Exploring the market risk profiles of U.S. and European stock insurers

Nicolaus Grochola*, Mark J. Browne†, Helmut Gründl‡, Sebastian Schlütter§

This version: June 2023**

Abstract

Market risks account for an integral part of insurers' risk profiles. We explore market risk sensitivities of insurers in the U.S. and Europe. Based on panel regression models and daily market data from 2012 to 2018, we find that sensitivities are particularly driven by insurers' product portfolio. The influence of interest rate movements on stock returns is 60% larger for U.S. than for European life insurers. For the former, interest rate risk is a dominant market risk with an effect that is five times larger than through corporate credit risk. For European life insurers, the sensitivity to interest rate changes is only 44% larger than towards CDS of government bonds, underlining the relevance of sovereign credit risk.

Keywords: Life insurance, interest rate risk, credit risk

JEL Classification: G01, G18, G22

---

* Contacting Author. Goethe University Frankfurt, Faculty of Economics and Business, International Center for Insurance Regulation, House of Finance, Theodor-W.-Adorno-Platz 3, 60629 Frankfurt am Main, Germany; Phone: +49 69 798 33680; E-mail: grochola@finance.uni-frankfurt.de.

† St. John's University, New York, School of Risk Management in the Tobin College of Business.

‡ Goethe University Frankfurt, International Center for Insurance Regulation.

§ Mainz University of Applied Sciences, Department of Business.

** The empirical data that support the findings of this study are available from third parties. Restrictions apply to the availability of these data, which were used under license for this study. Helmut Gründl and Sebastian Schlütter gratefully acknowledge funding from the Berkley Fellowship Program for a research stay at St. John's University, New York. None of the authors have any conflict of interest. We are grateful for comments and suggestions by Arina Brutyan, Peter Hieber, Christian Kubitza, and participants at the 2020 WRIEC, 2018 & 2021 Annual Meetings of the German Association for Insurance Studies, 2022 EERIA and seminars at Deutsche Bundesbank and St. John's University, New York. This version supersedes the previously circulating version "The Influence of Market Risks on the Stock Return of Life Insurance Companies".

1 Introduction

Life insurers have not entirely hedged their balance sheet exposure to market risks. As a result, market risks are threatening life insurers' financial stability more than, for instance, biometric risks.[1] Given that U.S. and European life insurers' investment portfolios consist largely of bonds,[2] interest rate risk and counterparty credit risk are specifically relevant types of market risks. Firstly, interest rate movements influence both sides of an insurer's balance sheet by affecting bond investments and the liability portfolio. Given the long maturities of life insurance contracts, two main channels of interest rate exposures are duration gaps[3] and fixed minimum returns guaranteed to policyholders[4] in most countries (cf. Table A1 in Appendix I). Secondly, counterparties' credit risk affects the default probabilities of fixed income investments directly. Therefore, a substantial change in the creditworthiness of an issuer can influence an insurer's solvency position. The relevance of credit risk has grown with the decline of interest rates: in order to search for yield, the share of insurers' bond investments with an A-rating decreased by 6 percentage points (ppt) in the U.S. and 19ppt in the EU.[5] The aim of this paper is to estimate market risk sensitivities according to their contribution to insurers' stock performance, taking several risk drivers and balance sheet characteristics into account.

The scholarly literature has studied how interest rates and credit risks affect (life) insurers. To our knowledge, however, there is no holistic analysis at the international level that combines these risk types in a joint empirical model. In terms of sensitivities to interest rates, the majority of papers consider U.S. insurance companies (cf. Table A2). Brewer et al. (1993) introduce a two-factor model derived from the finance literature (e.g., Flannery and James (1984)) to empirically estimate interest rate sensitivities of listed insurers when controlling for the stock market. Brewer et al. (2007) and Carson et al. (2008) provide evidence that increasing interest rates reduced life insurers' stock returns (and vice versa) during their study period of 1975 to

[1] For example, 81% of European Union (EU) life insurers' regulatory capital requirement result from market risks (including counterparty default risk) for standard formula users under the Solvency II regime in 2019 (cf. European Insurance and Occupational Pensions Authority (EIOPA) (2020a)). Market risks are among the top three reasons for life insurers' (near) failures alongside staff competence risk and investment risk (cf. EIOPA (2018)).
[2] 69% of U.S. life insurers' and 83.5% of European Economic Area (EEA) insurers' investments are allocated to bonds (cf. National Association of Insurance Commissioners (NAIC) (2021) and EIOPA (2017)).
[3] As technical provisions typically have a longer duration compared with fixed income securities, liabilities are more sensitive to interest rate changes than assets. As a result, falling interest rates increase the value of liabilities more strongly than the asset value. The width of the duration mismatch measured in years is called "duration gap".
[4] Policyholders with contractually guaranteed returns must receive benefits at least equaling previously paid premiums plus interest payments specified at the start of the contract. When the corresponding assets of life insurers mature, previous investment strategies may not generate sufficient yields to cover the guarantees.
[5] Between 2013 and 2020 (2011 and 2016), the share of bonds with an A-rating that were held by U.S. (EU) insurers fell from 68% to 61.8% (from 84% to 65%), while the share increased for B-grade bonds from 27% to 32.1% (11% to 26%) according to NAIC (2013, 2021) and EIOPA (2017).

2001. Moreover, Brewer et al. (2007) demonstrate that insurers' equity prices are particularly impacted by interest rates with long maturities and that sensitivities vary over time and insurer types. Park and Choi (2011) show that property and liability insurers' – i.e., non-life insurers' – stock returns are also influenced by interest rate movements during the sample period of 1992 to 2001. Berends et al. (2013) find that sensitivities of U.S. life insurers' stock returns to interest rate risks have changed over time: in a period before the financial crisis from 2007 to 2008, insurers were not significantly sensitive to interest rate changes, but in the low-yield environment after the crisis, insurers suffered from decreasing rates.

Further articles focus on detecting channels through which interest rates affect insurers. Many years prior to the low yield environment, Siglienti (2000) demonstrates that life insurers need to lower guaranteed minimum rates and avoid risky investments in order to generate sufficient returns. Similarly, Holsboer (2000) correctly predicts a switch to more unit-linked products,[6] where the investment risk is borne by policyholders, and emphasizes a higher awareness for market risks. In an empirical top-down approach, Hartley et al. (2017) compare stock-listed insurers of the U.S., the U.K. and continental European countries in terms of their sensitivities to interest rates in the low yield environment. For the U.K., where life insurance contracts typically do not include guaranteed returns, the authors find that insurers' stock returns are not significantly connected to interest rate movements. In contrast, they find a negative relationship for U.S. insurers and for firms with large exposures to the German life insurance market, where fixed minimum returns are common. In line with these findings, Koijen and Yogo (2022) show that U.S. insurers offering variable annuities suffer from the implied guaranteed returns for policyholders. Such guarantees are also implemented in participating (or "traditional") products that account for 75% of life insurance premiums in Europe (cf. Insurance Europe (2019)).[7] The guaranteed returns in Europe, however, are typically backed by capital reserves and allow for a smoothing of returns over different generations of policyholders rather than cross-sectional risk sharing, which is common in the U.S. (cf. Hombert and Lyonnet (2017)).

Regarding the patterns of yield curve changes, Czaja et al. (2009) provide evidence that German insurers' equity returns are influenced by the level and the curvature of the yield curve. More recently, Killins and Chen (2022) demonstrate a negative effect of a rising yield curve slope on insurers. The authors further detect asymmetric sensitivities across countries and time as well

[6] In 1997, 10.6% of premiums stemmed from unit-linked products (cf. Holsboer (2000)) compared to 25% in 2017 (cf. Insurance Europe (2019)). Unit-linked insurance products typically do not include minimum return guarantees. In terms of their balance sheet exposures, unit-linked insurers should be less sensitive to interest rate changes.

[7] 80% of European life insurance policies include guaranteed surrender values, which policyholders receive in case of an early withdrawal (cf. EIOPA (2019)).

as higher interest rate risk for life insurers compared with other insurer types. Using a German sample, Möhlmann (2021) finds an aggregate modified duration gap of six years.[8] He argues that life insurers do not aim for adequate duration matching, because they prefer illiquid long-term investment strategies. Similarly, Koijen and Yogo (2022) argue that insurers deliberately choose to have a duration gap, even though they could select adequate hedging strategies. In line with this theory, Ozdagli and Wang (2019) find that U.S. insurers do not perfectly match the duration of assets and liabilities in every single period.

In terms of credit risk, most research articles have examined its relevance for banks and non-financial firms.[9] There is only a small amount of literature analyzing the influence of credit risk on insurers. Bégin et al. (2019) show that the credit risk of financial institutions is significantly affected by crisis periods. In times of increasing default probabilities, the authors observe a transmission effect of banks on insurers in line with Chen et al. (2014). In addition, Billio et al. (2014) demonstrate that sovereign credit risk has a direct impact on insurance companies' losses, even before the European sovereign debt crisis of 2010 to 2012. Focusing on participating life insurance, Eckert et al.'s (2016) simulation model demonstrates that the value and risk situation of insurers is substantially influenced by the credit risk related to their bond investments. The authors also detect interaction effects between credit risk and other market risks, thereby underlining the relevance of considering credit risk exposures for adequate risk management. In an empirical approach, Düll et al. (2017) find that European insurance companies suffer from deteriorations in the creditworthiness of sovereign debt, which is measured by credit default swap (CDS) spreads of government bonds. Specifically, an increase in sovereign credit risk negatively affects insurers' financial strength. These results are alarming given that the Solvency II standard formula disregards credit risk for sovereign counterparties, and thus encourages riskier sovereign debt investments (cf. Wilson (2013)). Similarly, Becker and Ivashina (2015) and Becker et al. (2022) detect that the regulatory framework in the U.S. incentivizes insurers to take as much risk as possible conditional on the capital requirement.

