stage two empirical analysis in chapter 3. The betas and t-values indicate the direction of the relationship between each market risk and each insurer's stock price, as well as the magnitude of their influences during a given time window. Furthermore, high absolute t-values demonstrate the statistical significance of the relationship.

2.4 Resulting sensitivities

Our findings on insurers' sensitivity to market risk are broadly consistent with previous empirical studies. In terms of interest rates, insurers typically benefit from higher 10-year interest rates, i.e., they suffer from an increasing hpr (c.f. Hartley et al. (2017), Grochola et al. (2021)). Our estimated betas range between -0.927 and 0.302 with a median of -0.128 and 78% of coefficients being negative.[6] More precisely, for an insurer in the median, a 1% decrease in the one-day hpr of 10-year rates causes a 0.128% reduction in the insurer's stock return holding the other regressors constant. Out of 232 estimated regression coefficients for interest rate risks, 41% are statistically significant on the 10% level. The development of the distribution of estimated interest rate betas over time is illustrated in Figure 1a) where the median is shown

[6] According to our estimates, the insurer suffering most from falling interest rates in our sample is Storebrand ASA, the largest life insurer in Norway. In contrast, the insurer benefitting most from falling interest is Pozavarovalnica Sava dd, a relatively small non-life insurer from Slovenia.

along with the 25th and 75th percentile (upper and lower threshold of area with a gray background). For each year y (2016 to 2020), we display the betas estimated based on the ten years prior to the given year. For instance, the insurer level beta coefficients for the year 2020 depend on the stock return sensitivities in the period from 2010 to 2019. While the median interest rate beta is relatively constant over time, the interval of 50% of all estimates is becoming narrower, as the time period of the global financial crisis is not (or not completely) covered when estimating the regression coefficients for later years.



(a) Interest rate risk (b) Credit risk

(c) Stock market sensitivities

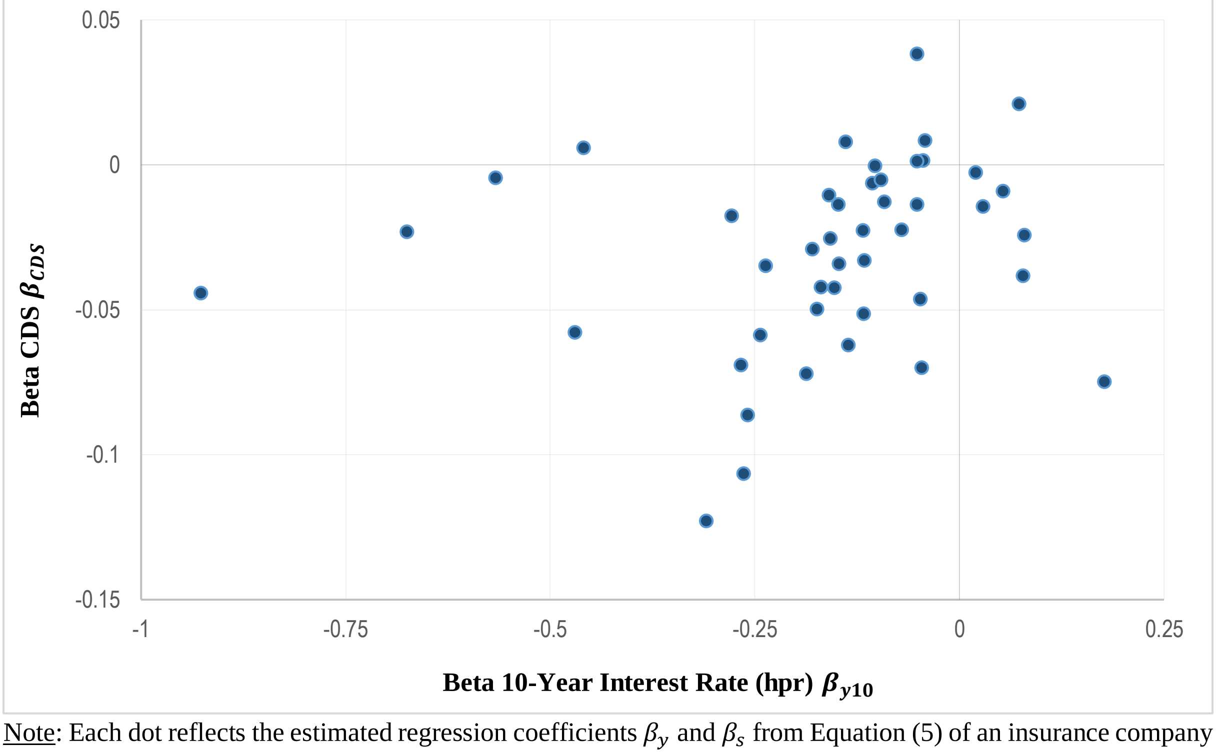
Note: The regression coefficients (y-axis) are estimated based on the insurer-level regression analyses formulated in Equation (5). The sensitivities of each year depend on the influence of the individual market risk factors on the stock performance of insurers in the ten years prior to year y (x-axis). The upper (lower) line reflects the 75th percentile (25th percentile) of the distribution in a given year. The middle line reflects the median. The gray area corresponds to the interval of 50% of beta estimates.

Figure 1: Estimated betas from stage one

Regarding credit risk sensitivities, European insurers on average benefit from a lower probability of default on domestic sovereign debt in line with Düll et al. (2017) and Grochola et al. (2021). More clearly than for interest rates, the estimated coefficients are mostly negative

(91% of all betas) and significant on the 10% level (67% of all betas).[7] The median value implies that an insurer's stock return decreases by 0.028% ceteris paribus after a 1% rise in domestic CDS spreads. The effect of a 1% change is, thus, smaller compared to 10-year interest rates. As shown in Figure 1b), the interval of 50% of all betas is relatively constant over time.

Insurers' sensitivities to stock market performance are the most relevant drivers of insurers' stock returns. The relationship is positive for all insurers and the coefficients are significant on a 10% level for 97.8% of firms. Thus, insurers' stock returns are positively connected to the Euro Stoxx 50 Index, even when controlling for interest rate and CDS spread changes.[8] Thus, stock market movements are the most relevant driver of insurers' stock returns in our model. Figure 1c) shows that both the 75th percentile and the median of regression coefficients are slightly falling in later years, indicating a lower dependence of insurers' performance on stock markets or overall economic growth in Europe.



Note: Each dot reflects the estimated regression coefficients β_y and β_s from Equation (5) of an insurance company in the period from 2010 to 2019. A company located at the bottom left would substantially suffer from falling interest rates and from rising default probabilities of domestic sovereign debt.

Figure 2: Insurer-specific estimates for sensitivities to interest rate and CDS fluctuations

[7] The largest credit risk sensitivities can be observed for Belgian insurers, with beta coefficients as low as -0.16. According to our data, the stock returns of Ageas SA and KBC Groep NV suffer most from rising domestic sovereign CDS spreads. We do not find insurers who significantly benefit from rising CDS spreads.

[8] We observe the highest stock market sensitivity coefficients of up to 1.49 for two large insurance groups: Aegon NV from the Netherlands and AXA SA from France.

Anecdotal evidence shows that the insurers that suffer most from falling interest rates and rising CDS spreads tend to use LTG measures more frequently. Of the 10 firms for which we estimate the highest interest rate risk (credit risk) in Figure 2, nine insurers (eight insurers) use at least one LTG measure. More specifically, we observe that many insurers with higher interest rate risk use the volatility adjustment and it has a relatively larger impact on their reported solvency ratio. Similarly, insurers with higher credit risk use tend to use the matching adjustment, which can substantially increase the solvency ratio. Anecdotal evidence for five insurance companies with large market risk sensitivities is shown in Figure A1 in Appendix II.

Notably, the estimated beta coefficients measuring sensitivities to interest rate β_{y10} and credit risk β_{CDS} are almost perfectly uncorrelated, as shown in Table 3. The correlation coefficients are negative and larger between the betas for stock market sensitivities β_m and the two other market risk betas. This indicates that insurers that suffer more from falling interest rates or rising CDS spreads tend to also suffer more from falling stock market indices.

Correlation coefficients	β_{y10}	β_{CDS}	β_m
β_{y10}	1		
β_{CDS}	0.01	1	
β_m	−0.40	−0.37	1

Table 3: Correlation matrix of market risk estimates (betas)

All estimated betas on the insurer level, which are used for the second stage of regression analyses described in Section 3, are presented in Table A3 Appendix II.[9] The summary statistics are shown in Table 4.

3 Determinants of long-term guarantee measures

3.1 Data

In the second stage of the empirical analysis, we investigate insurers' discretionary decisions under Solvency II. For this purpose, we use data published in the SFCRs of the years 2016 to 2020 for all 49 stock insurers in the sample on the group level. Quantitative regulatory data for 164 out of 233 insurer-year observations could be gathered from the data provider SNL and are based on the Quantitative Reporting Templates (QRTs). We have substantially double-checked the SNL data with the original SFCRs and have corrected seven insurer-year observations. To the best of our knowledge, neither SNL nor any other data provider offers data about the

[9] The missings ("NA") in Table A3 can be explained either by missing stock price data (e.g., ASR Nederland NV has not been listed on the stock market until June 10th 2016) or by removed insurer-year observations due to missing SFCR data.

composition of internal models as reported in the SFCRs. Therefore, we have hand-collected information from the SFCRs about important aspects of the design of internal models, such as whether certain modules are modeled internally and whether the risk related to investments in EU government bonds are taken into consideration. While the majority of SFCRs and the attached Quantitative Reporting Templates (QRTs) is in English language, we also manage to collect data from nine insurers (33 insurer-year observations) that did not publish their reports in English language.

In terms of the QRT data, our focus is on information which is based on the firm managements' discretionary decisions. This is mainly reflected by the use of LTG measures, i.e., the matching and volatility adjustment as well as the transitionals on technical provisions and interest rates.[10] These measures were introduced in 2014 as an amendment to the Solvency II framework directive. The matching (77b and c) and volatility adjustment (77d) were subordinated to article 77 of the European Commission (2009) which deals with the calculation of technical provisions. The other two LTG measures were introduced in a chapter dealing with transitional provisions for insurers and reinsurers in the articles 308c and 308d of the European Commission (2009)). These transitionals can only be used temporarily and allow insurers to gradually adjust to the regulatory changes in the calculation of capital reserves and risk-free interest rate assumptions for contracts concluded before 2016 until the year 2032 (cf. EIOPA (2016b)).

All these LTG measures influence – and typically improve – the reported solvency of insurance companies. Solvency II regulation prescribes capital buffers in form of SCR to cover for the potential negative consequences of an insurer's true risk profile. The SCR shall ensure that the undertaking's ruin probability over a one-year time horizon does not exceed 0.5%. It covers various types of risks including market risks, insurance risks (health, life, non-life), default risk and operational risks. The central outcome of Pillar I, which focuses on quantitative requirements towards insurers, is the Solvency Ratio which equals a firm's eligible Own Funds divided by its SCR:

$$Solvency\ Ratio_{i,y} = \frac{Eligible\ Own\ Funds_{i,y}}{SCR_{i,y}} \tag{6}$$

The Solvency Ratio is regularly used as a standalone figure reflecting an insurer's solvency position (cf. Crean and Foroughi (2017) and Mukhtarov et al. (2022)). Both the numerator and the denominator of the solvency ratio can be influenced by the use of LTG measures. The effect

[10] In our definition, LTG measures comprise the matching and volatility adjustment as well as both transitionals like in the definition provided by EIOPA (2020).

of each measure on the own funds and on the SCR on the group level is typically presented in an insurers' QRT S.22.01.22.[11] Insurance groups that do not use any LTG measure in a given year, do not need to report QRT S.22.01.22 when publishing their SFCR. For these insurers, we collect data on the eligible own funds and the SCR from QRT S.23.01.22 which focuses on the composition of own funds and which presents the Solvency ratio. Notably, all SFCRs and corresponding QRTs are publicly available and typically accessible via an insurer's investor relations section. Table A4 in Appendix III presents all hand collected quantitative data from the SFCRs for the years 2016 to 2020 from all 49 insurance companies in the sample and the chosen model for SCR calculation. In fact, there is a large heterogeneity in the application of the LTG measures across European insurers. Notably, particularly large insurers typically make use of at least one of the four LTG measures.

In our sample, the number of insurer-year observations with an applied LTG varies between 149 for the volatility adjustment and 6 for the transitional for interest rates, summing up to 262 observations. In 259 out of 262 observations, the LTG measure increases the reported solvency ratio. The three exceptional cases with an LTG measure reducing the solvency ratio occur for insurers that apply three LTG measures simultaneously over several years and with one of the three measures temporarily having a negative effect on the solvency ratio. In only one case, the effect is greater than 1ppt.[12] If the individual effects are summed up, the LTG measures always result in an increase in the solvency ratio. While the positive effect of LTGs on the solvency ratio reflects leeway in the implementation of Solvency II, their use includes potentially relevant information for policyholders, investors and other stakeholders. For this purpose, we investigate which factors drive those discretionary decisions and how strongly they impact the solvency ratio.