The existing literature leaves open questions in two respects in particular. Firstly, the empirical literature only takes an isolated view on the influence of interest rates or CDS spreads on the performance of insurance companies. By only considering the stock market index as a control variable and leaving out other potential influences, the results can be affected by an omitted

[8] On average, a decrease in interest rates by 1ppt results in a rise in the market value of liabilities that is 6ppt higher than the corresponding increase in the market value of assets.
[9] For instance, Acharya et al. (2014) emphasize the existence of a loop between sovereign credit risk, the health of the financial sector and bank bailouts.

variable bias, meaning that the influence of the particular risk driver can be underestimated or overestimated. To overcome this issue and to answer the question concerning the influence of market risks on life insurers' return comprehensively, we empirically investigate the impact of various market risk drivers on U.S. and European insurers' stock returns for the period between 2012 and 2018, i.e., a time frame covering the low interest rate environment. To be specific, we include relative changes in 10-year and 1-year interest rates and national stock market (volatility) indices in the empirical models. To measure insurers' sensitivities to sovereign counterparty credit risk, we design country-specific weighted government bond portfolios based on regulatory investment data from the NAIC and EIOPA. We include the corresponding relative changes in CDS spreads in the empirical model. In addition, we consider corporate credit risk by including average returns of CDS indices for different market segments. Notably, the correlations between changes in interest rates and CDS spreads are low, which justifies the chosen empirical approach by lowering concerns about multicollinearity.

Secondly, although market risks constitute an integral part of the risk profiles of life insurance companies globally, so far there has not been a comparison of which specific market risk (either interest rate or credit risk) is more influential for U.S. and European insurers. Most of the existing literature has measured market risk sensitivities of either U.S. or European insurance companies. To our knowledge, only Hartley et al. (2017) compare the interest rate risk of U.S. and U.K. life insurers. We use their findings as a motivation to analyze the heterogeneity in interest rate sensitivities between U.S. and European insurers in more depth and to extend the research question by investigating the relevance of counterparty credit risk ('credit risk' hereafter) on both continents. In addition, we identify insurer characteristics driving market risk sensitivities such as the share of life insurance reserves, unit-linked business and solvency.

We study life insurers' sensitivities to market risk factors in a low interest rate environment based on stock market reactions. For this top-down approach, we have chosen a multivariate panel regression model in line with the related literature investigating interest rate risk (e.g., Berends et al. (2013)). In addition to considering both sovereign and corporate credit risk, we introduce several further adjustments compared to previous empirical papers. Firstly, we use insurer fixed effects and cluster standard errors on the time level to strengthen the robustness of our results. Secondly, we introduce macroeconomic market risk drivers such as short-term interest rate movements and the levels of long-term interest rates and CDS spreads in addition to changes. Thirdly, we control for the insurer-specific variables size, leverage and the market-to-book ratio. Fourthly, we take the cross-sectional previous year's median as a threshold for defining a life insurer, a unit-linked insurer or a solvent firm. Finally, we include a wide range of alternative specifications (e.g., continuous insurer-specific variables, weekly data, controls for autocorrelation, adjustments of binary thresholds) for robustness checks in Appendix V. In our approach, we combine findings from several research papers including Brewer et al. (2007), Hartley et al. (2017), Düll et al. (2017) and Killins and Chen (2022).

The empirical results illustrate that insurers' sensitivities to market risks are particularly driven by their product lines. In addition to life insurers and less solvent firms, our paper also detects significantly larger market risk sensitivities for unit-linked insurance providers, even though they are typically not in the focus of regulatory reforms. On average, insurers suffer from falling interest rates, which is consistent with the existing literature. However, we find that the effect of interest rate movements on stock returns is 60% larger for U.S. life insurers than for European life insurers. In the U.S., interest rate movements are a dominant market risk factor with an impact that is five times larger than the impact of corporate bonds' CDS spreads. U.S. life insurers significantly suffer from rising default probabilities of corporate debt, but not from higher default probabilities of sovereign debt. This result is consistent with the fact that they invest a high asset share in corporate and secure domestic government bonds. For European life insurers, in contrast, changes in sovereign CDS spreads are more relevant than changes in corporate CDS spreads. The impact of sovereign CDS spreads on stock returns is only 44% smaller compared to the impact of long-term interest rates. The international comparison highlights that, especially in Europe, sovereign credit risk is important to insurers and its omission from the standard formula is a serious limitation.

The findings are of importance for insurance regulation and supervision acting in the interest of policyholders. The awareness for structural differences between risk profiles is necessary to enhance a level playing field of regulation. From a regulatory perspective, it matters whether the Solvency II standard formula in the EU should be designed differently with regard to market risks than the risk-based capital (RBC) in the U.S. There are varying approaches for protecting policyholders' interests by controlling life insurers' solvency levels or by reducing policyholders' losses through an insolvency. For refining insurance capital standards on both the national and international levels, it is an indispensable prerequisite to gain empirical evidence on the impact of different market risks on insurers' risk situation. An early detection of life insurers' financial distress lowers policyholders' default risk and benefits sound insurers and agents (cf. Carson and Hoyt (2000)). Our results are also of importance for shareholders and managers of stock insurance companies. They benefit from our findings which provide a profound basis for deciding how to structure their risk management activities efficiently, i.e., by taking differences in sensitivities across insurer types and countries into account.

The remainder of the article is organized as follows. Section 2 provides the empirical methodology. In this chapter, econometric issues are discussed, all variables used to tackle the research question are presented and the hypotheses and empirical models are set out. Section 3 provides the regression results. Section 4 concludes.

2 Empirical methodology

2.1 Econometric issues

For the empirical analysis of the market risk sensitivities, we collect daily data on stock prices and market risk drivers for the time frame between 1 January 2012 and 30 June 2018. The sample period is characterized by historically low interest rates in the aftermath of the global financial crisis. The previous literature suggests that insurers' interest rate sensitivities are relatively homogeneous within this market phase, but exhibited different patterns in earlier periods within or before the crisis (e.g., Brewer et al. (2007) and Hartley et al. (2017)). The chosen period comprises 1,658 trading days for which returns can be observed.[10] In line with Düll et al. (2017), we use daily data, which to our knowledge has only been done by Carson et al. (2008) in the empirical literature analyzing interest rate risk (cf. Table A2 in Appendix I), but for a portfolio of firms rather than on an insurer level, and for a different sample period (1991 to 2001). The granular approach of using daily data accounts for a higher frequency of risk transmissions and thus allows for a smaller share of noises due to individual shocks and hence more accurate estimates.[11] A potential econometric concern when using daily data is correlated shocks. To tackle this issue, we use heteroskedasticity-robust standard errors clustered on the day level analogously to Düll et al. (2017).[12] Some previous articles focus on a portfolio of insurers, mainly due to the lack of statistical significance for individual firms and idiosyncratic noise (e.g., Berends et al. (2013)). To ensure that the sensitivities measured in the panel regressions are not driven by individual insurers, we include insurer fixed effects.

The methodology of using stock returns as a measure for market risk sensitivities in a top-down approach, in line with Berends et al. (2013) and Hartley et al. (2017), has advantages and disadvantages. On the one hand, using stock returns allows for a high power of empirical testing. Stock market participants are assumed to be aware of insurers' product portfolios and

[10] We consider all weekdays, except for New Year's Day, Good Friday and December 25th, because stock markets are closed on those days in all countries that we observe. The number of observations for an insurer depends on the number of national holidays in its home country. For U.S. insurers, the time span covers 1,623 trading days.
[11] For instance, if an insurer-specific piece of information largely impacts its stock price on one day, this results in a single large error term which is less disturbing for regression coefficients when a higher data frequency is given.
[12] For robustness tests, we use weekly data and cluster standard errors also at the firm level (cf. Appendix V).

their balance sheet characteristics. When considering investment decisions, relevant information reported in annual reports, analysts' reports or other publications such as Solvency and Financial Condition Reports (SFCRs) can be observed and should thus be priced into an insurer's equity value in line with the efficient market hypothesis. These sources of information include insurer-specific data on risk management, the use of guaranteed products, the expected profitability and the financial health of insurers. We thus assume that stock price movements adequately reflect insurers' market risk exposures. On the other hand, there are some drawbacks of using stock returns. Firstly, mutual insurance companies are not included in the sample because they are not listed on stock markets. Mutual insurers' market risk sensitivities could be estimated through a bottom-up approach, which, however, is impractical due to the lack of regular product and performance data.[13] It should thus be kept in mind that our findings only express market risk sensitivities of stock-listed insurers. Secondly, some insurers may also engage in non-insurance business (cf. Berends et al. (2013)). To avoid misinterpreting sensitivities that are actually linked to other business areas, we include listed subsidiaries when their parent company's main income is not generated from insurance business.[14] In addition, we exclude subsidiaries when both parent and subsidiary company mainly engage in insurance business in order to avoid impairing the external validity of our results.[15]

2.2 Dependent variable

For the sample, we consider all publicly listed U.S. and European insurers for which daily stock data can be gathered from Refinitiv. Eight firms with fewer than 300 stock price observations in the sample period are excluded, as they are subject to low data frequencies. The resulting sample consists of 94 U.S. and 69 European joint-stock insurance companies.[16]

For the dependent variable in the regression models, we rely on the total return index (TRI). The TRI is set to 100 on the day of a firm's initial public offering. It accounts for stock price changes due to dividend payments and fluctuations in the number of a firm's outstanding shares. Therefore, the TRI combines relevant information to display a company's historical stock market performance in a single figure. We use the relative daily changes $r_{i,t}$ as a measure for

[13] Bottom-up approaches investigating the interest rate risk of insurers have been applied by Möhlmann (2021) and Kablau and Weiß (2014) using regulatory data from the German Bundesbank.
[14] For instance, instead of the investment bank Natixis S.A. from France and the financial service company Unipol Gruppo S.p.A. from Italy, we include their respective insurance subsidiaries Coface S.A. and UnipolSai S.p.A.
[15] For instance, the German insurer Hannover Rück SE (parent company: Talanx AG) and the French insurer Euler Hermes S.A. (parent company: Allianz SE) are excluded from the sample.
[16] The sample contains nine out of ten firms that have ever been marked as global systemically important insurers (G-SIIs) by the Financial Stability Board. The only G-SII that is not included is Ping An Insurance from China.

the stock return. It is given for each insurer i on each day t, where $t_{previous}$ is the last day for which stock data is available for a particular insurer[17]:

$$r_{i,t} = \frac{TRI_{i,t}}{TRI_{i,t_{previous}}} - 1 \quad (1)$$

If $TRI_{i,t}$ is not available, e.g., due to a public holiday on day t in the country where insurer i is listed, then $r_{i,t}$ is set to unavailable. In addition, we remove observations of $r_{i,t}$ if the stock price is unchanged for at least three consecutive days, as this signals a lack of data availability.