As we systematically analyze SFCRs and the corresponding QRTs, we calculate the impact of the use of the four LTG measures on the solvency ratio from Equation (6). In 2016, the average solvency ratio would have been 60ppt lower without the use of these measures (cf. EIOPA (2016b)). This difference was shrinking to 28ppt in 2020, reflecting that the influence of LTG measures, and particularly of the transitionals, on the solvency ratio reduces with insurers

[11] Few insurers use the more extensive QRT S.22.01.21, which is binding for insurers on the solo entity level, to also report the influence of LTG measures on the group level.

[12] Two of the three cases are attributable to the Spanish multiline insurer Mapfre SA. The company uses three LTG measures in all years in the sample. While the matching adjustment increases the solvency ratio by about 3ppt until 2018, the effect is negative in 2019 (-6.37ppt) and 2020 (-0.84ppt). Nevertheless, in both years the other LTG measures lead to an overall increase in the solvency ratio as a result of the LTG measures. In the case of Phoenix Group Holdings, the volatility adjustment has a slightly negative effect in 2019 (-0.002ppt), while two other LTG measures each substantially increase the solvency ratio (by around 40ppt each).

adapting to the new regulation (cf. EIOPA (2020)). Similarly, the share of insurers which needed LTG measures in order to report an at least 100% solvency ratio fell from 11% in 2017 to 4% in 2020 (cf. EIOPA (2017b, 2020)).[13] In our sample, the share of noncompliance with SCR without LTG measures would be between 6% and 7.3% of observations where the former is the more conservative estimate.[14] A ratio below 100% indicates that an insurer's own funds are insufficient to meet regulatory requirements under the first pillar of Solvency II. In this case, insurers are obligated to take corrective actions within six months to restore compliance (cf. EIOPA (2016b)). The consequences depend on the severity of the situation and the regulations of the corresponding national supervisory authority. Potential actions can be capital injections, recovery and restructuring plans, and sanctions.[15]

In our analyses, we want to include the solvency ratio that insurers would experience without using LTGs. Based on the QRTs, this information cannot be precisely calculated, since the QRTs only report the impact per LTG and these impacts cannot be summed up across LTGs. In fact, the LTG measures influence each other, and therefore the exact solvency ratio without all LTG measures cannot be determined for insurers using at least one of the adjustments or transitionals in the same year. Hence, we calculate for each LTG measure k, each insurer i and each year y the solvency ratio in the absence of this LTG. If an insurer does not use LTG k in a given year, then the impact of the LTG equals zero.

$$Solvency\ pre\ LTG\ k_{i,y} = Solvency\ Ratio_{i,y} - Impact\ of\ LTG\ k_{i,y} \\ ,with\ k = \{1,2,3,4\} \tag{7}$$

The overall descriptive statistics of the variables used in the second stage of our empirical analysis are presented in Table 4. This includes the Solvency II quantitative data mentioned in Equation (7) and binary variables reflecting the composition of internal models. As potential determinants of insurers discretionary choices regarding LTG measures we use the insurer level beta coefficients estimated in the first stage and two distinguishing firm characteristics: the share of insurance reserves stemming from life and health insurance business and the natural

[13] Note that there are also cases where insurers report solvency ratios below 100% and do not use LTG measures. One example is the Cypriot non-life insurer Cosmos Insurance PCL with a reported solvency ratio of 65.6% in 2016. Thus, the insurer did not comply with the SCR in the given year and had to initiate a recapitalization and restructuring plan to bolster its solvency position.

[14] 6% represents the share of solvency ratios below 100% when excluding the LTG measure with the largest impact for a given insurer-year. 7.3% is the share when adding up the effects of all LTG measures. We do not observe a case where insurers do not fulfill the SCR according to their reported solvency ratio.

[15] The consequences are more severe if an insurer does not comply with the Minimum Capital Requirement (MCR). The MCR usually accounts for 25% to 45% of SCR and represents the minimum level of financial security mandated by Solvency II. If an insurer does not comply with the MCR, the supervisor intervenes and withdraws the firm's business license if the MCR is not met again within a period of three months (cf. EIOPA (2016b)).

logarithm of the size (measured by total tangible assets). Without the firm characteristics, we have 232 total observations and our models including the firm characteristics rely on 225 observations.[16]

	N	Mean	Median	SD	p1	p5	p95	p99
Beta coefficients from Stage 1								
Beta y10$_{i,y}$ (interest rate risk sensitiv.)	232	-0.14	-0.13	0.18	-0.74	-0.46	0.11	0.23
Beta CDS$_{i,y}$ (credit risk sensitivity)	232	-0.03	-0.03	0.03	-0.15	-0.09	0.01	0.03
Beta Index$_{i,y}$ (equity risk sensitivity)	232	0.65	0.62	0.36	0.06	0.10	1.36	1.48
Solvency II quantitative data (in ppt)								
VA Impact$_{i,y}$ (abs. effect on Solvency)	233	0.11	0.02	0.20	0.00	0.00	0.49	0.98
MA Impact$_{i,y}$ (abs. effect on Solvency)	233	0.07	0.00	0.26	0.00	0.00	0.50	1.57
TP Impact$_{i,y}$ (abs. effect on Solvency)	233	0.11	0.00	0.21	0.00	0.00	0.58	0.77
Solvency pre VA$_{i,y}$	233	1.92	1.86	0.45	1.12	1.26	2.81	3.16
Solvency pre MA$_{i,y}$	233	1.96	1.98	0.54	0.25	1.00	2.85	3.18
Solvency pre TP$_{i,y}$	233	1.92	1.93	0.42	0.99	1.23	2.57	3.16
Solvency pre LTG$_{i,y}$	233	1.80	1.79	0.49	0.25	0.98	2.49	3.11
Solvency II modeling								
Internal Model$_{i,y}$ (binary)	233	0.51	1.00	0.50	0.00	0.00	1.00	1.00
Internal Market Risk$_{i,y}$ (binary)	233	0.41	0.00	0.49	0.00	0.00	1.00	1.00
Internal Interest Rate Risk$_{i,y}$ (binary)	233	0.36	0.00	0.48	0.00	0.00	1.00	1.00
Internal Spread Risk$_{i,y}$ (binary)	233	0.39	0.00	0.49	0.00	0.00	1.00	1.00
Internal Default Risk$_{i,y}$ (binary)	233	0.32	0.00	0.47	0.00	0.00	1.00	1.00
EU Gov Bond Spread Risk$_{i,y}$ (binary)	233	0.19	0.00	0.40	0.00	0.00	1.00	1.00
EU Gov Bond Default Risk$_{i,y}$ (binary)	233	0.09	0.00	0.28	0.00	0.00	1.00	1.00
Firm characteristics								
Life Share$_{i,y}$ (in ppt)	226	0.42	0.45	0.29	0.00	0.00	0.85	0.96
ln(Size$_{i,y}$)	231	17.35	17.59	2.00	12.97	14.09	20.39	20.63

Note: The variables for stage two of regression are all at insurer-year level. The beta coefficients are collected from stage one described in Section 2. All Solvency II data (both quantitative and qualitative) is hand-collected from SFCRs. Further firm characteristics are retrieved from SNL. The sample starts in 2016 and ends in 2020. It includes 49 European insurers.

Table 4: Descriptive statistics (stage two)

The four LTG measures have different functions. To gradually adapt to the changes in the regulatory framework from Solvency I to Solvency II, insurance companies are allowed to use transitionals for technical provisions (1) and interest rates (2). The transitional for technical provisions enables insurers to smooth the capital impact over a 16-year period, during which the effect of the transitional is linearly decreasing. Similarly, the transitional for interest rates spreads the impact of the change in interest rate calculation standards over the same period (cf. EIOPA (2018)). The former is applied by 35.6% of stock insurers in the sample in 2020 and considerably increases their solvency ratios by 27.4ppt on average (cf. Figure 3). The effect is however decreasing over time, as the transitional has led to an average increase by 35.3ppt in 2016. In contrast, the transitional for interest rates is not being used on a large scale, as only between one and two insurers per year are applying it in our sample. Thus, we do not perform

[16] The difference between the number of observations for beta coefficients and solvency II quantitative data stems from the Dutch life insurer ASR Nederland who has not been listed on stock markets until June 10, 2016. Thus, no regressions have been performed in the first stage for this insurer in year 2016. In terms of firm characteristics, we have missing life insurance share data for KBC Groep NV from Belgium and Old Mutual PLC from the U.K.

regressions for analyzing the determinants of the transitional on interest rates. Instead, for the transitional on technical provisions, we expect it to be particularly used by insurers with an otherwise low solvency ratio.

Furthermore, the impact of the volatility (3) and the matching adjustment (4) on the solvency ratio could be related to insurers' market risk sensitivities. Because the volatility adjustment mitigates the effect of short-term fluctuations in financial markets, we expect it to be particularly relevant for insurers with wide duration gaps and higher interest rate risks. Notably, this measure is applied by even 68.9% of insurers in our sample in 2020 (cf. Figure 3) and is thus becoming more popular over time (50.9% in 2016) while the average effect is relatively constant. The use of the matching adjustment is tied to legal requirements including adequate duration matching and the declaration to hold assets until maturity (cf. EIOPA (2018)). Thus, it is only being applied by few insurance companies. Typically, the matching adjustment lowers capital requirements for spread risk and thereby leads to a higher solvency ratio. We expect this measure to be mainly applied by insurers with riskier fixed-income investments and thus higher credit risk sensitivities. Out of the four measures, the matching adjustment has the largest average impact on the solvency ratio with 59.1ppt. Both, its share and its impact are relatively constant over the sample period.

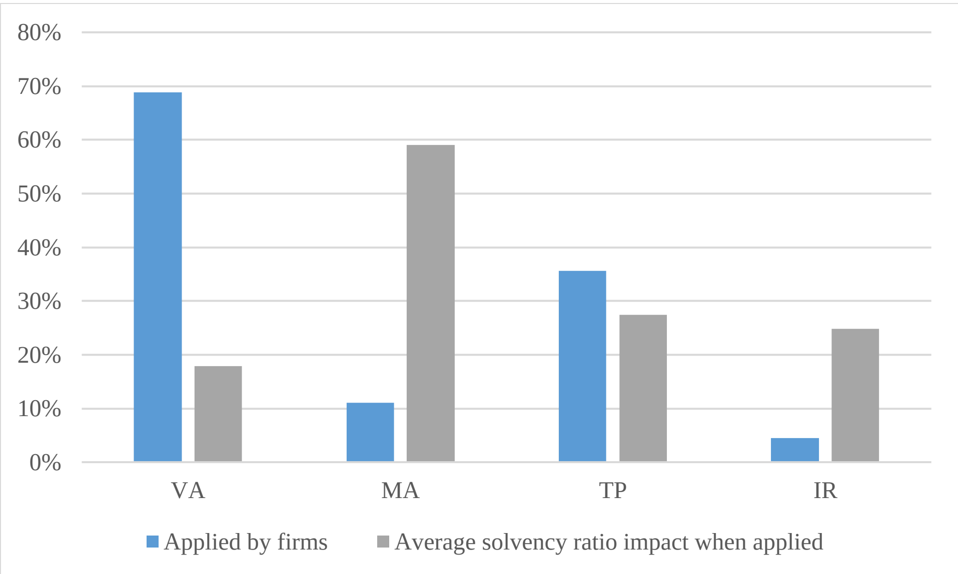


Figure 3: Use of LTG measures in 2020

Figure 3 illustrates the use of LTG measures in the year 2020, where "VA" stands for volatility adjustment, "MA" for matching adjustment", "TP" for transitional for technical provisions and "IR" for transitional for interest rates. The blue columns "Applied by firms" show how many insurers in our sample use a certain LTG measure and the gray columns "Average solvency ratio impact when applied" demonstrate the mean effect for those firms that use this transitional or adjustment. We observe extreme cases with the volatility adjustment improving a solvency ratio from 102% to 230% and the matching adjustment improving a solvency ratio from just 25% to 189%.