Descriptive statistics of the 163 individual insurers' daily stock returns $r_{i,t}$ are presented in Table A3 and Table A4 in Appendix II. Altogether, U.S. (European) insurers in the sample hold \$4.3 trillion (\$8.1 trillion) of assets. This corresponds to 48% of total U.S. insurance companies' assets and 70% of EEA insurers' total assets.[18] The aggregate descriptive statistics in Table 1 show that on average, an U.S. (European) insurer's TRI increased by 0.09ppt (0.08ppt) per day with a high standard deviation of 2.77ppt (2ppt).

2.3 Independent variables

In the empirical models, we use interest rates with 10-year-maturities as a measure for long-term interest rates. For U.S. insurers, we use the 10-year Treasury Constant Maturity Rate, which is gathered from the Federal Reserve Economic Data (FRED). For European insurers, we use European Central Bank (ECB) estimates of the Euro yield curve based on sovereign debt from Eurozone countries with an AAA-rating.[19] To control for the term structure of interest rates, we also collect data on short-term rates with 1-year-maturities from the respective sources. This allows us to analyze, for instance, how stock returns change after a decrease in long-term interest rates while keeping short-term rates constant. The coefficients for the interest rate variables thereby take into account changes in the slope of the yield curve, which has a negative relationship with insurers' stock returns (cf. Killins and Chen (2022)). Considering short-term rates is also relevant due to the heterogeneity in the duration of insurers' assets.

The central variable for relative interest rate changes is the holding period return (hpr) within one trading day, which is in line with Brewer et al. (2007). For long-term rates, the hpr equals

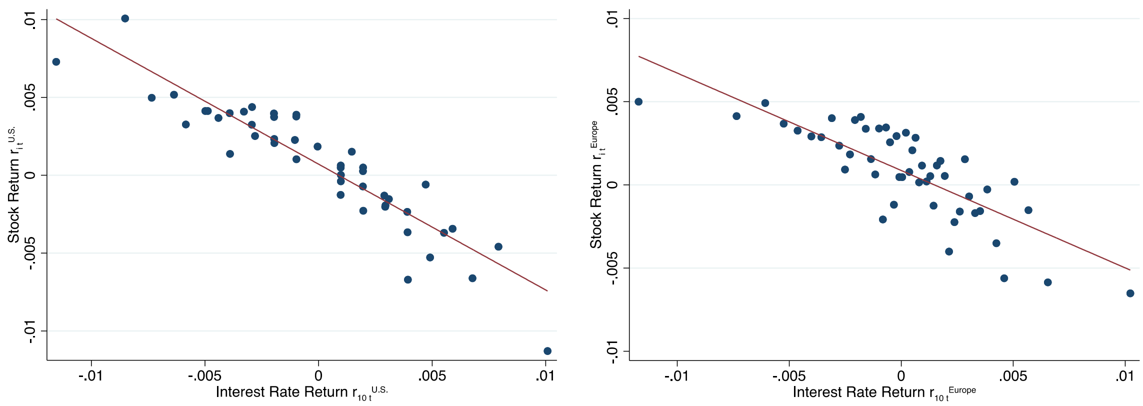
---

[17] In our robustness section in Appendix V, we use two alternative definitions for $r_{i,t}$. Firstly, we consider the number of trading days that have passed since the last stock price observation. Secondly, we only consider stock returns when exactly one trading day has passed. As shown in Table A9, the regression results are unaffected.
[18] In total, U.S. insurers held \$9 trillion assets in 2016 according to statistical compilations published by the NAIC for life, health and property/casualty insurers. EEA insurers held €10.5 trillion (≈ \$11.63 trillion) of assets in 2016 (cf. EIOPA (2016)). The calculation is based on an average Euro-to-Dollar currency rate of 1.108 in mid-2016.
[19] As rating changes result in a different composition of government bonds, the Euro yield curve continuously represents safe investment opportunities, which are preferred by regulators (e.g., own fund tiers in Solvency II).

the return that is achieved by buying a zero-coupon bond with the interest rate yield $y10_{t_{previous}}$ and then selling it on the next day. Assuming that the bond price is unchanged, the hpr is only positive after a decline in interest rates, i.e., when the insurer sells a bond guaranteeing higher yields than the market is currently offering. It applies (analogously for 1-year interest rates):

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

There is a negative linear relationship between the hpr of long-term interest rates $r_{y10,t}$ and insurers' stock returns $r_{i,t}$ illustrated in Figure 1. Due to the definition of the hpr, a negative relationship implies that on average, stock returns are larger when interest rates rise. Interest rate movements seemingly have a larger impact on U.S. insurers' stock returns (Figure 1a) than on European insurers' stock returns (Figure 1b), illustrated by a slightly steeper curve in the red line, which is the best fit of a univariate OLS regression.



(a) U.S. sample

(b) European sample

Note: The figures depict binned scatterplots of stock returns and the hpr for the 10-year interest rate. The observations for $r_{y10,t}$ are grouped into 50 bins of equal size. Each dot represents the mean of $r_{y10,t}$ (x-axis) and the mean of insurers' stock returns $r_{i,t}$ (y-axis) within each bin. The red line illustrates the regression line from a univariate linear model. Figure 1a) uses data for U.S. insurers and Figure 1b) for European insurers.

Figure 1: Binned scatterplots of stock returns and changes in interest rates

In addition to the hpr, we control for the level of 10-year interest rates given that stock returns may be influenced by the level of the term structure (cf. Czaja et al. (2009)). We only find a small positive correlation coefficient for the interest rate levels in the U.S. and Europe (0.10), but a larger one for the hpr (0.53) reflecting daily changes in the sample period. The descriptive statistics in Table 1 show that during the sample period from 2012 to mid-2018, interest rates in the U.S. were on average larger (mean of 2.22% compared with 1.09% in Europe) and rising, while they were falling in the Eurozone (a positive mean of $r_{y10,t}$ implies falling interest rates).

	N	Mean	p50	SD	p1	p5	p95	p99
Insurer characteristics (insurer-day level in ppt)								
$r_{i,t}$ (U.S., stock return)	135,659	0.09	0.05	2.77	-5.36	-2.65	2.80	5.84
$r_{i,t}$ (Europe, stock return)	99,637	0.08	0.03	2.00	-4.94	-2.55	2.77	5.27
Insurer characteristics (insurer-year level)								
Life $Share_{i,y-1}$	793	0.30	0.30	0.31	0.00	0.00	0.85	0.93
Unit-linked $Share_{i,y-1}$	793	0.10	0.00	0.18	0.00	0.00	0.52	0.83
RBC $Ratio_{i,y}$ (U.S.)	155	12.08	6.69	32.63	3.13	3.64	17.62	251.50
Solvency $Ratio_{i,y}$ (Europe)	122	2.09	2.02	0.49	1.25	1.46	2.97	3.29
$Life_{i,y-1}$ (binary)	793	0.30	0.00	0.46	0.00	0.00	1.00	1.00
$Unit_{i,y-1}$ (binary)	793	0.21	0.00	0.41	0.00	0.00	1.00	1.00
$Solvency_{i,y}$ (binary)	277	0.50	0.00	0.50	0.00	0.00	1.00	1.00
$\ln(Size_{i,y-1})$	793	16.17	16.10	2.31	11.16	12.15	20.12	20.69
$Leverage_{i,y-1}$ (ratio)	793	0.50	0.29	0.97	0.00	0.00	1.63	4.86
$Market\text{-}to\text{-}Book_{i,y-1}$ (ratio)	793	1.52	1.10	1.83	0.28	0.50	3.51	7.05
Macroeconomic characteristics (country-day level in ppt)								
$r_{m,o,t}$ (market return)	31,506	0.04	0.05	1.25	-3.27	-1.81	1.84	3.15
$r_{v,o,t}$ (volatility return)	11,451	0.26	-0.10	8.84	-14.83	-8.84	10.83	20.27
$r_{Sov,o,t}$ (Sovereign CDS return)	31,506	-0.08	-0.05	3.15	-7.52	-3.66	3.60	8.96
$Sov_{o,t}$ (Sovereign CDS level)	31,506	1.44	0.52	5.36	0.11	0.15	3.38	11.31
Macroeconomic characteristics (day level in ppt)								
$r_{y10,t}$ (U.S., 10-year hpr)	1,623	-0.00	0.00	0.43	-1.08	-0.71	0.68	0.99
$r_{y10,t}$ (Europe, 10-year hpr)	1,658	0.02	0.03	0.36	-1.02	-0.60	0.54	0.85
$y10_t$ (U.S., interest rate level)	1,623	2.22	2.23	0.40	1.49	1.59	2.88	3.00
$y10_t$ (Europe, interest rate level)	1,658	1.09	0.77	0.80	-0.14	0.02	2.50	2.70
$r_{y1,t}$ (U.S., 1-year hpr)	1,623	-0.01	0.00	0.16	-0.51	-0.30	0.20	0.40
$r_{y1,t}$ (Europe, 1-year hpr)	1,658	0.01	0.01	0.13	-0.36	-0.19	0.20	0.32
$r_{Corp,t}$ (U.S., Corp. CDS return)	1,623	0.15	-0.05	2.62	-5.20	-2.60	3.55	8.54
$r_{Corp,t}$ (Europe, Corp. CDS return)	1,658	0.18	-0.11	3.16	-6.59	-2.91	3.60	11.44