In addition to the LTGs, there are several further discretionary decisions in the calculation of the Solvency Capital Requirement, which we collect from SFCRs. Specifically, we investigate whether insurers use an internal model or the standard formula. Note that the standard formula determines the SCR in a multilevel approach. At the lowest level, the so-called submodules, the SCR is determined for example for interest rate risks and spread risks. These submodules are aggregated to the module level. Interest rate risks and spread risks are part of the module for market risks. Another module reflects the SCR for default risks. Insurers can replace the complete SCR calculation with their own "full" internal model, or they could place only (sub)modules by a "partial" internal model. Internal models are meant to fit better to the insurers' risk profile and need to be approved by the regulator. We have collected the information about the SCR calculation mostly from the section E.4 in SFCRs entitled "Section E.4: Differences between the standard formula and any internal model used". Overall, we find for 51% of insurer-year observations that insurers use a full or partial internal model (cf. Table 4). Only few insurers (9.4% of observations) in our sample use full internal models on the group level. A substantially larger share of insurers (41.6% of observations) uses partial internal models. For these firms, it is particularly interesting to observe which modules they calculate internally and to investigate potential drivers of these decisions. Thus, we design several binary variables shown in Table 4. For instance, $Internal\ Market\ Risk_{i,y}$ equals one if an insurer i in a given year y uses an internal model for the SCR market risk module (meaning that at least one submodule is modelled internally), and zero otherwise. $Internal\ Interest\ Rate\ Risk_{i,y}$ equals one if the interest rate submodule, which is subordinated to the market risk module, is modeled internally.

We further investigate whether insurers using internal models take into account the spread risk and default risk for investments in government bonds issued by countries from the European Union (EU) when calculating their SCR. According to Article 180 (2) of the European Commission (2015) insurers are not required to account for the sovereign credit risk from these investments under Solvency II. While this regulation provides an incentive to invest in EU government bonds, it has been criticized for neglecting a market risk even though Solvency II aims at a market-consistent valuation of assets and liabilities (cf. Wilson (2013), Thibeault and

Wambeke (2014), Düll et al. (2017)). For EU sovereign spread risk (default risk), we find for 19% (9%) of insurer-year observations that insurers include this type of risk in their SCR calculation on a voluntary basis (cf. Table 4).

3.2 Empirical approach

We now investigate to what extent the market risk sensitivities from stage one of our empirical analysis (cf. chapter 2) and/or other insurer characteristics influence the insurers' discretionary decisions in the implementation of Solvency II.

In a first series of analyses, we explain the usage of LTG measures. To this end, we consider regression models with the impact of the LTG measure on the solvency ratio as the dependent variable (VA, MA and TP impact). Regressors are the market risk sensitivities from stage 1 as well as the solvency ratio calculated without the LTG from Equation (7), indicating whether a measure is applied to increase the reported solvency ratio. Furthermore, we control for the size of the companies which is measured by the natural logarithm of tangible assets and the share of life insurance business measured by the portion of technical provision from life and health insurance. The data for the two variables for size and life business are collected from SNL Financial Data. As our sample consists of 49 insurance companies and we observe their solvency situation at three different points in time, we perform panel regressions.

For each model, we use the Hausman test to find whether fixed effects exist. In our models for the VA impact and MA impact, the Hausman test suggests that fixed effects are not significant (p-values > 0.2) and hence, we use the more efficient random effects models which also account for autocorrelation. Notably, our results for these models are robust to using fixed effects. Only in the model for the TP impact, we implement a fixed effects regression model, as suggested by the Hausman test (p-value = 0.0001). Thus, we estimate the following three models:

$$\begin{aligned} VA\ impact_{i,y} = \sum_{j=1}^{3} \beta_j\ Sensitivity_{j,i,y} + \beta_4\ Solvency\ pre\ VA_{i,y} + \beta_5\ ln(Size_{i,y}) \\ + \beta_6\ Life_{i,y} + \alpha_i + \varepsilon_{i,y} \end{aligned} \tag{8}$$

$$\begin{aligned} MA\ impact_{i,y} = \sum_{j=1}^{3} \beta_j\ Sensitivity_{j,i,y} + \beta_4\ Solvency\ pre\ MA_{i,y} + \beta_5\ ln(Size_{i,y}) \\ + \beta_6\ Life_{i,y} + \alpha_i + \varepsilon_{i,y} \end{aligned} \tag{9}$$

$$TP\ impact_{i,y} = \sum_{j=1}^{3} \beta_j\ Sensitivity_{j,i,y} + \beta_4\ Solvency\ pre\ TP_{i,y} + \beta_5\ ln(Size_{i,y}) + \beta_6\ Life_{i,y} + u_{i,} + \varepsilon_{i,y} \tag{10}$$

All variables in Equations (8) – (10) relate to an insurer i in year y. $Sensitivity_{j,i,y}$ represents the estimated beta coefficients towards the three market risks j from the first stage of the empirical analysis. These are $\beta_{y10,i,p}$, $\beta_{CDS,i,p}$ and $\beta_{m,i,p}$ from Equation (5) measuring the sensitivities of insurers to long-term interest rates, sovereign CDS spreads and the Euro Stoxx 50 stock market index.[17] $Solvency\ pre\ LTG\ k_{i,y}$ is model-specific and subtracts the value of the dependent variable from the solvency ratio in line with Equation (7). Thus in each model, β_4 indicates whether the probability to use and the extent of the impact of an LTG measure is higher for an insurer with otherwise low solvency ratios. Based on the variance inflation factors that never exceed a value of 10 for the variables of interest, there is no evidence of multicollinearity. We control for $ln(Size_{i,y})$ and the share of life insurance reserves $Life_{i,y}$. α_i represents random effects, $u_{i,}$ insurer fixed effects and $\varepsilon_{i,y}$ is the error term.

In a second series of analyses, we explore the drivers of discretionary decisions in terms of the SCR calculation. For this purpose, we perform logistic regressions with the binary variables for Solvency II modeling (cf. Table 4) as dependent variables. We assume random effects and, for the most part, we use the same independent variables as in previous models. One difference refers to the calculation of the solvency ratio without LTG measures. Since Solvency II does not allow the effects of LTG measures to be added up, we define the variable as: [18]

$$Solvency\ pre\ LTG1_{i,y} = Solvency\ Ratio_{i,y} - max\{Impact\ of\ LTG\ k_{i,y}\} \tag{11}$$

The general formula for the logistic panel regressions is shown below. Please note that the binary variable dependent binary variable differs across our models (e.g., instead of $Binary_{i,y}$, we use $Internal\ Model_{i,y}$, $EU\ Gov\ Bond\ Spread\ Risk_{i,y}$, etc.).

$$log \frac{P(Binary_{i,y} = 1)}{1 - P(Binary_{i,y} = 1)} = \sum_{j=1}^{3} \beta_j\ Sensitivity_{j,i,y} + \beta_4\ Solvency\ pre\ LTG1_{i,y} + \beta_5\ ln(Size_{i,y}) + \beta_6\ Life_{i,y} + \alpha_i + \varepsilon_{i,y} \tag{12}$$

[17] Note that, for instance, $Sensitivity_{m,i,2020} = \beta_{m,i,2010-2019}$, because we use 10-year time windows to estimate the betas in stage one of our empirical analysis (cf. chapter 2.3). To avoid a reverse causality issue, we lag the end of the time window period p by one year relative to the year y.

[18] The empirical findings for the drivers of internal models are robust to using the reported solvency ratio instead of $Solvency\ pre\ LTG1_{i,y}$.

3.3 Results

The regression results for our empirical models investigating the determinants of the impact of LTG measures on the solvency ratio are illustrated in Table 5, Table 6 and Table 7. While the regression models in the columns (1) – (2) are robustness tests, our empirical models from Equations (8) to (10) which are described in the previous section are tested in column (3).

	(1)	(2)	(3)
Dependent variable:	VA Impact$_{i,y}$ (ppt effect on Solvency ratio)		
Solvency pre VA$_{i,y}$	-0.080***	-0.082***	-0.083***
	(0.000)	(0.000)	(0.000)
Beta y10$_{i,y}$	-0.198***		-0.208***
	(0.003)		(0.003)
Beta CDS$_{i,y}$	0.171		0.230
	(0.627)		(0.537)
Beta Index$_{i,y}$	0.042		-0.032
	(0.443)		(0.626)
ln(Size$_{i,y}$)		0.024**	0.023
		(0.037)	(0.106)
Life Share$_{i,y}$		0.159**	0.149**
		(0.029)	(0.043)
No. of obs.	232	226	225
No. of insurers	49	47	47
R^2 within	0.064	0.029	0.058
R^2 overall	0.206	0.335	0.371
R^2 between	0.230	0.365	0.403
Standardized beta coefficients			
Beta y10$_{i,y}$	-.18		-.19

Note: Random effect regressions of insurers' yearly use of the volatility adjustment on market risk coefficients from 2016 to 2020. Sources: SFCRs (impact of long term guarantees measures and transitionals from QRT S.22.01.22), SNL (insurer-level size and share of life insurance reserves). The market risk coefficients (betas) are estimated in the first stage of regression analyses. ***, **, * indicate significance at the 1%, 5% and 10% levels respectively. P-values are in parentheses.

Table 5: Determinants of the impact of the volatility adjustment on the solvency ratio

For the volatility adjustment and the empirical results presented in Table 5, the solvency ratio without the LTG has a highly significant impact. The coefficient -0.083 implies that for two otherwise identical insurance companies with solvency ratios that differ by 100ppt, the insurer with the lower value will on average adjust its reported solvency ratio by 8.3ppt upwards solely by the use of the volatility adjustment.

Moreover, the results reveal that a higher interest rate risk as perceived by financial investors has a significant effect on the impact of the LTG measure on the solvency ratio.[19] A 1ppt decrease in the sensitivity measure $\beta_{y10,i,p}$ from the first stage of regression analysis in Section 2 leads to a ceteris paribus rise in the influence of the volatility adjustment by 0.21ppt (column

[19] Note that a negative coefficient implies that insurers who suffer a lot from falling interest rates use the LTG measure to a larger extent.

(3)). The standardized beta coefficients imply that a one standard deviation decrease in $\beta_{y10,i,p}$ (0.18ppt, cf. Table 4) increases the impact of the volatility adjustment by 0.19 standard deviations (0.038ppt). This finding can be explained by the fact that the volatility adjustment immunizes insurers against short-term changes in interest rates. Therefore, firms that are more sensitive towards fluctuations in long-term yields tend to make use of the adjustment on a large scale. Our result indicates that insurers applying the volatility adjustment are characterized by a wider duration gap and/or large bond investments. This finding can be particularly interesting for policyholders and investors trying to filter relevant information regarding interest rate risk from SFCRs. Notably, the effect is still significant when controlling for the portion of technical provisions from life insurance business. Also, we find that the impact of the volatility adjustment on the solvency ratio is significantly higher for life insurers. In fact, a pure life insurer adjusts its solvency ratio by approximately 15ppt upwards by using the volatility adjustment in comparison with an otherwise equal pure non-life insurer. According to the empirical analysis, the sensitivities towards equity and credit risk cannot be identified as significant determinants for the use and the influence of the volatility adjustment. The effect of $ln(Size_{i,y})$ is borderline insignificant in column (3), however the coefficient indicates that the volatility adjustment is rather being used by large insurers.

The regression results for the matching adjustment are shown in Table 6. While a significant effect of $Solvency\,pre\,MA_{i,y}$ can be observed in column (1) and (2), it is borderline insignificant in column (3). Thus, even though the matching adjustment has the largest average impact on the solvency ratio of all LTG measures, we do not find evidence that it is more frequently being used by insurers with otherwise low solvency ratios. Also, the coefficients for $Solvency\,pre\,MA_{i,y}$ are substantially smaller compared with the correspondent variable $Solvency\,pre\,VA_{i,y}$ in Table 5.

Nevertheless, the empirical results verify a significant effect of the credit risk measure on the use of the matching adjustment. A 1ppt decrease in $\beta_{CDS,i,p}$ leads to an increase in the impact of the matching adjustment by 0.527ppt (column (3)), keeping all other variables constant. The standardized beta coefficients are roughly twice as high as for the volatility adjustment and $\beta_{y10,i,p}$. Thus, ceteris paribus, an insurer with a by one standard deviation lower $\beta_{CDS,i,p}$ (0.03ppt, cf. Table 4) experiences a by 0.37 standard deviations higher matching adjustment impact (0.0962ppt). The effect of the credit risk sensitivities is reasonable considering that the matching adjustment typically lowers the capital requirements for spread risk and, thus, leads to a decrease in the SCR. As a consequence, insurers with larger credit risk sensitivities, e.g., due to riskier assets, have a higher incentive to use this LTG measure. In addition, empirical results indicate that the impact of the matching adjustment on the solvency ratio is significantly more pronounced for larger insurers. This finding is particularly related to the high regulatory requirements that are tied to the permission to use LTG measures in terms of adequate duration matching.