Note: The stock return is at insurer-day level and retrieved from Refinitiv. Further insurer characteristics are at insurer-year level and retrieved from SNL, apart from the RBC ratio (NAIC) and the solvency ratio (hand-collected from SFCRs). Macroeconomic characteristics are partly at country-day level, retrieved from Refinitiv (stock and volatility indices) and Markit (sovereign CDS spreads) and partly at day level, retrieved from the FRED (interest rates in the U.S.), the ECB (interest rates in Europe) and Refinitiv (corporate CDS spreads). The sample starts in 2012 and ends in mid-2018; it includes 94 U.S. and 69 European insurers.

Table 1: Descriptive statistics for insurer-level data and macroeconomic characteristics

As a second market risk driver of interest, we consider default probabilities of sovereign debt. In line with Düll et al. (2017), we use CDS spreads of government bonds denominated in U.S. dollars with a 5-year maturity for detecting credit risk sensitivities. The choice of this variable is motivated by the large share of particularly European insurers' investments in sovereign debt, with governments as corresponding credit counterparties.[20] CDS spreads adequately reflect default probabilities of a bond issuer, as they are tied to the issuer's credit quality. For this reason, CDS spreads are considered in empirical studies focusing on the systemic risk of insurers (e.g., Chen et al. (2014) and Bégin et al. (2019)) and in banking research (e.g., Acharya et al. (2014)). The CDS spreads are obtained from Markit and correspond to the probability of a country's default within five years after the issue date. A country's default implies that a government does not fulfill its payment obligations to creditors.

[20] 50% of EEA life insurers' (12% of U.S. life insurers') bond investments are allocated to government bonds in Q4 2020. Across all EEA (U.S.) insurers, this corresponds to $3 trillion ($0.86 trillion) invested in government bonds (cf. EIOPA (2021), NAIC (2021)).

To realistically reflect the exposure to sovereign debt, we construct a weighted portfolio of government bonds for each country of origin o where insurers in the sample are headquartered. For this aim, we collect data from the NAIC and the EIOPA, who both report on the distribution of insurers' government bond investments per issuing country c at a home country level o. We restrict the given shares to countries c for which CDS data are available and scale the sum of all shares per home country o to one. Table 2 shows the resulting shares for government bond exposures in the second quarter (Q2) of 2018. For example, we obtain that German insurers (rows) invest 11% of their government bond exposure in French sovereign debt (columns), 51% in German sovereign debt etc. In line with the findings of Düll et al. (2017), a home bias can be observed for most countries (see gray cells in Table 2). In particular, U.S. insurers invest by far the largest share (96%) of their government bond exposure into U.S. sovereign debt. We allow the portfolio composition to vary over time by using five time frames p (2012–2014, 2015–2016, Q1 2017–Q4 2017, Q1 2018, Q2 2018), given the available data.[21] The calculated government bond exposure shares are defined as weights $w_{c,o,p}$, depending on the country of issuance c, country of origin o and time frame p.

	Austr.	Belg.	Denm	Finla.	Franc.	Germ.	Greec	Hung.	Irela.	Italy	Neth.	Norw.	Polan.	Slove.	Spain	U.K.	U.S.
Austria	34%	11%	0%	3%	12%	10%	0%	0%	5%	4%	4%	0%	6%	4%	6%	0%	0%
Belgium	5%	61%	0%	1%	13%	5%	0%	0%	2%	5%	1%	0%	1%	0%	5%	0%	0%
Denmark	0%	1%	42%	1%	5%	29%	0%	0%	1%	3%	2%	0%	0%	0%	6%	0%	10%
Finland	3%	2%	0%	30%	10%	35%	0%	0%	1%	0%	13%	0%	0%	0%	2%	1%	2%
France	3%	5%	0%	0%	72%	2%	0%	0%	1%	7%	1%	0%	0%	0%	6%	0%	0%
Germany	6%	8%	0%	1%	11%	51%	0%	0%	2%	3%	2%	0%	2%	1%	6%	2%	4%
Greece	1%	3%	0%	0%	11%	8%	56%	0%	2%	7%	2%	0%	1%	0%	6%	0%	1%
Hungary	0%	0%	0%	0%	0%	0%	0%	99%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Ireland	4%	4%	0%	2%	19%	18%	0%	0%	8%	11%	4%	0%	1%	0%	6%	12%	11%
Italy	0%	1%	0%	0%	3%	1%	0%	0%	1%	87%	0%	0%	0%	0%	6%	0%	0%
Netherlands	9%	8%	0%	3%	14%	28%	0%	0%	2%	2%	30%	0%	0%	0%	3%	0%	1%
Norway	3%	4%	4%	4%	15%	8%	0%	0%	0%	0%	2%	49%	0%	0%	1%	2%	7%
Poland	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	99%	0%	0%	0%	0%
Slovenia	4%	3%	0%	1%	5%	12%	1%	2%	1%	7%	4%	0%	5%	44%	6%	0%	2%
Spain	0%	1%	0%	0%	1%	1%	0%	0%	0%	8%	0%	0%	0%	0%	88%	0%	0%
U.K.	0%	1%	0%	0%	2%	4%	0%	0%	0%	1%	1%	0%	0%	0%	0%	80%	10%
U.S.	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	4%	96%

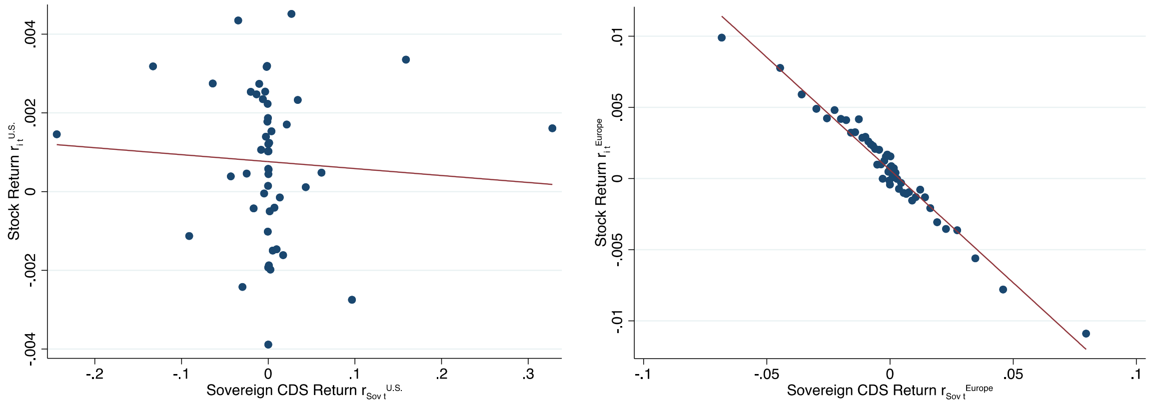
Note: The table shows the allocation of insurers' government bond exposures in their home countries (rows) to countries of issuance (columns) in Q2 2018. For instance, 11% of Austrian insurers' sovereign debt is invested in Belgian government bonds, while 5% of Belgian insurers' exposure is invested in Austrian government bonds. The following bond asset classes are categorized as government bonds in line with EIOPA (2021): Central government, supra-national, regional government, local authorities, treasury, covered, national central bank and others. For U.S. insurers', the illustrated data stems from NAIC (2017a,b).

Table 2: Distribution of government bond exposures per insurers' home country

[21] For European insurers, country-specific government bond exposure data is available for the first time in Q4 2013 (cf. EIOPA (2014)), followed by Q4 2015 (cf. EIOPA (2016)). Starting with Q4 2017, data is available on a quarterly basis from EIOPA (2021). For U.S. insurers, we use regulatory data on foreign bond exposures for the years 2014 (cf. NAIC (2016a), Tables 6 and 8) and 2016 (cf. NAIC (2017a), Table 3) and combine it with data on U.S. government bond exposures from NAIC (2016b, Table 4) and (2017b, Table 5). We assume the exposures to be constant within a time frame p.

We collect sovereign CDS data $CDS_{c,t}$ for all countries of issuance c listed in the columns of Table 2.[22] Each insurer is assigned to CDS quotes based on the set of weights $w_{c,o,p}$ of its country of origin o in the given time frame p. Thus, we use country-specific data as a measure for sovereign default probabilities. For each day t, we calculate the relative daily change in the government bonds' CDS spread of each country c. Using the weights $w_{c,o,p}$ from regulatory data, we then calculate daily yields of a portfolio for each home country o where insurers in the sample are headquartered. We use the daily weighted default risk as an independent variable in the empirical models. It is denoted as $r_{Sov,o,t}$ and calculated accordingly:

$$r_{Sov,o,t} = \frac{\sum CDS_{c,t} \cdot w_{c,o,p}}{\sum CDS_{c,t_{previous}} \cdot w_{c,o,p}} - 1 \qquad (3)$$



(a) U.S. sample (b) European sample

Note: The figures depict binned scatterplots of stock returns and the return of country-specific sovereign CDS spreads. The observations for $r_{Sov,o,t}$ are grouped into 50 bins of equal size. Each dot represents the mean of $r_{Sov,o,t}$ (x-axis) and the mean of insurers' stock returns $r_{i,t}$ (y-axis) within each bin. The red line illustrates the regression line from a univariate linear model. Figure 2a) uses data for U.S. insurers and Figure 2b) for European insurers.

Figure 2: Binned scatterplots of stock returns and sovereign CDS returns

Descriptive statistics for the independent variables measuring sovereign default probabilities $r_{Sov,o,t}$ are presented in Table A5 in Appendix II. The statistics are shown for each country of origin o of the insurers in the sample. Since a peak during the European sovereign debt crisis in early 2012, CDS spreads have mostly decreased. The U.S. is the only country in the sample where credit spreads were on average rising during the sample period (by 0.15ppt per day), however they remained on a considerably low level.[23] Over the entire sample, CDS spreads on average fell by 0.08ppt per day with a mean level of 1.44% (cf. Table 1). For U.S. insurers, the

[22] We additionally collect CDS spreads for government bonds from Switzerland and Iceland. We assume that insurers from these two countries invest all of their sovereign debt exposure in domestic government bonds due to the lack of data on the allocation of insurers' assets on a country level.

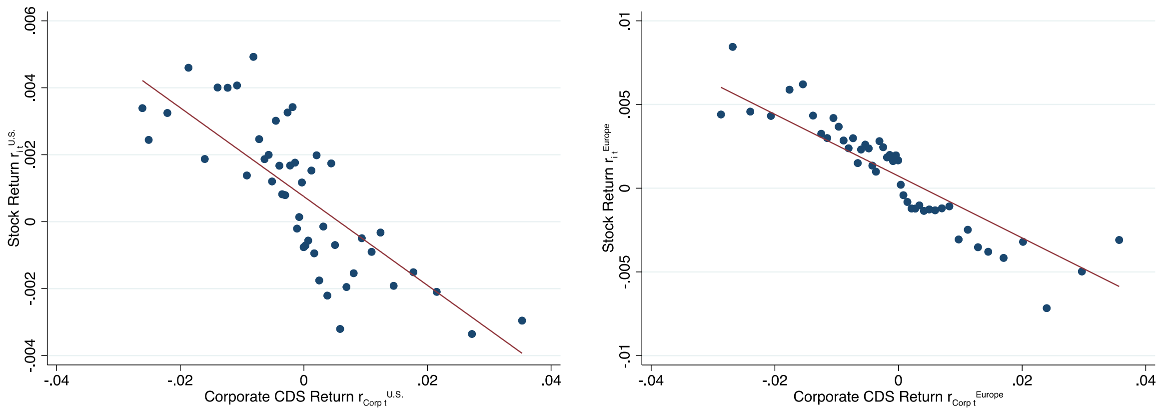
[23] In the entire sample period, the largest level of CDS spreads of U.S. government bonds is 1%. This is the lowest maximum value behind sovereign debt from Norway (0.6%) and Germany (0.9%).

correlation between stock returns and movements in CDS spreads of government bonds illustrated in Figure 2a) is seemingly low. In contrast, Figure 2b) depicts a strong negative linear relationship between sovereign CDS spread returns and European insurers' stock returns.

To provide a full picture of the risks associated with insurers' investments, we also consider corporate credit risk. This is particularly relevant for U.S. insurers, as 36% of their invested assets and cash are allocated to corporate bonds (cf. NAIC (2021)). We calculate the average of the spreads of CDS indices $CDS_{s,t}$ for nine different market sectors s collected from Refinitiv database.[24] The spreads reflect the default probabilities of corporate bonds. We construct a variable $r_{Corp,t}$ capturing corporate credit risk by daily average returns of the sector indices s:

$$r_{Corp,t} = \frac{\sum CDS_{s,t}}{\sum CDS_{s,t_{previous}}} - 1 \tag{4}$$

In contrast to sovereign debt, the CDS spreads of corporate bonds on average increased during the sample period (by 15ppt per average day in the U.S. and by 18ppt in Europe, cf. Table 1). Figure 3 shows a negative correlation between insurers' stock returns and corporate CDS spreads, again with a stronger correlation for European insurers.



(a) U.S. sample (b) European sample

Note: The figures depict binned scatterplots of stock returns and the return of corporate CDS spreads. The observations for $r_{Corp,t}$ are grouped into 50 bins of equal size. Each dot represents the mean of $r_{Corp,t}$ (x-axis) and the mean of insurers' stock returns $r_{i,t}$ (y-axis) within each bin. The red line illustrates the regression line from a univariate linear model. Figure 3a) uses data for U.S. insurers and Figure 3b) for European insurers.

Figure 3: Binned scatterplots of stock returns and corporate CDS returns

In order to control for overall economic conditions, we gather daily data from Refinitiv database on national index prices $Stock\ index_{o,t}$ and volatility index prices $Volatility\ index_{o,t}$. For U.S. insurers, for instance, we use daily returns of the S&P 500 index and of the S&P 500 Volatility

[24] We obtain data for nine CDS indices based on different market sectors: banking, CSM goods, electrical power, energy company, manufacturing, other financial, service company, telephone and transport.

index (VIX) to measure stock market movements.[25] A macroeconomic shock affecting all firms simultaneously is typically reflected by stock market indices. Related literature investigating the influence of interest rates on stock prices (e.g., Brewer et al. (2007), Berends et al. (2013), Hartley et al. (2017)) also considers market returns in empirical models, mainly because insurers' equity prices are strongly correlated with economic growth (cf. Kessler et al. (2017)). Therefore, as is the case for most types of firms, insurers typically have lower stock returns in a recession.[26] In contrast, volatility indices reflect future expected stock price fluctuations. The implied volatilities are also included in the empirical models tested by Düll et al. (2017), because a larger frequency in market movements can influence stock returns. We use the relative daily changes of the indices as control variables in the empirical models:

$$r_{m,o,t} = \frac{Stock\ index_{o,t}}{Stock\ index_{o,t_{previous}}} - 1 \tag{5}$$

$$r_{v,o,t} = \frac{Volatility\ index_{o,t}}{Volatility\ index_{o,t_{previous}}} - 1 \tag{6}$$

The descriptive statistics for the independent variables for market returns and volatilities are presented in Table A6 in Appendix II on a country level. Accordingly, the highest average daily stock market returns were achieved in Denmark (0.06%) and the lowest in Cyprus (-0.06%). The stock indices were also most volatile in Cyprus (standard deviation of 2.23%) and least volatile in Croatia (0.57%). On average, national stock market indices increased by 0.04% per day with a standard deviation of 1.25% (cf. Table 1).

Table 3 shows the correlation coefficients between the introduced independent variables with daily frequency which are included in all empirical models for estimating insurers' risk sensitivities. Notably, there are only small correlations between the most important independent variables of our analysis, i.e., percentage changes in long-term interest rates, sovereign CDS spreads and corporate CDS spreads, indicating that our results are not affected by multicollinearity.[27] In contrast, a strong negative correlation can be observed for returns of stock indices and the respective volatility indices (-0.59) in line with Giot (2005).

[25] For European countries for which we are not able to identify or gather data for a national volatility index, we use the Euro Stoxx 50 Volatility index instead. The relevance of the Euro Stoxx 50 index as an indicator of market developments in Europe is underlined by Brechmann and Czado (2013). Data on national volatility indices is successfully obtained for stock markets in France, Germany, the Netherlands, Switzerland, the U.K. and the U.S.

[26] In times of economic downturns, insurers typically face lower investment returns, need to pay out higher claims and face larger shortfalls in premium payments.

[27] The absence of multicollinearity is supported by variance inflation factors (VIFs) which do not exceed a value of 5 for the variables presented in Table 3 for all regression models.

Apart from interest rates and corporate CDS spreads, for which we differentiate between U.S. and European insurers, all market risk variables are country-specific. For handling extreme outliers, we winsorize the stock return and the continuous independent variables for the empirical analysis.[28]

Correlation coefficients	$r_{y10,t}$	$r_{y1,t}$	$r_{Sov,o,t}$	$r_{Corp,t}$	$r_{m,o,t}$	$r_{v,o,t}$
$r_{y10,t}$	1					
$r_{y1,t}$	0.42	1				
$r_{Sov,o,t}$	0.05	0.02	1			
$r_{Corp,t}$	0.09	0.01	0.06	1		
$r_{m,o,t}$	-0.28	-0.10	-0.09	-0.22	1	
$r_{v,o,t}$	0.23	0.11	0.04	0.15	-0.59	1

Table 3: Correlation matrix of the independent variables for market risk drivers

To reflect insurance companies' product portfolio and financial strength, we consider balance sheet data on a firm level. We detect three relevant characteristics that are obtained from the SNL Financial Database: the share of life insurance business, the share of unit-linked business and the solvency ratio. We perform a median split on each of the three continuous variables.[29] Thus, we create binary variables based on thresholds that are set according to the previous year's median of the cross-sectional distribution from the sample x (either U.S. or European sample).[30] For instance, the median share of life insurance reserves by European insurers in the sample in 2012 is 42% (cf. Table A7 in Appendix II). If an European insurer i's $Life\ Share_{i,2012}$ exceeds this value in 2012, the indicator variable $Life_{i,2012}$ is set to one according to the definitions shown in Table 4. A firm is thus defined as a life insurer in year y if it belongs to the companies with the largest 50% of life insurance reserves across the given sample x. For our regression models, we use lagged values of insurer characteristics. In this way, we avoid a potential bias in our estimates for insurers' market risk sensitivities which might result from a direct effect of interest rates or CDS spreads on an insurer's balance sheet. Our regression results are robust to choosing alternative thresholds (e.g., 40th and 60th percentile and mean)

[28] The highest 0.5% of observations are downgraded to the 99.5% quantile and the lowest 0.5% of returns are upgraded to the 0.5% quantile (5% and 95% for returns of corporate bonds $r_{Corp,t}$ due to more outliers, cf. Table 1). The robustness checks in Appendix V demonstrate that the results still hold when winsorizing is omitted.