Dependent variable:	(1)	(2)	(3)
	MA Impact$_{i,y}$ (ppt effect on Solvency ratio)		
Solvency pre MA$_{i,y}$	-0.021**	-0.019*	-0.017
	(0.049)	(0.090)	(0.115)
Beta y10$_{i,y}$	-0.036		-0.019
	(0.298)		(0.609)
Beta CDS$_{i,y}$	-0.594***		-0.527***
	(0.001)		(0.007)
Beta Index$_{i,y}$	0.011		-0.016
	(0.779)		(0.701)
ln(Size$_{i,y}$)		0.042***	0.040***
		(0.000)	(0.000)
Life Share$_{i,y}$		-0.040	-0.009
		(0.450)	(0.863)
No. of obs.	232	226	225
No. of insurers	49	47	47
R^2 within	0.061	0.045	0.095
R^2 overall	0.199	0.208	0.206
R^2 between	0.199	0.225	0.218
Standardized beta coefficients			
Beta CDS$_{i,y}$	-.43		-.37

Note: Random effect regressions of insurers' yearly use of the matching adjustment on market risk coefficients from 2016 to 2020. Sources: SFCRs (impact of long term guarantees measures and transitionals from QRT S.22.01.22), SNL (insurer-level size and share of life insurance reserves). The market risk coefficients (betas) are estimated in the first stage of regression analyses. ***, **, * indicate significance at the 1%, 5% and 10% levels respectively. P-values are in parentheses.

Table 6: Determinants of the impact of the matching adjustment on the solvency ratio

Moreover, in Table 7 we investigate the impact of the transitional for technical provisions which can only be used temporarily and allows insurers to gradually adjust to the changes in the calculation of capital reserves from Solvency I to Solvency II until the year 2032. The coefficient of the solvency ratio calculated without the LTG measure, $Solvency\ pre\ TP_{i,y}$, is negative and highly significant. Thus, more solvent insurers are less likely to use the LTG measure. According to column (3), which corresponds to the model presented in Equation (10) including fixed effects, for two otherwise equal insurers which a solvency ratio differing by 100ppt, the less solvent insurers will use the transitional to adjust its solvency ratio upwards by 10ppt on average.

Like for the volatility adjustment, the coefficient of $\beta_{y10,i,p}$ is negative and significant for the transitional on technical provisions, showing that insurers facing higher interest rate risk tend to use the LTG measure more frequently and to a larger extent (cf. Table 7). The standardized beta coefficients, however, are closer at 0 and the p-value is larger. For this transitional, we do not find further significant determinants driving insurer's decisions towards using the measure to a large extent. Hence, it seems that the use of this transitional can be driven by several factors which differ among insurers and potentially also among countries such as the requirements of national supervisors.

	(1)	(2)	(3)
Dependent variable:	TP Impact$_{i,y}$ (ppt effect on Solvency ratio)		
Solvency pre TP$_{i,y}$	-0.096***	-0.093***	-0.100***
	(0.000)	(0.000)	(0.000)
Beta y10$_{i,y}$	-0.144*		-0.166*
	(0.077)		(0.059)
Beta CDS$_{i,y}$	0.040		-0.059
	(0.926)		(0.898)
Beta Index$_{i,y}$	0.028		0.023
	(0.777)		(0.821)
ln(Size$_{i,y}$)		-0.053	-0.051
		(0.124)	(0.143)
Life Share$_{i,y}$		0.025	0.077
		(0.864)	(0.613)
No. of obs.	232	226	225
No. of insurers	49	47	47
R^2 within	0.091	0.089	0.108
R^2 overall	0.007	0.027	0.036
R^2 between	0.002	0.040	0.061
Standardized beta coefficients			
Beta y10$_{i,y}$	-.13		-.14

Note: Firm fixed effect regressions of insurers' yearly use of the transitional on technical provisions on market risk coefficients from 2016 to 2020. Sources: SFCRs (impact of long term guarantees measures and transitionals from QRT S.22.01.22), SNL (insurer-level size and share of life insurance reserves). The market risk coefficients (betas) are estimated in the first stage of regression analyses. ***, **, * indicate significance at the 1%, 5% and 10% levels respectively. P-values are in parentheses.

Table 7: Determinants of the impact of the transitional on technical provisions on the solvency ratio

Table 8 presents the results of the logistic regression defined in Equation (12). The binary dependent variables reflect further discretionary choice that insurers have under Solvency II. In column (1), the dependent variable is $Internal\ Model_{i,y}$ which equals one if an insurer uses a partial or full internal model to calculate its SCR. The regression coefficients demonstrate that the probability of choosing an internal model is significantly larger for more solvent insurers, those with smaller credit risk sensitivities, higher stock market sensitivities and for larger insurers. Overall, these findings seem plausible. For instance, higher stock market sensitivities point to high CAPM betas, which imply higher cost of capital and, thus, a greater incentive to reduce the regulatory capital requirement by means of an internal model. Insurers with large credit risks might prefer not to choose internal models, since they can already use the matching adjustment in order to reduce the SCR for spread and concentration risk. Also, larger insurers might be characterized by more complex risk profiles which make an internal model necessary to comply with Solvency II requirements; at the same time, these insurers can make better use of economies of scale when implementing internal models.

	(1) Internal Model$_{i,y}$	(2) Internal Interet Rate Risk$_{i,y}$	(3) EU Gov Bond Spread Risk$_{i,y}$
Solven. p. LTG1$_{i,y}$	8.634***	3.703	3.894
	(0.000)	(0.167)	(0.246)
Beta y10$_{i,y}$	7.006	28.035***	-2.277
	(0.448)	(0.009)	(0.808)
Beta CDS$_{i,y}$	130.390***	317.966***	45.524
	(0.005)	(0.000)	(0.304)
Beta Index$_{i,y}$	28.950**	16.303**	16.459**
	(0.013)	(0.038)	(0.036)
ln(Size$_{i,y}$)	3.701***	9.808***	9.879***
	(0.001)	(0.000)	(0.000)
Life Share$_{i,y}$	-9.269	-15.407***	3.071
	(0.194)	(0.003)	(0.742)
No. of obs.	225	225	225
No. of insurers	47	47	47
Wald chi^2	40.800	71.550	35.645
Log likelihood	-44.279	-29.305	-13.581
Sigma	15.171	17.326	12.466
Rho	0.986	0.989	0.979

Note: Logarithmic regressions of insurers' yearly use of internal models on market risk coefficients from 2016 to 2020 with random effects. Sources: SFCRs (qualitative information on internal models from Section E.4 and solvency ratio from QRT S.22.01.22), SNL (insurer-level size and share of life insurance reserves). The market risk coefficients (betas) are estimated in the first stage of regression analyses. ***, **, * indicate significance at the 1%, 5% and 10% levels respectively. P-values are in parentheses.

Table 8: Determinants of internal models

In column (2), we investigate the drivers of insurers' decision to replace the standard formula's interest rate risk submodule, which is part of the market risk module, by a (partial) internal model. This replacement is more likely for insurers with smaller interest rate risk and credit sensitivities, potentially because these firms are capable of finding strategies to immunize against market movements. As for internal models in general, the decision is also significantly linked to larger stock market sensitivities. Moreover, using an internal interest rate risk module is significantly more likely for larger insurers and for non-life insurers, which is an insurer type with typically low exposures to interest rates.

Lastly, we analyze the probability to consider the spread risk stemming from EU government bonds in an internal model, even though these investments are exempt from spread and default risk under Solvency II. Our empirical findings in column (3) of Table 8 demonstrate that the probability significantly increases with an insurer's CAPM beta and its size. These are both factors which result in an increased attention by regulators. Especially large insurers consider all potential market risks in their SCR calculation to have their true risk profiles being reflected by SCR.

3.4 Robustness

The presented empirical findings are robust to a large set of adjustments. In particular, we perform the following set of robustness tests compared to the initial specifications in Equations (8), (9), (10):[20]

1. Use of t-values instead of betas for estimating insurers' sensitivities to interest rates, CDS spreads and the stock market index;
2. use of 5-year time windows instead of 10-year time windows for estimating insurers' market risk sensitivities in the first stage of the empirical analysis;
3. use of weighted CDS returns based on country-wise investments of insurers with asset allocation data from EIOPA in line with Grochola et al. (2021) instead of measuring sensitivities to national sovereign CDS spreads;
4. use of national stock indices for estimating insurers' stock market sensitivities as perceived by financial investors instead of using the Euro Stoxx 50 index for all insurers;
5. winsorizing of stock returns in the first stage of regression analysis as well as winsorizing the estimated beta coefficients for the second stage of empirical regressions. This robustness test ensures that the findings are not driven by extreme outliers;
6. including five micro-cap insurers with total assets below $250 million as of year-end 2020 in the sample. While our empirical findings are less significant for this subgroup, they still hold for the extended sample.

4 Conclusion

One of the major objectives of Solvency II is to provide a fair view on the risk and solvency position of European insurance companies. For this aim, the new regulatory framework takes an economic and risk-based approach with the solvency ratio as the central outcome of Pillar I. Nevertheless, insurers have some leeway in the implementation of Solvency II which allows them to adjust their reported solvency ratio upwards by the use of LTG measures. In this paper we investigate how strongly these transitionals and adjustments impact the solvency ratio and which factors drive the insurers' discretionary decisions.

[20] The corresponding regression tables are all available upon request.

To tackle the research question, we measure stock insurers' risk sensitivities as perceived by financial investors and compare the estimated risk profiles with relevant information in SFCRs. By performing multivariate regression analyses on an insurer level, we can reproduce the results of academic research papers in terms of interest rate and credit risk (cf. Berends et al. 2013, Hartley et al. 2017, Düll et al. (2017)). This implies that we find a negative impact of decreasing rates on insurers' stock prices in the low interest rate environment and the vast majority of companies benefits from decreasing default risks of domestic government debt. The obtained beta coefficients from the market data analysis serve as sensitivity estimates for interest rate risk, credit risk and stock market sensitivities.

After systematically analyzing SFCRs, we find that on average the matching adjustment has the largest average impact as it increases the solvency ratio by 59ppt. Its influence on the solvency ratio is significantly more pronounced for large insurers with high sovereign credit risk. This observation can be explained by the fact that the matching adjustment is only applied by 11.1% of stock listed insurers in 2020 because it is linked to high regulatory requirements in terms of adequate duration matching. In contrast, the volatility adjustment is applied by 69% of insurers in our sample. We detect that the impact of the LTG measure on the solvency ratio is significantly larger for life insurers with high interest rate risk as perceived by financial investors. The volatility adjustment and the transtitional for technical provisions seem to provide a regulatory loophole to avoid higher solvency capital requirements that would be fair under a market-oriented risk management approach. On average the volatility adjustment (transitional for technical provisions) increases the solvency ratio by 8ppt (10ppt) in absolute terms if the unadjusted solvency ratio differs by 100ppt ceteris paribus. This finding signals that these LTG measures are mainly applied by insurers with an otherwise low reported solvency ratio. While Solvency II aims at providing a risk based economic approach, this optional adjustment for the underlying SCR calculation prevents Solvency II reports from providing a standalone figure to transparently inform about insurers' risk exposures and their solvency position. As the volatility adjustment and other LTG measures allow insurers to gradually adjust their solvency ratios upwards (by 28ppt on average in 2020, cf. EIOPA (2020)), our empirical results indicate that the implementation of these measures may result in adverse selection in a similar fashion as compared to the banking sector.