[29] Using a median split for binary variables is a common approach in the empirical finance literature (see, e.g., Bertrand and Morse (2011) and Frydman and Wang (2020)), as it allows for an easier interpretation of coefficients.

[30] The U.S. sample contains far more insurers that are not engaged in life insurance business at all (34 out of 72 firms) than the European sample (13 out of 52 firms). Even stronger patterns can be observed for the unit-linked business in the U.S. (50 out of 72 firms) than for Europe (16 out of 52 firms). To ensure the comparability of market risk sensitivities across samples, we add a specification for defining life and unit-linked insurers in the U.S. sample. To avoid getting a threshold equal or close to zero, we calculate the medians of life or unit-linked business of insurers where $Life\ Share_{i,y} > 0$ or $Unit\ linked\ Share_{i,y} > 0$ respectively. This approach provides similar thresholds across both samples (cf. Table A7).

and to using continuous variables such as $Life\ Share_{i,y-1}$ instead of binary indicator variables based on insurers' balance sheet data (cf. Appendix V, overview in Table A9). The insurer-specific binary variables $Life_{i,y-1}$ and $Unit_{i,y-1}$ will be further denoted as $X_{i,y-1}$. Other lagged characteristics that we have tested with binary variables that turned out not to be robust are presented in Table A8 in Appendix III.

Variable	**Definition**
$Life\ Share_{i,y}$	$\frac{Life\ and\ Health\ Insurance\ Reserves_{i,y}}{Total\ Liabilities_{i,y}}$
$Life_{i,y}$	$\begin{cases} 1, if\ Life\ Share_{i,y} > p_{50}(Life\ Share^{x}_{.,y}) \\ 0, otherwise \end{cases}$
$Unit\text{-}linked\ Share_{i,y}$	$\frac{Separate\ Account\ Liabilities_{i,y}}{Total\ Liabilities_{i,y}}$
$Unit_{i,y}$	$\begin{cases} 1, if\ Unit\ linked\ Share_{i,y} > p_{50}(Unit\ linked\ Share^{x}_{.,y}) \\ 0, otherwise \end{cases}$
$RBC\ Ratio_{i,y}$	$\frac{Adjusted\ Capital_{i,y}}{Risk\ based\ Capital_{i,y} \cdot 2}$
$Solvency^{US}_{i,y}$	$\begin{cases} 1, if\ RBC\ Ratio_{i,y} > p_{50}(RBC\ Ratio_{.,y}) \\ 0, otherwise \end{cases}$
$Solvency\ Ratio_{i,y}$	$\frac{Eligible\ Own\ Funds_{i,y}}{Solvency\ Capital\ Requirement\ (SCR)_{i,y}}$
$Solvency^{EU}_{i,y}$	$\begin{cases} 1, if\ Solvency\ Ratio_{i,y} > p_{50}(Solvency\ Ratio_{.,y}) \\ 0, otherwise \end{cases}$
$Size_{i,y}$	$ln\ (Total\ Assets_{i,y})$
$Leverage_{i,y}$	$\frac{Total\ Debt_{i,y}}{Total\ Equity_{i,y}}$
$Market\text{-}to\text{-}Book_{i,y}$	$\frac{Stock\ Price_{i,y}}{Book\ Value\ per\ Share_{i,y}}$

Table 4: Balance sheet variables (binary and continuous)

In terms of solvency, we use different ratios for U.S. and European insurers: the RBC ratio for U.S. insurers is obtained from the NAIC and the solvency ratio based on the Solvency II framework for EU insurers is hand-collected from SFCRs. The rules for calculating these two ratios are different in many respects. On the one hand, the calculations for some risks categories as well as their aggregation tend to be more detailed and are considered to be more risk-sensitive under Solvency II (cf. Holzmüller (2009)). On the other hand, Solvency II allows for replacing the standard formula with an internal risk model and for voluntary long-term guarantee (LTG) measures.[31] Therefore, the two ratios have substantially different distributions. For instance, the $RBC\ Ratio_{i,y}$ has a median of 481% in contrast to 202% for the $Solvency\ Ratio_{i,y}$ under Solvency II. To enable a robust analysis despite these structural differences, we integrate the ratios into our analyses in the form of binary variables. The corresponding binary variable $Solvency_{i,y}$ displays the most solvent 50% of insurers according to the respective measure.[32]

We introduce further insurer-specific characteristics similar to Killins and Chen (2022). These are continuous control variables that have an influence on stock returns based on related finance literature such as Fama and French (1992): $Size_{i,y-1}$, $Leverage_{i,y-1}$ and $Market\ to\ Book_{i,y-1}$. These insurer-level continuous control variables are also collected from the SNL Financial Database on a yearly basis and will further be denoted as $Y_{i,y-1}$.

2.4 Hypotheses

To investigate how market risks impact insurers' stock performance, we examine the influence of relative changes in long-term interest rate $r_{y10,t}$, sovereign CDS spreads $r_{Sov,o,t}$ and corporate CDS spreads $r_{Corp,t}$ on stock returns $r_{i,t}$. In addition, we interact the binary variables $Life_{i,y-1}$, $Unit_{i,y-1}$ and $Solvency_{i,y}$ with each of the three market risk variables to detect insurer characteristics driving those market risk sensitivities. Below, we explain the hypotheses that we subsequently test empirically.

Effect of interest rate movements $r_{y10,t}$: We investigate the impact of changes in long-term interest rates on insurers' stock returns in a prolonged period of low interest rates. Arguably, interest rate reductions after 2007 spurred economic growth. However, both life and non-life insurers are exposed to interest rate risk due to their liabilities and a duration mismatch compared with their balance sheets' asset side. Berends et al. (2013), and Hartley et al. (2017) demonstrate empirically that in the low rate environment following the financial crisis, insurance companies in general suffer from falling yields. Similarly, while controlling for economic growth, we expect a positive relationship between changes in interest rates and insurers' stock returns. Our hypothesis is as follows:

H1: Insurers suffer from falling interest rates.

[31] Even though LTGs impair the informative value of solvency ratios in relation to insurers' financial strength, stock markets react significantly to solvency ratios reported in SFCRs (cf. Gatzert and Heidinger (2020) and Mukhtarov et al. (2022)).

[32] Typically, only a small number of insurers becomes insolvent. Relating to this argument, we find that our results still hold if we choose lower thresholds for $Solvency_{i,y}$, such as the 30% and 40% quantile.

Interaction effect of interest rate movements and life insurers $r_{y10,t} \cdot Life_{i,y-1}$: According to practioners' views, life insurers tend to have a duration gap, because markets do not provide sufficient long-term investment opportunities (e.g., Frey (2012)). In addition, Caballero et al. (2017) and Greenwood and Vayanos (2010) stress that long-term bonds typically offer unattractive yields. While further literature (Koijen and Yogo (2022), Möhlmann (2021) and Kubitza et al. (2023)) argues that life insurers do not aim for perfect hedging, a fraction of interest rate risk clearly remains unhedged. Two main channels of interest rate exposures are duration gaps and fixed guarantees embedded in life insurance policies in most countries (cf. Table A1). As corresponding assets mature, guarantees are putting life insurers under great pressure in the low yield environment after 2012.[33] In the U.S., contractually promised rates may affect cash surrender values for universal life and whole life insurance products. If interest rates fall below these guarantees, they are "in the money". As a result, surrender rates will go down, and as a consequence, liability duration, and thus the interest rate risk exposure of life insurers, will rise (cf. Kubitza et al. (2023)). It is, therefore, also the case that policyholder behavior influences the interest rate risk of life insurers. Deposit-type products, which are savings policies, also contain investment guarantees and are therefore another channel of interest rate risk exposure.[34] According to the European Systemic Risk Board (ESRB) (2015), guaranteed life insurance products are also popular in several European countries.[35] Due to the exposure of life insurers' balance sheets to interest rate risk, we expect:

H2: Insurers with a high share of life insurance reserves suffer more from falling interest rates.

Interaction effect of interest rate movements and unit-linked insurers $r_{y10,t} \cdot Unit_{i,y-1}$: Unit and index-linked life insurance products have become more popular in Europe during the low interest rate environment (cf. EIOPA (2020b)).[36] This type of life insurance gives policyholders greater influence over the investment allocation relating to their contracts. Typically, unit-linked policyholders bear the majority of the investment risk. Nevertheless, unit-linked trusts are long-term savings products which often have a product component with an interest rate guarantee and a long duration of the expected payoffs to policyholders. Therefore, unit-linked insurance providers' balance sheets are exposed to interest rate risk (see

[33] When the insurers' investment income falls below their expenses, insurers can face liquidity issues and thus have an incentive to hold riskier portfolios. Koijen and Yogo (2022) argue that guaranteed minimum returns provide an insurance against market risks, as they shield policyholders from interest rate movements.
[34] Deposit-type products make up around 9% of U.S. life insurers' reserves (cf. Berends et al. (2013)).
[35] Guaranteed returns are popular in Germany, Italy, Netherlands, Switzerland, Austria, Spain, Denmark, Norway and Sweden. Guarantees in France are typically not binding (cf. Hombert and Lyonnet (2017)). For further information regarding the use of guaranteed returns in different countries see Eling and Holder (2013a,b).
[36] In the remaining of this paper, we use the term "unit-linked products" as an umbrella term.

Figure A1 in Appendix IV for an illustration of a stylized insurer's balance sheet with an interest rate exposure due to traditional life and unit-linked insurance products). In the U.S., variable annuities are a popular product combining mutual funds with fixed guarantees (cf. Koijen and Yogo (2022)).[37] Moreover, unit-linked contracts are often being offered by life insurers with broad product portfolios and large liabilities on traditional participating policies. For this reason, the binary variable $Unit_{i,y-1}$ implicitly identifies insurers focusing on long-term, interest rate sensitive products. In addition, life insurers that are particularly exposed to low interest rates due to guarantees in their back-book may have shifted towards unit-linked products.[38] Thus, offering unit-linked products may characterize those insurers with a particularly high interest rate exposure. We therefore hypothesize:

H3: Insurers with a high share of reserves relating to unit-linked products suffer more from falling interest rates.

Interaction effect of interest rate movements and solvent insurers $r_{y10,t} \cdot Solvency_{i,y}$: In Europe, the solvency ratio has been a key measure reflecting insurers' solvency position and financial strength in a single figure ever since Solvency II came into effect in 2016. The experimental literature demonstrates that insurers' solvency risk substantially influences policyholders' willingness to pay (cf. Zimmer et al. (2009, 2018) and Lorson et al. (2012)). In an event study, Gatzert and Heidinger (2020) as well as Mukhtarov et al. (2022) provide empirical evidence that insurers' stock returns react significantly to the solvency ratios published under Solvency II. For U.S. insurers, we consider the RBC ratio as a measure of solvency, which we also collect for the years 2016 to 2018. We expect the returns of less solvent insurers to be particularly sensitive to interest rate fluctuations. Less solvent insurers have smaller capital buffers and are thus closer to regulatory action, which influences the demand for insurance products and limits investment opportunities. Consequently, it follows that:

H4: Less solvent insurers suffer more from falling interest rates.

Effect of movements in CDS spread $r_{Sov,o,t}$ and $r_{Corp,t}$: According to Acharya et al. (2014), CDS spreads of government bonds adequately reflect the default risk of a country. Insurers traditionally invest a large portion of their assets in sovereign debt. In addition, they also hold

[37] During the last 30 years, variable annuities have gained great importance in life insurers' portfolios and make up around one third of U.S. life insurers' reserves (cf. Berends et al. (2013)).

[38] In Germany, several life insurers stopped offering guaranteed products to decrease their exposure as their existing stock of participating contracts gradually expires. Generali Deutschland and Ergo (a subsidiary of MunichRe) even transferred parts of their stock of guaranteed insurance contracts to so-called "run-off" insurers, which efficiently manage existing policies without selling contracts themselves.

other fixed income securities, such as corporate bonds. In the U.S., the share of life insurers' corporate debt investments even outweighs the share of sovereign debt. For European insurers, Düll et al. (2017) find their financial positions are negatively impacted by increases in CDS spreads. In line with this finding, we expect:

H5: Insurers suffer from rising default probabilities of fixed income securities.

Interaction effect of CDS movements and life insurers $r_{Sov,o,t} \cdot Life_{i,y-1}$ and $r_{Corp,t} \cdot Life_{i,y-1}$: For life insurers, we expect two different effects to exist in terms of their stock returns' sensitivities to credit risk. On the one hand, insurers might benefit from higher future returns for fixed-income securities going along with increased CDS spreads. This is particularly relevant within the Solvency II framework, which does not prescribe additional capital requirements for investments in sovereign debt from EU countries with large default probabilities (cf. Art. 180 (2) of European Commission (2015)). On the other hand, market values of bonds decrease as CDS spreads rise. The decrease is larger for a longer duration of the bond. Hence, life insurers, which tend to hold long-term bonds, suffer more from increased CDS spreads compared with non-life or composite insurers. Due to opposed implications, the resulting effect of the interaction between default probabilities and life insurance business on stock returns is rather ambiguous. Our hypothesis reflects the latter, market-value-based aspect:

H6: Insurers with a high share of life insurance reserves suffer more from rising default probabilities of fixed income securities.

Interaction effect of CDS movements and unit-linked insurers $r_{Sov,o,t} \cdot Unit_{i,y-1}$ and $r_{Corp,t} \cdot Unit_{i,y-1}$: Policyholders bear the investment risk for unit-linked shares of life insurance products. Hence, the insurer's equity capital is immunized with respect to default risk for bond investments related to these unit-linked shares. However, insurers offering unit-linked products typically have a long duration of assets as they hold long-term fixed income securities (cf. Figure A1 in Appendix IV). Thus, unit-linked insurance providers are in fact substantially affected by a fall in the market value of bonds after a rise in CDS spreads. In addition, rising CDS spreads signal increased uncertainties on fixed income markets. Thus, there is a negative effect on the demand of long-term savings products, particularly when potential new policyholders receive no or little guarantees. We derive:

H7: Insurers with a high share of reserves relating to unit-linked products suffer more from rising default probabilities of fixed income securities.

Interaction effect of CDS movements and solvent insurers $r_{Sov,o,t} \cdot Solvency_{i,y}$: For solvent insurers, an increase in sovereign CDS spreads is expected to have fewer negative effects, as the rising market uncertainty has a smaller impact on an insurer's market capitalization. Solvent insurers can even attempt to seize the opportunity to invest in riskier government bonds, as they are robust enough to face potential losses through a longer period. We thus hypothesize:

H8: Less solvent insurers suffer more from rising default probabilities of sovereign debt.

2.5 Empirical model and tackling of research question

To test the hypotheses, we consider three OLS panel regression models, which we extend successively. The main variables of interest are relative changes in interest rates $r_{y10,t}$ and returns of sovereign credit spreads based on weighted country-specific portfolios $r_{Sov,o,t}$ and corporate credit spreads $r_{Corp,t}$. In addition, we consider several control variables. Firstly, economic developments are taken into account using daily returns in national stock and volatility indices $r_{m,o,t}$ and $r_{v,o,t}$. Secondly, we control for changes in short-term interest rates $r_{y1,t}$. Thirdly, we consider the level of long-term interest rates $y10_t$ and CDS spreads of sovereign bonds $CDS_{Sov,o,t}$.[39] Together these variables are denoted as market risk level controls $L_{o,t}$. Including levels in regression models allows ensuring that sensitivities (measured by β_{1-2}) are driven by changes rather than levels. In all models, we include insurer fixed effects u_i and standard errors clustered by time. With the given specifications, Model I focuses on measuring the sensitivity of stock returns to relative changes in interest rates and CDS spreads in a multivariate regression:

$$\begin{aligned} r_{i,t} = \alpha + \beta_1\, r_{y10,t} + \beta_2\, r_{Sov,o,t} + \beta_3\, r_{Corp,t} + \beta_4\, r_{m,o,t} + \beta_5\, r_{v,o,t} \\ + \beta_6\, r_{y1,t} + \gamma\, L_{o,t} + u_i + \varepsilon_{i,t} \end{aligned} \qquad \text{Model I}$$

Model II extends Model I by incorporating yearly insurer-specific information. In particular, we include interaction terms by multiplying the returns of all market risk variables of interest $r_{L,o,t}$, i.e., $r_{y10,t}$, $r_{Sov,o,t}$ and $r_{Corp,t}$ with each binary variable $X_{i,y-1}$ where X represents life or unit-linked insurers according to the definitions in Table 4.[40] In addition to the interaction terms, we include the main effects $X_{i,y-1}$ (i.e., $Life_{i,y-1}$ and $Unit_{i,y-1}$) in the empirical model to measure ceteris paribus effects (cf. Angrist and Pischke (2009)). We introduce further insurer-

[39] We do not control for the level of CDS spreads of corporate bonds, because $r_{Corp,o,t}$ is based on the average returns of corporate CDS indices for different market segments and the levels are not comparable between indices.
[40] In a robustness test, we also control for the interaction between each of the insurer-specific binary variables $X_{i,y-1}$ with stock market returns $r_{m,o,t}$, similar to Hartley et al. (2017). In a further specification, we include interactions of $r_{L,o,t}$ with a binary indicator variable for insurers' size (cf. Appendix V).

specific control variables $Y_{i,y-1}$. These are characteristics which might have an influence on stock returns based on related finance literature, such as Fama and French (1992): $Size_{i,y}$ (calculated as the natural logarithm of total assets), $Leverage_{i,y}$ (debt-to-equity ratio) and $Market\text{-}to\text{-}Book_{i,y}$ (stock price divided by book value per share). It follows:

$$r_{i,t} = \alpha + \beta_1\, r_{y10,t} + \beta_2\, r_{Sov,o,t} + \beta_3\, r_{Corp,t} + \beta_4\, r_{m,o,t} + \beta_5\, r_{v,o,t} + \beta_6\, r_{y1,t} + \eta \textstyle\sum_L r_{L,o,t} \cdot X_{i,y-1} + \zeta\, X_{i,y-1} + \vartheta\, Y_{i,y-1} + \gamma\, L_{o,t} + u_i + \varepsilon_{i,t} \qquad \text{Model II}$$

Model III extends Model II by introducing $Solvency^{x}_{i,y}$ as a sample-specific binary variable (with x: either U.S. or Europe) together with its interaction with the relative changes of long-term interest rates $r_{y10,t}$ and sovereign CDS spreads $r_{Sov,o,t}$. We use a separate model for introducing solvency because in Europe it has only been consistently observable since the introduction of Solvency II in 2016. Hence, the sample period in Modell III comprises the years 2016 to mid-2018. In the U.S. sample, RBC ratios have been obtained for 53 insurers.