Appendix

I. Descriptive statistics

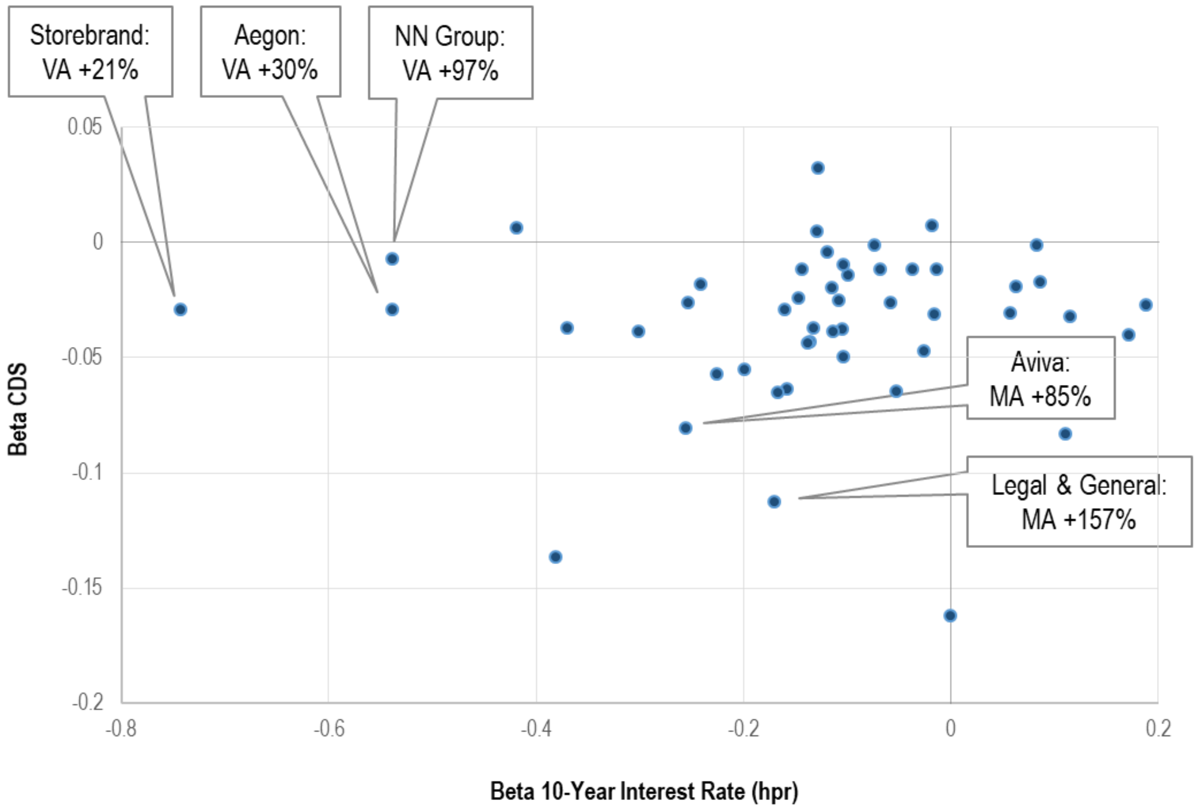
Name	Country	First day in sample	Last day in sample	Mean stock returns	SD stock returns	Min. stock return	Max. stock return
UNIQA Insurance Group AG	Austria	20.03.06	30.12.19	0.00%	1.69%	-15.88%	9.96%
Vienna Insurance Group AG	Austria	20.03.06	30.12.19	0.01%	2.08%	-17.93%	16.26%
Ageas SA	Belgium	20.03.06	30.12.19	0.04%	2.70%	-26.47%	29.54%
KBC Groep NV	Belgium	20.03.06	30.12.19	0.05%	3.26%	-24.92%	49.91%
Alm Brand A/S	Denmark	20.03.06	30.12.19	0.01%	2.26%	-21.17%	28.30%
Topdanmark A/S	Denmark	20.03.06	30.12.19	0.06%	1.55%	-9.48%	15.11%
Tryg A/S	Denmark	20.03.06	30.12.19	0.06%	1.46%	-12.73%	7.75%
Sampo Plc	Finland	20.03.06	30.12.19	0.06%	1.57%	-16.67%	10.72%
Axa SA	France	20.03.06	30.12.19	0.04%	2.44%	-18.41%	21.87%
CNP Assurances SA	France	20.03.06	30.12.19	0.03%	1.77%	-13.45%	11.73%
Coface SA	France	27.06.14	30.12.19	0.04%	2.00%	-29.73%	11.61%
Scor SE	France	20.03.06	30.12.19	0.05%	1.69%	-11.42%	14.50%
Allianz SE	Germany	20.03.06	30.12.19	0.05%	1.88%	-12.99%	19.49%
Muenchener Rueck AG	Germany	20.03.06	30.12.19	0.05%	1.45%	-10.54%	15.62%
Nürnberger Beteiligungs AG	Germany	20.03.06	30.12.19	0.05%	1.74%	-14.72%	25.40%
Rheinland Holding AG	Germany	20.03.06	30.12.19	0.10%	3.41%	-19.35%	19.51%
Talanx AG	Germany	02.10.12	30.12.19	0.07%	1.34%	-6.57%	5.23%
Wuestenrot & Wuerttem. AG	Germany	20.03.06	30.12.19	0.02%	1.81%	-13.22%	13.86%
European Reliance Gen. Ins.	Greece	20.03.06	30.12.19	0.12%	3.06%	-17.14%	19.61%
FBD Holdings PLC	Ireland	20.03.06	30.12.19	-0.01%	2.27%	-25.08%	20.03%
Assicurazioni Generali SpA	Italy	20.03.06	30.12.19	0.01%	1.72%	-16.77%	13.10%
Societa Cattolica di Assic. Sc	Italy	20.03.06	30.12.19	-0.01%	1.92%	-17.43%	17.30%
UnipolSai Assicurazioni SpA	Italy	20.03.06	30.12.19	0.00%	4.05%	-58.82%	119.81%
Vittoria Assicurazioni SpA	Italy	20.03.06	25.09.18	0.05%	1.67%	-10.80%	19.73%
Aegon NV	Netherl.	20.03.06	30.12.19	0.02%	2.80%	-24.18%	35.28%
ASR Nederland NV	Netherl.	10.06.16	30.12.19	0.08%	1.36%	-7.43%	6.76%
Delta Lloyd NV	Netherl.	22.02.10	23.12.16	0.22%	2.92%	-7.93%	10.78%
NN Group NV	Netherl.	02.07.14	30.12.19	0.06%	1.34%	-8.03%	8.77%
Gjensidige Forsikring ASA	Norway	10.12.10	30.12.19	0.09%	1.26%	-10.31%	12.28%
Protector Forsikring ASA	Norway	25.05.07	30.12.19	0.12%	2.63%	-22.39%	24.98%
Storebrand ASA	Norway	20.03.06	30.12.19	0.05%	2.83%	-19.55%	27.95%
Powszechny Zaklad Ubez. SA	Poland	12.05.10	30.12.19	0.03%	1.49%	-6.59%	7.27%
Pozavarovalnica Sava dd	Slovenia	12.06.08	30.12.19	0.05%	2.24%	-11.36%	14.91%
Zavarovalnica Triglav dd	Slovenia	09.09.08	30.12.19	0.03%	1.78%	-10.20%	8.91%
Grupo Catalana Occidente SA	Spain	20.03.06	30.12.19	0.04%	2.03%	-8.42%	13.26%
Mapfre SA	Spain	20.03.06	30.12.19	0.03%	2.08%	-12.58%	17.11%
Admiral Group PLC	UK	20.03.06	30.12.19	0.08%	1.88%	-25.61%	25.50%
Aviva PLC	UK	20.03.06	30.12.19	0.03%	2.43%	-33.37%	25.10%
Beazley PLC	UK	20.03.06	30.12.19	0.09%	1.82%	-13.10%	14.58%
Chesnara PLC	UK	20.03.06	30.12.19	0.07%	2.03%	-14.51%	11.09%
Direct Line Insurance Group	UK	11.10.12	30.12.19	0.07%	1.21%	-7.16%	12.62%
Hansard Global PLC	UK	13.12.06	30.12.19	0.01%	2.28%	-14.36%	20.10%
Legal & General Group PLC	UK	20.03.06	30.12.19	0.07%	2.40%	-28.88%	27.51%
Old Mutual PLC	UK	20.03.06	29.12.17	0.06%	2.68%	-21.60%	30.33%
Phoenix Group Holdings	UK	18.11.09	30.12.19	0.05%	1.49%	-11.54%	11.17%
Prudential PLC	UK	20.03.06	28.12.18	0.07%	2.58%	-20.00%	23.46%
RSA Insurance Group PLC	UK	20.03.06	30.12.19	0.03%	1.71%	-20.84%	18.43%
St. James's Place PLC	UK	20.03.06	30.12.19	0.07%	2.18%	-16.18%	27.05%
Standard Life Aberdeen PLC	UK	10.07.06	29.12.17	0.06%	2.21%	-17.31%	20.51%

Table A1: Stock returns on insurer level

	N	Mean	Median	SD	Min	Max
Robustness equity risk variables (country-day level level in ppt)						
$r_{m,c,t}$ (Index return, all countries)	51,342	0.012	0.05	1.43	-33.21	-49.89
$r_{m,Austria,t}$ (Index return)	3,302	0.000	0.04	1.54	-9.74	12.77
$r_{m,Belgium,t}$ (Index return)	3,489	0.005	0.03	1.22	-7.98	9.96
$r_{m,Denmark,t}$ (Index return)	3,371	0.032	0.08	1.29	-11.06	9.73
$r_{m,Finland,t}$ (Index return)	3,399	0.024	0.04	1.40	-8.52	9.73
$r_{m,France,t}$ (Index return)	3,491	0.013	0.04	1.38	-9.04	11.18
$r_{m,Germany,t}$ (Index return)	3,455	0.017	0.07	1.34	-7.23	11.40
$r_{m,Greece,t}$ (Index return)	3,338	-0.018	0.04	1.96	-13.42	14.37
$r_{m,Ireland,t}$ (Index return)	3,425	0.009	0.03	1.45	-13.03	10.22
$r_{m,Italy,t}$ (Index return)	3,467	-0.005	0.04	1.58	-12.48	11.49
$r_{m,Netherlands,t}$ (Index return)	3,519	0.016	0.05	1.29	-9.14	10.55
$r_{m,Norway,t}$ (Index return)	3,395	0.037	0.08	1.56	-10.66	11.65
$r_{m,Poland,t}$ (Index return)	3,385	0.018	0.04	1.20	-7.95	6.27
$r_{m,Slovenia,t}$ (Index return)	3,411	0.008	0.01	1.47	-33.21	49.89
$r_{m,Spain,t}$ (Index return)	3,475	0.003	0.05	1.47	-12.35	14.43
$r_{m,UK,t}$ (Index return)	3,420	0.015	0.04	1.15	-8.85	9.84

Table A2: National stock index returns on country level

II. Estimated market risk sensitivities (betas)



Note: "VA" ("MA") stands for "volatility adjustment" ("matching adjustment"). The number behind "VA" or "MA" shows the impact that the respective LTG measure has on the solvency ratio of a given insurer in the year 2019. Each dot reflects the estimated regression coefficients β_y and β_s from Equation (5) of an insurance company in the period from 2009 to 2018. A company located at the bottom left would substantially suffer from falling interest rates and from rising default probabilities of domestic sovereign debt.

Figure A1: Insurer-specific estimates for sensitivities to interest rate and CDS fluctuation

Sensitivities (betas)		2006-2015			2007-2016			2008-2017			2009-2018			2010-2019		
Name	**Country**	**y10**	**CDS**	**Index**	**y10**	**CDS**	**Index**	**y10**	**CDS**	**Index**	**y10**	**CDS**	**Index**	**y10**	**CDS**	**Index**
UNIQA Insurance Group AG	Austria	-0.09	-0.02	0.32	-0.12	-0.02	0.35	-0.17	-0.02	0.35	-0.13	0.01	0.41	-0.14	0.01	0.46
Vienna Insurance Group AG	Austria	0.03	-0.05	0.82	-0.01	-0.05	0.83	-0.07	-0.04	0.84	-0.14	-0.04	0.80	-0.18	-0.03	0.72
Ageas SA	Belgium	-0.38	-0.15	1.14	-0.39	-0.14	1.11	-0.40	-0.15	1.10	-0.38	-0.14	0.99	-0.26	-0.11	0.98
KBC Groep NV	Belgium	0.08	-0.15	1.40	0.03	-0.14	1.39	-0.01	-0.15	1.39	0.00	-0.16	1.36	-0.31	-0.12	1.22
Alm Brand A/S	Denmark	-0.12	-0.02	0.62	-0.09	-0.03	0.61	-0.08	-0.03	0.60	0.06	-0.03	0.56	0.02	0.00	0.53
Topdanmark A/S	Denmark	-0.11	-0.01	0.56	-0.10	-0.02	0.56	-0.07	-0.01	0.55	-0.10	-0.01	0.48	-0.10	-0.01	0.46
Tryg A/S	Denmark	-0.23	0.00	0.46	-0.19	-0.01	0.48	-0.18	-0.01	0.47	-0.12	0.00	0.47	-0.05	0.00	0.48
Sampo Plc	Finland	-0.27	-0.03	0.74	-0.25	-0.03	0.73	-0.27	-0.04	0.72	-0.11	-0.04	0.77	-0.16	-0.03	0.72
Axa SA	France	-0.22	-0.03	1.49	-0.28	-0.03	1.48	-0.32	-0.03	1.48	-0.37	-0.04	1.39	-0.47	-0.06	1.26
CNP Assurances SA	France	-0.32	-0.04	0.71	-0.31	-0.04	0.72	-0.32	-0.04	0.71	-0.25	-0.03	0.81	-0.24	-0.03	0.85
Coface SA	France	-0.11	-0.02	0.31	-0.22	-0.02	0.45	-0.25	-0.02	0.47	-0.24	-0.02	0.50	-0.28	-0.02	0.48
Scor SE	France	-0.22	-0.02	0.65	-0.22	-0.02	0.66	-0.21	-0.02	0.64	-0.14	-0.01	0.63	-0.16	-0.01	0.68
Allianz SE	Germany	0.05	-0.02	1.09	0.02	-0.02	1.07	0.03	-0.02	1.07	-0.04	-0.01	1.00	-0.09	-0.01	0.94
Muenchener Rueck AG	Germany	0.02	0.00	0.73	0.04	0.00	0.74	0.05	0.00	0.74	0.08	0.00	0.75	0.05	-0.01	0.71
Nürnberger Beteiligungs AG	Germany	0.06	-0.03	0.08	0.06	-0.03	0.08	0.04	-0.03	0.07	-0.01	-0.01	0.06	-0.04	0.00	0.11
Rheinland Holding AG	Germany	-0.32	0.03	0.07	-0.12	0.02	0.10	-0.07	0.03	0.10	-0.13	0.03	0.02	-0.05	0.04	0.03
Talanx AG	Germany	0.07	-0.01	0.61	0.03	-0.01	0.66	-0.04	-0.01	0.65	-0.07	0.00	0.66	-0.10	0.00	0.65
Wuestenrot & Wuerttem. AG	Germany	0.09	-0.03	0.27	0.07	-0.03	0.28	0.03	-0.03	0.27	-0.07	-0.01	0.22	-0.11	-0.01	0.25
European Reliance Gen. Ins.	Greece	-0.14	-0.02	0.35	-0.05	-0.02	0.35	0.03	-0.02	0.33	0.09	-0.02	0.31	-0.05	-0.01	0.28
FBD Holdings Plc	Ireland	-0.10	-0.04	0.36	-0.12	-0.04	0.35	-0.18	-0.03	0.34	-0.16	-0.03	0.32	-0.12	-0.03	0.33
Assicurazioni Generali SpA	Italy	-0.17	-0.06	0.84	-0.21	-0.06	0.87	-0.25	-0.07	0.86	-0.23	-0.06	0.99	-0.24	-0.06	0.97
Societa Cattolica di Assic. Sc	Italy	-0.10	-0.05	0.66	-0.13	-0.06	0.67	-0.18	-0.06	0.67	-0.16	-0.06	0.67	-0.19	-0.07	0.61
UnipolSai Assicurazioni SpA	Italy	0.02	-0.07	0.89	-0.01	-0.07	0.91	-0.05	-0.07	0.90	-0.05	-0.06	0.95	-0.05	-0.07	0.93
Vittoria Assicurazioni SpA	Italy	-0.11	-0.04	0.41	-0.13	-0.04	0.40	-0.15	-0.04	0.39	-0.11	-0.02	0.42	-0.15	-0.01	0.41
Aegon NV	Netherl.	-0.28	-0.04	1.47	-0.35	-0.04	1.45	-0.44	-0.04	1.46	-0.54	-0.03	1.39	-0.68	-0.02	1.16
ASR Nederland NV	Netherl.	NA	NA	NA	-0.46	0.05	0.63	-0.38	0.02	0.63	-0.42	0.01	0.68	-0.46	0.01	0.73
Delta Lloyd NV	Netherl.	-0.31	-0.04	1.15	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
NN Group NV	Netherl.	-0.42	0.03	0.41	-0.39	-0.03	0.58	-0.52	-0.01	0.59	-0.54	-0.01	0.63	-0.57	0.00	0.65
Gjensidige Forsikring ASA	Norway	0.05	-0.02	0.43	0.04	-0.01	0.45	0.02	0.00	0.45	-0.02	0.01	0.47	-0.04	0.01	0.46
Protector Forsikring ASA	Norway	0.17	-0.04	0.30	0.09	-0.04	0.31	0.11	-0.06	0.28	0.19	-0.03	0.41	0.07	0.02	0.41
Storebrand ASA	Norway	-0.68	0.00	1.15	-0.72	0.00	1.13	-0.78	-0.01	1.13	-0.74	-0.03	1.06	-0.93	-0.04	0.99
Powszechny Zaklad Ubez. SA	Poland	-0.14	-0.08	0.33	-0.17	-0.08	0.33	-0.17	-0.07	0.34	-0.17	-0.07	0.37	-0.14	-0.06	0.38
Pozavarovalnica Sava dd	Slovenia	0.30	-0.04	0.27	0.23	-0.05	0.25	0.24	-0.04	0.26	0.11	-0.08	0.08	0.18	-0.08	0.08
Zavarovalnica Triglav dd	Slovenia	-0.26	-0.05	0.17	-0.23	-0.05	0.16	-0.24	-0.05	0.16	-0.20	-0.05	0.08	-0.12	-0.05	0.07
Grupo Catalana Occidente SA	Spain	-0.14	-0.06	0.71	-0.16	-0.06	0.71	-0.15	-0.06	0.70	-0.14	-0.04	0.77	-0.15	-0.04	0.76
Mapfre SA	Spain	-0.08	-0.06	0.92	-0.10	-0.06	0.94	-0.15	-0.06	0.94	-0.10	-0.05	0.99	-0.17	-0.05	0.99
Admiral Group PLC	UK	-0.26	-0.01	0.62	-0.20	-0.01	0.61	-0.17	-0.01	0.57	-0.10	-0.01	0.52	-0.12	-0.02	0.52
Aviva PLC	UK	-0.34	-0.03	1.17	-0.37	-0.05	1.17	-0.35	-0.07	1.14	-0.26	-0.08	1.11	-0.27	-0.07	0.96
Beazley PLC	UK	-0.14	-0.01	0.57	-0.08	0.00	0.58	-0.09	-0.01	0.54	-0.11	-0.02	0.45	0.08	-0.02	0.46
Chesnara PLC	UK	-0.17	-0.01	0.25	-0.14	-0.01	0.26	-0.07	-0.02	0.25	-0.06	-0.03	0.20	-0.07	-0.02	0.26
Direct Line Insurance Group	UK	-0.08	-0.04	0.34	-0.13	-0.05	0.39	-0.12	-0.04	0.39	-0.13	-0.04	0.40	-0.17	-0.04	0.41
Hansard Global PLC	UK	0.22	-0.03	0.22	0.16	-0.03	0.20	0.16	-0.04	0.17	0.11	-0.03	0.18	0.08	-0.04	0.13
Legal & General Group PLC	UK	-0.13	-0.04	1.05	-0.17	-0.06	1.06	-0.14	-0.09	1.02	-0.17	-0.11	0.99	-0.26	-0.09	0.84
Old Mutual PLC	UK	0.09	-0.02	1.22	0.16	-0.03	1.21	NA	NA	NA	NA	NA	NA	NA	NA	NA
Phoenix Group Holdings	UK	0.10	-0.01	0.39	0.12	-0.03	0.44	0.08	-0.03	0.44	0.06	-0.02	0.46	0.03	-0.01	0.49
Prudential PLC	UK	-0.06	-0.01	1.24	-0.13	-0.02	1.24	-0.12	-0.03	1.21	NA	NA	NA	NA	NA	NA
RSA Insurance Group PLC	UK	-0.16	0.00	0.66	-0.16	-0.01	0.64	-0.15	-0.01	0.62	-0.15	-0.02	0.53	-0.15	-0.03	0.53
St. James's Place PLC	UK	-0.20	0.00	0.86	-0.21	-0.01	0.87	-0.19	-0.02	0.83	-0.02	-0.03	0.83	-0.05	-0.05	0.84
Standard Life Aberdeen PLC	UK	-0.03	-0.01	0.99	-0.07	-0.01	1.02	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table A3: Estimated beta coefficients on insurer level

III. Data collected from SFCRs

Firm name	Country	Year	LTGs Used	Solvency Reported	VA Impact	MA Impact	TP Impact	IR Impact	Model for SCR calculation
UNIQA Insurance Group AG	Austria	2016	1	202%	8%	0%	0%	0%	Standard Formula
UNIQA Insurance Group AG	Austria	2017	1	250%	2%	0%	0%	0%	Partial Internal
UNIQA Insurance Group AG	Austria	2018	1	248%	21%	0%	0%	0%	Partial Internal
UNIQA Insurance Group AG	Austria	2019	1	216%	36%	0%	0%	0%	Partial Internal
UNIQA Insurance Group AG	Austria	2020	1	170%	40%	0%	0%	0%	Partial Internal
Vienna Insurance Group AG	Austria	2016	1	195%	9%	0%	0%	0%	Partial Internal
Vienna Insurance Group AG	Austria	2017	1	220%	4%	0%	0%	0%	Partial Internal
Vienna Insurance Group AG	Austria	2018	1	239%	5%	0%	0%	0%	Partial Internal
Vienna Insurance Group AG	Austria	2019	1	210%	5%	0%	0%	0%	Partial Internal
Vienna Insurance Group AG	Austria	2020	2	238%	7%	0%	43%	0%	Partial Internal
Ageas SA	Belgium	2016	2	174%	17%	0%	8%	0%	Partial Internal
Ageas SA	Belgium	2017	2	191%	4%	0%	9%	0%	Partial Internal
Ageas SA	Belgium	2018	2	216%	40%	0%	11%	0%	Partial Internal
Ageas SA	Belgium	2019	2	203%	11%	0%	9%	0%	Partial Internal
Ageas SA	Belgium	2020	2	199%	13%	0%	9%	0%	Partial Internal
KBC Groep NV	Belgium	2016	1	203%	12%	0%	0%	0%	Standard Formula
KBC Groep NV	Belgium	2017	1	212%	2%	0%	0%	0%	Standard Formula
KBC Groep NV	Belgium	2018	1	217%	20%	0%	0%	0%	Standard Formula
KBC Groep NV	Belgium	2019	1	202%	5%	0%	0%	0%	Standard Formula
KBC Groep NV	Belgium	2020	1	222%	6%	0%	0%	0%	Standard Formula
Alm Brand A/S	Denmark	2016	1	374%	15%	0%	0%	0%	Partial Internal
Alm Brand A/S	Denmark	2017	1	285%	7%	0%	0%	0%	Partial Internal
Alm Brand A/S	Denmark	2018	1	305%	11%	0%	0%	0%	Partial Internal
Alm Brand A/S	Denmark	2019	1	316%	5%	0%	0%	0%	Partial Internal
Alm Brand A/S	Denmark	2020	1	305%	6%	0%	0%	0%	Partial Internal
Topdanmark A/S	Denmark	2016	1	174%	31%	0%	0%	0%	Partial Internal
Topdanmark A/S	Denmark	2017	1	204%	31%	0%	0%	0%	Partial Internal
Topdanmark A/S	Denmark	2018	1	196%	41%	0%	0%	0%	Partial Internal
Topdanmark A/S	Denmark	2019	1	177%	17%	0%	0%	0%	Partial Internal
Topdanmark A/S	Denmark	2020	1	170%	18%	0%	0%	0%	Partial Internal
Tryg A/S	Denmark	2016	0	194%	0%	0%	0%	0%	Partial Internal
Tryg A/S	Denmark	2017	0	281%	0%	0%	0%	0%	Partial Internal
Tryg A/S	Denmark	2018	0	165%	0%	0%	0%	0%	Partial Internal
Tryg A/S	Denmark	2019	0	162%	0%	0%	0%	0%	Partial Internal
Tryg A/S	Denmark	2020	0	183%	0%	0%	0%	0%	Partial Internal
Sampo Plc	Finland	2016	2	155%	1%	0%	6%	0%	Standard Formula
Sampo Plc	Finland	2017	2	156%	2%	0%	6%	0%	Standard Formula
Sampo Plc	Finland	2018	2	140%	3%	0%	5%	0%	Standard Formula
Sampo Plc	Finland	2019	2	174%	2%	0%	6%	0%	Standard Formula
Sampo Plc	Finland	2020	2	176%	2%	0%	6%	0%	Standard Formula
Axa SA	France	2016	1	197%	39%	0%	0%	0%	Partial Internal
Axa SA	France	2017	1	205%	40%	0%	0%	0%	Partial Internal
Axa SA	France	2018	1	193%	40%	0%	0%	0%	Partial Internal
Axa SA	France	2019	1	198%	43%	0%	0%	0%	Partial Internal
Axa SA	France	2020	1	200%	61%	0%	0%	0%	Partial Internal
CNP Assurances SA	France	2016	1	177%	11%	0%	0%	0%	Standard Formula
CNP Assurances SA	France	2017	1	190%	3%	0%	0%	0%	Standard Formula
CNP Assurances SA	France	2018	1	187%	21%	0%	0%	0%	Standard Formula
CNP Assurances SA	France	2019	1	227%	8%	0%	0%	0%	Standard Formula
CNP Assurances SA	France	2020	1	208%	9%	0%	0%	0%	Standard Formula

Firm name	Country	Year	LTGs Used	Solvency Reported	VA Impact	MA Impact	TP Impact	IR Impact	Model for SCR calculation
Coface SA	France	2016	0	150%	0%	0%	0%	0%	Standard Formula
Coface SA	France	2017	0	153%	0%	0%	0%	0%	Standard Formula
Coface SA	France	2018	0	172%	0%	0%	0%	0%	Standard Formula
Coface SA	France	2019	0	203%	0%	0%	0%	0%	Partial Internal
Coface SA	France	2020	0	204%	0%	0%	0%	0%	Partial Internal
Scor SE	France	2016	0	225%	0%	0%	0%	0%	Full Internal
Scor SE	France	2017	0	213%	0%	0%	0%	0%	Full Internal
Scor SE	France	2018	0	215%	0%	0%	0%	0%	Full Internal
Scor SE	France	2019	0	226%	0%	0%	0%	0%	Full Internal
Scor SE	France	2020	0	220%	0%	0%	0%	0%	Full Internal
Allianz SE	Germany	2016	1	218%	21%	0%	0%	0%	Partial Internal
Allianz SE	Germany	2017	1	229%	18%	0%	0%	0%	Partial Internal
Allianz SE	Germany	2018	1	229%	28%	0%	0%	0%	Partial Internal
Allianz SE	Germany	2019	1	212%	25%	0%	0%	0%	Partial Internal
Allianz SE	Germany	2020	2	240%	40%	0%	33%	0%	Partial Internal
Muenchener Rueck AG	Germany	2016	1	316%	0%	0%	49%	0%	Full Internal
Muenchener Rueck AG	Germany	2017	2	297%	0%	0%	53%	0%	Full Internal
Muenchener Rueck AG	Germany	2018	2	295%	1%	0%	49%	0%	Full Internal
Muenchener Rueck AG	Germany	2019	2	274%	5%	0%	39%	0%	Full Internal
Muenchener Rueck AG	Germany	2020	2	240%	3%	0%	32%	0%	Full Internal
Nürnberger Beteiligungs AG	Germany	2016	1	262%	0%	0%	113%	0%	Standard Formula
Nürnberger Beteiligungs AG	Germany	2017	1	341%	0%	0%	100%	0%	Standard Formula
Nürnberger Beteiligungs AG	Germany	2018	1	283%	0%	0%	77%	0%	Standard Formula
Nürnberger Beteiligungs AG	Germany	2019	1	286%	0%	0%	62%	0%	Standard Formula
Nürnberger Beteiligungs AG	Germany	2020	1	270%	0%	0%	56%	0%	Standard Formula
Rheinland Holding AG	Germany	2016	2	244%	9%	0%	66%	0%	Standard Formula
Rheinland Holding AG	Germany	2017	2	260%	3%	0%	69%	0%	Standard Formula
Rheinland Holding AG	Germany	2018	2	234%	14%	0%	58%	0%	Standard Formula
Rheinland Holding AG	Germany	2019	2	217%	4%	0%	38%	0%	Standard Formula
Rheinland Holding AG	Germany	2020	2	287%	12%	0%	0%	48%	Standard Formula
Talanx AG	Germany	2016	2	236%	49%	0%	50%	0%	Partial Internal
Talanx AG	Germany	2017	2	253%	41%	0%	47%	0%	Partial Internal
Talanx AG	Germany	2018	2	252%	35%	0%	43%	0%	Partial Internal
Talanx AG	Germany	2019	2	246%	54%	0%	36%	0%	Full Internal
Talanx AG	Germany	2020	2	260%	60%	0%	54%	0%	Full Internal
Wuestenrot & Wuerttem. AG	Germany	2016	2	194%	7%	0%	52%	0%	Standard Formula
Wuestenrot & Wuerttem. AG	Germany	2017	2	201%	1%	0%	47%	0%	Standard Formula
Wuestenrot & Wuerttem. AG	Germany	2018	2	255%	29%	0%	65%	0%	Standard Formula
Wuestenrot & Wuerttem. AG	Germany	2019	2	238%	8%	0%	55%	0%	Standard Formula
Wuestenrot & Wuerttem. AG	Germany	2020	2	233%	10%	0%	48%	0%	Standard Formula
European Reliance Gen. Ins.	Greece	2016	1	125%	2%	0%	0%	0%	Standard Formula
European Reliance Gen. Ins.	Greece	2017	1	146%	1%	0%	0%	0%	Standard Formula
European Reliance Gen. Ins.	Greece	2018	1	160%	4%	0%	0%	0%	Standard Formula
European Reliance Gen. Ins.	Greece	2019	1	168%	1%	0%	0%	0%	Standard Formula
European Reliance Gen. Ins.	Greece	2020	1	175%	1%	0%	0%	0%	Standard Formula
FBD Holdings Plc	Ireland	2016	0	126%	0%	0%	0%	0%	Standard Formula
FBD Holdings Plc	Ireland	2017	0	164%	0%	0%	0%	0%	Standard Formula
FBD Holdings Plc	Ireland	2018	0	165%	0%	0%	0%	0%	Standard Formula
FBD Holdings Plc	Ireland	2019	0	193%	0%	0%	0%	0%	Standard Formula
FBD Holdings Plc	Ireland	2020	0	197%	0%	0%	0%	0%	Standard Formula
Assicurazioni Generali SpA	Italy	2016	1	178%	45%	0%	0%	0%	Partial Internal
Assicurazioni Generali SpA	Italy	2017	1	207%	42%	0%	0%	0%	Partial Internal
Assicurazioni Generali SpA	Italy	2018	1	217%	66%	0%	0%	0%	Partial Internal
Assicurazioni Generali SpA	Italy	2019	1	224%	59%	0%	0%	0%	Partial Internal
Assicurazioni Generali SpA	Italy	2020	2	224%	68%	0%	1%	0%	Partial Internal

Firm name	Country	Year	LTGs Used	Solvency Reported	VA Impact	MA Impact	TP Impact	IR Impact	Model for SCR calculation
Societa Cattolica di Assic. Sc	Italy	2016	1	186%	13%	0%	0%	0%	Standard Formula
Societa Cattolica di Assic. Sc	Italy	2017	1	239%	3%	0%	0%	0%	Standard Formula
Societa Cattolica di Assic. Sc	Italy	2018	1	171%	21%	0%	0%	0%	Standard Formula
Societa Cattolica di Assic. Sc	Italy	2019	1	175%	7%	0%	0%	0%	Standard Formula
Societa Cattolica di Assic. Sc	Italy	2020	1	187%	8%	0%	0%	0%	Standard Formula
UnipolSai Assicurazioni SpA	Italy	2016	1	243%	8%	0%	0%	0%	Partial Internal
UnipolSai Assicurazioni SpA	Italy	2017	1	263%	2%	0%	0%	0%	Partial Internal
UnipolSai Assicurazioni SpA	Italy	2018	1	253%	27%	0%	0%	0%	Partial Internal
UnipolSai Assicurazioni SpA	Italy	2019	1	284%	5%	0%	0%	0%	Partial Internal
UnipolSai Assicurazioni SpA	Italy	2020	1	318%	3%	0%	0%	0%	Partial Internal
Vittoria Assicurazioni SpA	Italy	2016	1	219%	4%	0%	0%	0%	Standard Formula
Vittoria Assicurazioni SpA	Italy	2017	1	216%	2%	0%	0%	0%	Standard Formula
Vittoria Assicurazioni SpA	Italy	2018	1	257%	11%	0%	0%	0%	Standard Formula
Vittoria Assicurazioni SpA	Italy	2019	1	257%	1%	0%	0%	0%	Standard Formula
Vittoria Assicurazioni SpA	Italy	2020	1	194%	2%	0%	0%	0%	Standard Formula
Aegon NV	Netherl.	2016	3	157%	24%	2%	1%	0%	Partial Internal
Aegon NV	Netherl.	2017	3	201%	31%	2%	1%	0%	Partial Internal
Aegon NV	Netherl.	2018	3	211%	35%	2%	1%	0%	Partial Internal
Aegon NV	Netherl.	2019	2	201%	22%	2%	0%	0%	Partial Internal
Aegon NV	Netherl.	2020	2	196%	30%	2%	0%	0%	Partial Internal
ASR Nederland NV	Netherl.	2016	1	189%	14%	0%	0%	0%	Standard Formula
ASR Nederland NV	Netherl.	2017	1	195%	1%	0%	0%	0%	Standard Formula
ASR Nederland NV	Netherl.	2018	1	195%	27%	0%	0%	0%	Standard Formula
ASR Nederland NV	Netherl.	2019	1	193%	8%	0%	0%	0%	Standard Formula
ASR Nederland NV	Netherl.	2020	1	199%	8%	0%	0%	0%	Standard Formula
Delta Lloyd NV	Netherl.	2016	1	143%	33%	0%	0%	0%	Standard Formula
NN Group NV	Netherl.	2016	3	241%	122%	0%	3%	1%	Partial Internal
NN Group NV	Netherl.	2017	3	199%	75%	0%	1%	1%	Partial Internal
NN Group NV	Netherl.	2018	3	230%	128%	0%	3%	1%	Partial Internal
NN Group NV	Netherl.	2019	3	218%	97%	0%	5%	1%	Partial Internal
NN Group NV	Netherl.	2020	3	210%	98%	0%	4%	1%	Partial Internal
Gjensidige Forsikring ASA	Norway	2016	0	147%	0%	0%	0%	0%	Standard Formula
Gjensidige Forsikring ASA	Norway	2017	0	137%	0%	0%	0%	0%	Standard Formula
Gjensidige Forsikring ASA	Norway	2018	0	169%	0%	0%	0%	0%	Partial Internal
Gjensidige Forsikring ASA	Norway	2019	0	231%	0%	0%	0%	0%	Partial Internal
Gjensidige Forsikring ASA	Norway	2020	0	199%	0%	0%	0%	0%	Partial Internal
Protector Forsikring ASA	Norway	2016	0	163%	0%	0%	0%	0%	Standard Formula
Protector Forsikring ASA	Norway	2017	0	201%	0%	0%	0%	0%	Standard Formula
Protector Forsikring ASA	Norway	2018	0	175%	0%	0%	0%	0%	Standard Formula
Protector Forsikring ASA	Norway	2019	0	168%	0%	0%	0%	0%	Standard Formula
Protector Forsikring ASA	Norway	2020	1	190%	4%	0%	0%	0%	Standard Formula
Storebrand ASA	Norway	2016	2	157%	16%	0%	9%	0%	Standard Formula
Storebrand ASA	Norway	2017	2	172%	10%	0%	13%	0%	Standard Formula
Storebrand ASA	Norway	2018	1	173%	21%	0%	0%	0%	Standard Formula
Storebrand ASA	Norway	2019	1	187%	21%	0%	0%	0%	Standard Formula
Storebrand ASA	Norway	2020	2	178%	17%	0%	12%	0%	Standard Formula
Powszechny Zaklad Ubez. SA	Poland	2016	0	250%	0%	0%	0%	0%	Standard Formula
Powszechny Zaklad Ubez. SA	Poland	2017	0	208%	0%	0%	0%	0%	Standard Formula
Powszechny Zaklad Ubez. SA	Poland	2018	0	222%	0%	0%	0%	0%	Standard Formula
Powszechny Zaklad Ubez. SA	Poland	2019	0	245%	0%	0%	0%	0%	Standard Formula
Powszechny Zaklad Ubez. SA	Poland	2020	0	236%	0%	0%	0%	0%	Standard Formula
Pozavarovalnica Sava dd	Slovenia	2016	0	204%	0%	0%	0%	0%	Standard Formula
Pozavarovalnica Sava dd	Slovenia	2017	0	216%	0%	0%	0%	0%	Standard Formula
Pozavarovalnica Sava dd	Slovenia	2018	0	218%	0%	0%	0%	0%	Standard Formula
Pozavarovalnica Sava dd	Slovenia	2019	0	220%	0%	0%	0%	0%	Standard Formula
Pozavarovalnica Sava dd	Slovenia	2020	0	198%	0%	0%	0%	0%	Standard Formula

Firm name	Country	Year	LTGs Used	Solvency Reported	VA Impact	MA Impact	TP Impact	IR Impact	Model for SCR calculation
Zavarovalnica Triglav dd	Slovenia	2016	0	246%	0%	0%	0%	0%	Standard Formula
Zavarovalnica Triglav dd	Slovenia	2017	0	222%	0%	0%	0%	0%	Standard Formula
Zavarovalnica Triglav dd	Slovenia	2018	0	216%	0%	0%	0%	0%	Standard Formula
Zavarovalnica Triglav dd	Slovenia	2019	0	223%	0%	0%	0%	0%	Standard Formula
Zavarovalnica Triglav dd	Slovenia	2020	0	240%	0%	0%	0%	0%	Standard Formula
Grupo Catalana Occidente SA	Spain	2016	2	200%	1%	0%	16%	0%	Standard Formula
Grupo Catalana Occidente SA	Spain	2017	2	210%	0%	0%	2%	0%	Partial Internal
Grupo Catalana Occidente SA	Spain	2018	1	207%	2%	0%	0%	0%	Partial Internal
Grupo Catalana Occidente SA	Spain	2019	2	213%	1%	0%	10%	0%	Partial Internal
Grupo Catalana Occidente SA	Spain	2020	2	216%	1%	0%	10%	0%	Partial Internal
Mapfre SA	Spain	2016	3	210%	2%	3%	18%	0%	Standard Formula
Mapfre SA	Spain	2017	3	200%	0%	3%	17%	0%	Standard Formula
Mapfre SA	Spain	2018	3	190%	3%	3%	15%	0%	Standard Formula
Mapfre SA	Spain	2019	3	187%	1%	-6%	14%	0%	Standard Formula
Mapfre SA	Spain	2020	3	193%	1%	-1%	14%	0%	Partial Internal
Admiral Group PLC	UK	2016	0	183%	0%	0%	0%	0%	Standard Formula
Admiral Group PLC	UK	2017	1	193%	3%	0%	0%	0%	Standard Formula
Admiral Group PLC	UK	2018	1	170%	5%	0%	0%	0%	Standard Formula
Admiral Group PLC	UK	2019	1	170%	5%	0%	0%	0%	Standard Formula
Admiral Group PLC	UK	2020	1	209%	1%	0%	0%	0%	Standard Formula
Aviva PLC	UK	2016	3	172%	6%	90%	33%	0%	Partial Internal
Aviva PLC	UK	2017	3	169%	3%	74%	31%	0%	Partial Internal
Aviva PLC	UK	2018	3	180%	14%	82%	31%	0%	Partial Internal
Aviva PLC	UK	2019	3	183%	13%	85%	29%	0%	Partial Internal
Aviva PLC	UK	2020	3	178%	22%	85%	27%	0%	Partial Internal
Beazley PLC	UK	2016	0	237%	0%	0%	0%	0%	Full Internal
Beazley PLC	UK	2017	0	223%	0%	0%	0%	0%	Full Internal
Beazley PLC	UK	2018	0	202%	0%	0%	0%	0%	Full Internal
Beazley PLC	UK	2019	0	151%	0%	0%	0%	0%	Full Internal
Beazley PLC	UK	2020	0	159%	0%	0%	0%	0%	Full Internal
Chesnara PLC	UK	2016	0	158%	0%	0%	0%	0%	Standard Formula
Chesnara PLC	UK	2017	0	146%	0%	0%	0%	0%	Standard Formula
Chesnara PLC	UK	2018	0	158%	0%	0%	0%	0%	Standard Formula
Chesnara PLC	UK	2019	0	155%	0%	0%	0%	0%	Standard Formula
Chesnara PLC	UK	2020	1	156%	2%	0%	0%	0%	Standard Formula
Direct Line Insurance Group	UK	2016	1	165%	3%	0%	0%	0%	Partial Internal
Direct Line Insurance Group	UK	2017	1	165%	2%	0%	0%	0%	Partial Internal
Direct Line Insurance Group	UK	2018	1	170%	3%	0%	0%	0%	Partial Internal
Direct Line Insurance Group	UK	2019	1	165%	1%	0%	0%	0%	Partial Internal
Direct Line Insurance Group	UK	2020	1	191%	1%	0%	0%	0%	Partial Internal
Hansard Global PLC	UK	2016	0	246%	0%	0%	0%	0%	Standard Formula
Hansard Global PLC	UK	2017	0	249%	0%	0%	0%	0%	Standard Formula
Hansard Global PLC	UK	2018	0	242%	0%	0%	0%	0%	Standard Formula
Hansard Global PLC	UK	2019	0	243%	0%	0%	0%	0%	Standard Formula
Hansard Global PLC	UK	2020	0	187%	0%	0%	0%	0%	Standard Formula
Legal & General Group PLC	UK	2016	2	163%	0%	124%	75%	0%	Partial Internal
Legal & General Group PLC	UK	2017	2	181%	0%	137%	72%	0%	Partial Internal
Legal & General Group PLC	UK	2018	2	189%	0%	165%	71%	0%	Partial Internal
Legal & General Group PLC	UK	2019	2	179%	0%	157%	60%	0%	Partial Internal
Legal & General Group PLC	UK	2020	2	175%	0%	159%	56%	0%	Partial Internal
Old Mutual PLC	UK	2016	0	122%	0%	0%	0%	0%	Standard Formula
Old Mutual PLC	UK	2017	0	123%	0%	0%	0%	0%	Standard Formula
Phoenix Group Holdings	UK	2016	2	140%	0%	36%	47%	0%	Partial Internal
Phoenix Group Holdings	UK	2017	2	138%	0%	34%	39%	0%	Partial Internal
Phoenix Group Holdings	UK	2018	3	146%	0%	42%	38%	0%	Partial Internal
Phoenix Group Holdings	UK	2019	3	140%	0%	41%	40%	0%	Partial Internal
Phoenix Group Holdings	UK	2020	3	145%	1%	50%	33%	0%	Partial Internal

Firm name	Country	Year	LTGs Used	Solvency Reported	VA Impact	MA Impact	TP Impact	IR Impact	Model for SCR calculation
Prudential PLC	UK	2016	3	171%	3%	53%	17%	0%	Partial Internal
Prudential PLC	UK	2017	3	168%	2%	45%	13%	0%	Partial Internal
Prudential PLC	UK	2018	3	192%	8%	38%	10%	0%	Partial Internal
RSA Insurance Group PLC	UK	2016	0	158%	0%	0%	0%	0%	Full Internal
RSA Insurance Group PLC	UK	2017	0	163%	0%	0%	0%	0%	Full Internal
RSA Insurance Group PLC	UK	2018	0	170%	0%	0%	0%	0%	Full Internal
RSA Insurance Group PLC	UK	2019	0	178%	0%	0%	0%	0%	Full Internal
RSA Insurance Group PLC	UK	2020	0	189%	0%	0%	0%	0%	Full Internal
St. James's Place PLC	UK	2016	0	141%	0%	0%	0%	0%	Standard Formula
St. James's Place PLC	UK	2017	0	133%	0%	0%	0%	0%	Standard Formula
St. James's Place PLC	UK	2018	0	137%	0%	0%	0%	0%	Standard Formula
St. James's Place PLC	UK	2019	0	126%	0%	0%	0%	0%	Standard Formula
St. James's Place PLC	UK	2020	0	124%	0%	0%	0%	0%	Standard Formula
Standard Life Aberdeen PLC	UK	2016	3	177%	2%	32%	36%	0%	Partial Internal
Standard Life Aberdeen PLC	UK	2017	3	185%	1%	34%	24%	0%	Partial Internal

Table A4: Solvency II data on insurer level (displayed on five pages)

Literature

Berends, K., McMenamin, R., Plestis, T., Rosen, R. (2013), 'The sensitivity of life insurance firms to interest rate changes', *Federal Reserve Bank of Chicago Economic Perspectives*, 37 (2): 47-78.

Brechmann, E. C., Czado, C. (2013), 'Risk management with high-dimensional vine copulas: An analysis of the Euro Stoxx 50', *Statistics & Risk Modeling*, 30 (4): 307-342.

Brewer, E., Carson, J. M., Elyasiani, E., Mansur, I., Scott, W. L. (2007), 'Interest rate risk and equity values of life insurance companies: A GARCH-M model', *Journal of Risk and Insurance*, 74 (2): 401-423.

Campbell, J. Y., Lettau, M., Malkiel, B. G., Xu, Y. (2001), 'Have individual stocks become more volatile? An empirical exploration of idiosyncratic risk', *The Journal of Finance*, 56 (1): 1-43.

Carson, J. M., Elyasiani, E., Mansur, I. (2008), 'Market risk, interest rate risk, and inter-dependencies in insurer stock returns: A System-GARCH model', Journal of Risk and Insurance, 75 (4): 873-891.

Colliard, J.-E. (2019), 'Strategic Selection of Risk Models and Bank Capital Regulation', *Management Science*, 65 (6): 2591-2606.

Crean, A., Foroughi, K. (2017), 'Solvency II one year on : One step forward, two steps back', Willis Towers Watson / Autonomous, https://www.wtwco.com/-/media/wtw/insights/2017/04/solvency-ii-one-year-on.pdf.

Da, Z., Guo, R. J., & Jagannathan, R. (2012), 'CAPM for estimating the cost of equity capital: Interpreting the empirical evidence', *Journal of Financial Economics*, 103 (1): 204-220.

Düll, R., König, F., Ohls, J. (2017), 'On the exposure of insurance companies to sovereign risk portfolio investments and market forces', *Journal of Financial Stability*, 31: 93-106.

Duverne, D., Hele, J. (2017), 'How the Insurance Industry Manages Risk', in: Hufeld, F., Koijen, R. S. J., Thimann, C. (Eds.), The Economics, Regulation, and Systemic Risk of Insurance Markets, Oxford University Press, Oxford, Ch. 3: 55-75.

EIOPA (2014), 'EIOPA Insurance stress test 2014', EIOPA-BOS-14-203, November 2014, https://www.eiopa.europa.eu/system/files/2019-09/stress_test_report_2014.pdf.

EIOPA (2016a), '2016 EIOPA Insurance Stress Test Report', EIOPA 16/302, December 2016, https://www.eiopa.europa.eu/system/files/2019-09/eiopa-bos-16-302_insurance_stress_test_2016_report.pdf.

EIOPA (2016b), 'Report on long-term guarantees measures and measures on equity risk 2016', EIOPA-BoS-16/279, December 2016, https://register.eiopa.europa.eu/Publications/Responses/EIOPA-BoS-16-279_LTG_REPORT_2016.pdf.

EIOPA (2017a), 'Investment behavior report', EIOPA-BoS-17/230, November 2017, https://www.eiopa.europa.eu/system/files/2020-01/investment_behaviour_report.pdf.

EIOPA (2017b), 'Report on long-term guarantees measures and measures on equity risk 2017', EIOPA-BoS-17/334, December 2017, https://register.eiopa.europa.eu/Publications/Reports/2017-12-20%20LTG%20Report%202017.pdf.

EIOPA (2018), 'Report on long-term guarantees measures and measures on equity risk 2018', EIOPA-BoS-18/471, December 2018, https://register.eiopa.europa.eu/Publications/Reports/2018-12-18%20_LTG%20AnnualReport2018.pdf.

EIOPA (2020), 'Report on long-term guarantees measures and measures on equity risk 2020', EIOPA-BoS-20/706, December 2020, https://www.eiopa.europa.eu/system/files/2020-12/eiopa-bos-20-706-long-term-guarantees-ltg-report-2020.pdf.

European Commission (2009), 'Directive 2009/138/EC of the European Parliament and of the Council of 25 November 2009 on the taking-up and pursuit of the business of Insurance and Reinsurance (Solvency II)', *Official Journal of the European Union*, December 2009.

European Commission (2015), 'Commission Delegated Regulation (EU) 2015/35 of 10 October 2014 supplementing Directive 2009/138/EC of the European Parliament and of the Council on the taking-up and pursuit of the business of Insurance and Reinsurance (Solvency II)', *Official Journal of the European Union*, January 2015.

Frey, A. (2012) 'Facing the interest rate challenge', *Sigma Study*, No. 4/2012, Swiss Re, https://www.swissre.com/institute/research/sigma-research/sigma-2012-04.html.

Gatzert, N., Hedinger, D. (2020), ‘An Empirical Analysis of Market Reactions to the First Solvency and Financial Condition Reports in the European Insurance Industry’, *Journal of Risk and Insurance,* 87 (2): 407-436.

Grochola, N., Browne, M. J., Gründl, H., Schlütter, S. (2021), ‘Exploring the market risk profiles of U.S. and European life insurers’, ICIR Working Paper Series No. 39/2021.

Hakenes, H., Schnabel, I. (2011), ‘Bank size and risk-taking under Basel II’, *Journal of Banking & Finance*, 35 (6): 1436-1449.

Hartley, D., Paulson, A., Rosen, R. J. (2017), ‘Measuring Interest Rate Risk in the Life Insurance Sector: The U.S. and the U.K.’, in: Hufeld, F., Koijen, R. S. J., Thimann, C. (Eds.), *The Economics, Regulation, and Systemic Risk of Insurance Markets*, Oxford University Press, Oxford, Ch. 6: 124-150.

Lins, K. V., Servaes, H., Tamayo, A. (2017), ‘Social capital, trust, and firm performance: The value of corporate social responsibility during the financial crisis’, *The Journal of Finance,* 72(4): 1785-1824.

Möhlmann, A. (2021), ‘Interest rate risk of life insurers – evidence from accounting data’, *Financial Management,* 50 (2): 587-612.

Mukhtarov, S., Schoute, M., Wielhouwer, J. L. (2022), ‘The information content of the Solvency II ratio relative to earnings’, *Journal of Risk and Insurance,* 89(1): 237-266.

Plosser, M. C., Santos, J. A. C. (2014), ‘Banks' Incentives and the Quality of Internal Risk Models’, Staff Reports 704, Federal Reserve Bank of New York.

Thibeault, A., Wambeke, M. (2014), ‘Regulatory impact on banks' and insurers' investments’, Vlerick Business School Working Paper.

Wilson, T. C. (2013), ‘Risk Management in the Face of Risky Sovereign Debt: Four Observations’, *BIS Papers*, No. 72, 130-135.