$$r_{i,t} = \alpha + \beta_1\, r_{y10,t} + \beta_2\, r_{Sov,o,t} + \beta_3\, r_{Corp,t} + \beta_4\, r_{m,o,t} + \beta_5\, r_{v,o,t} + \beta_6\, r_{y1,t} + \beta_7\, r_{y10,t} \cdot Solvency^{x}_{i,y} + \beta_8\, r_{Sov,o,t} \cdot Solvency^{x}_{i,y} + \beta_9\, Solvency^{x}_{i,y} + \eta \textstyle\sum_L r_{L,o,t} \cdot X_{i,y-1} + \zeta\, X_{i,y-1} + \vartheta\, Y_{i,y-1} + \gamma\, L_{o,t} + u_i + \varepsilon_{i,t} \qquad \text{Model III}$$

We apply the Models I−III to two different samples x: first only to U.S. insurers, then only to European insurers. In this manner, we detect differences in sensitivities of stock returns to market risk drivers and test which effects are robust across both samples. Notably, the presented differences between U.S. and European insurers in terms of their sensitivities to interest rate risk and credit risk are highly significant (p-value of 0.000), which underlines the existence of structural differences between those insurance markets. For the European sample, we also examined differences which are linked to the countries where insurers are headquartered. For this purpose, we assigned insurers' home countries into groups with potentially higher market risk sensitivities (allocation to multiple groups possible): large average duration gaps, large use of guarantees, large default probabilities of sovereign bonds, non-euro area countries, non-Solvency II-countries. We did not find significantly higher market risk sensitivities for insurers from European countries belonging to any of these groups.[41] Our presented findings are also robust to using country fixed effects instead of firm fixed effects.

[41] Limitations for the lack of differences are that (1) many of the stock-listed insurers in the sample operate in several European countries and (2) the number of insurers per country is relatively low (cf. Table A4).

3 Results

The coefficients and p-values from Model I, which focuses on the effects of market risk drivers on stock returns while controlling for their levels and economic growth, are illustrated in Table 5. In line with hypothesis *H1*, we find that across all samples, insurers suffer from falling long-term interest rates.[42] The empirical model thus confirms previous findings by Berends et al. (2013) and Hartley et al. (2017), when comprising several market risks in a single regression with daily data and introducing further specifications (e.g., insurer fixed effects and standard errors clustered at the day level). Notably, the size of the beta coefficients for $r_{y10,t}$ is similar for the initial U.S. and European samples (columns (1) and (2)), indicating a similar degree of stock return sensitivity to interest rate changes by insurance companies in general (including life and non-life insurers). Hence, a one-day hpr of 10-year rates of 1ppt (for instance due to a fall in interest rates from roughly 0.1% to 0%)[43] decreases the stock return of insurers by 0.2ppt on average, while keeping other variables constant.

The coefficient on $r_{y10,t}$ is higher when we restrict the sample to insurers with a high share of life insurance reserves, i.e., with condition $Life_{i,y-1} = 1$ being satisfied (columns (3)-(4)). Then, a hpr of 1ppt on average decreases stock returns of U.S. life insurers by 0.45ppt and those of European life insurers by 0.284ppt. This implies a difference in sensitivities of 58%. We observe even more pronounced differences when considering standardized beta coefficients, which allow for a meaningful comparison of the effects of variables with different volatilities.[44] These empirical findings underline that interest rate risk is more relevant for U.S. life insurers. One possible reason might be cross-sectional risk sharing and the widespread use of guaranteed minimum returns in the U.S. Also, we observe differences in regulation. Compared with the Solvency II framework in Europe, U.S. insurers have smaller regulatory incentives to lower their interest rate risk exposure. In fact, U.S. life insurers invest a larger share of their assets in corporate bonds, which are typically riskier than government bonds (47% and 12% of invested assets, cf. NAIC (2021)). In contrast, European insurers further reduced the riskiness of their

[42] As we use the hpr for the independent variables measuring changes in interest rates, a negative sign in the coefficients in Tables 5-7 implies a positive impact of rising interest rates on stock returns.

[43] To comprehend the conversion between interest rate and hpr, suppose that the 10-year interest rate reduces from 0.001 to 0. Using Equation (2), this reduction translates into a hpr of:

$$r_{y10,t} = \left(\frac{1 + y10_{t_{previous}}}{1 + y10_t}\right)^{10} - 1 = \left(\frac{1 + 0.001}{1 + 0}\right)^{10} - 1 = 0.01005 \approx 0.01$$

[44] Ceteris paribus, a one standard deviation (SD) increase in the one-day hpr for long-term interest rates (0.43ppt, cf. Table 1) leads to an average decrease in U.S. life insurers' stock returns by 0.123 SD (0.341ppt) (column (3)). In contrast, a one SD increase in the hpr for 10-year interest rates in Europe (0.36ppt) on average lowers stock returns of European life insurers by only 0.062 SD (0.124ppt) (column (4)). Thus, the resulting effect of interest rate changes on the stock performance is twice as large for U.S. compared with European life insurers.

asset as a result of the sovereign debt crisis of 2010 to 2012. Due to these differences in the asset portfolios, a relatively larger share of interest rate risks remains for U.S. insurers. A further reason for large interest rate risk in the U.S. highlighted by Hartley et al. (2017) is the use of loans and the ability of policyholders to time their borrowing and withdrawal decisions to interest rate changes. Often, policyholders can even adjust their savings payments and, given a fixed guaranteed return, have an incentive to increase their savings amount when interest rates fall. In addition, Koijen and Yogo (2015) argue that U.S. life insurers sold policies below their actuarial values in 2008 in order to increase accounting profits during the financial crisis. Also, the U.S. insurance market is more segmented into property & casualty on the one hand, and the life insurance industry on the other hand. Instead, many of the large stock listed European life insurers also offer non-life insurance and therefore have a broader product diversification. Accordingly, the European sample exhibits a smaller difference in the interest rate sensitivities between all insurers and life insurers only (columns (2) and (4)).

	(1)	(2)	(3)	(4)
Dependent variable:	$r_{i,t}$ (stock return)			
Sample:	U.S.	Europe	U.S. life	Europe life
$r_{y10,t}$ (10-year interest rate hpr)	-0.205***	-0.200***	-0.450***	-0.284***
	(0.000)	(0.000)	(0.000)	(0.000)
$r_{y1,t}$ (1-year interest rate hpr)	-0.169**	0.136	-0.268**	0.170
	(0.039)	(0.113)	(0.023)	(0.132)
$r_{Sov,o,t}$ (sovereign CDS return)	0.002	-0.031***	0.003	-0.031***
	(0.285)	(0.000)	(0.197)	(0.000)
$r_{Corp,t}$ (corporate CDS return)	-0.010	-0.046***	-0.026**	-0.040***
	(0.249)	(0.000)	(0.026)	(0.000)
$r_{m,o,t}$ (market return)	0.848***	0.642***	0.977***	0.756***
	(0.000)	(0.000)	(0.000)	(0.000)
$r_{v,o,t}$ (volatility return)	-0.001	-0.006***	0.000	-0.006***
	(0.657)	(0.000)	(0.997)	(0.008)
Insurer Fixed Effects	Yes	Yes	Yes	Yes
$y10_t$ and $CDS_{o,t}$ (levels)	Yes	Yes	Yes	Yes
No. of obs.	135,659	99,637	30,613	40,910
No. of insurers	94	69	24	31
Adj. R^2	0.158	0.205	0.304	0.313
Adj. R^2 within	0.158	0.205	0.304	0.313
Standardized beta coefficients				
10-year interest rate	-.049	-.043	-.123	-.062
Sovereign CDS	.006	-.041	.012	-.043
Corporate CDS	-.008	-.042	-.023	-.037

Note: Fixed effect regressions of insurers' daily stock returns on market risk drivers from 2012 to mid-2018. Sources: Refinitiv (insurer-level stock returns, country-level stock and volatility indices), FRED (U.S. interest rates), ECB (interest rates in Europe), Markit (sovereign CDS spreads), Bloomberg (corporate CDS indices), NAIC & EIOPA (distribution of government bond investments). Standard errors are clustered at the day level. ***, **, * indicate significance at the 1%, 5% and 10% levels respectively. P-values are in parentheses.

Table 5: Regression results for the empirical Model I

In terms of short-term interest rate changes measured by $r_{y1,t}$, we again observe differing sensitivities between U.S. and European life insurers. The former benefit significantly from falling 1-year rates while the latter suffer from rising 1-year yields (columns (3) and (4)). European life insurers thus seem to prefer a steep yield curve.

Substantial differences between the sensitivities of U.S. and European insurers are also given in terms of credit risk. European insurers significantly suffer from increasing default probabilities of sovereign and corporate debt, measured by changes in CDS spreads of portfolios (1) of government bonds on a country level $r_{Sov,o,t}$ and (2) of different market segments $r_{Corp,t}$. In general, a 1ppt increase in CDS spreads of government (corporate) bonds lowers insurers' stock returns by 0.031ppt (0.04ppt) (column (2)). Hypothesis *H5* is thus supported for the European sample. Regarding standardized beta coefficients, we find that for both, sovereign and corporate debt, a one standard deviation (SD) increase in CDS spreads (3.15ppt) leads, on average, to a 0.04 SD (0.08ppt) decrease in the stock performance (column (2)). To quantify the relevance of the market risk drivers for life insurers, we compare the impact of changes in interest rates and CDS spreads. For the 50% of European insurers with the largest life insurance share, we find that credit risk has a relatively smaller impact on stock returns than interest rate risk. However, the effect of a one SD change is only 44% larger for interest rates than for sovereign CDS spreads, and 68% larger than for corporate CDS spreads.[45] Aggregating the effects caused by changes in default probabilities of government and corporate bonds leads to a larger impact on stock returns than due to 10-year interest rate changes. Thus, our paper highlights the importance of considering credit risk for adequate risk management, while it has received relatively little attention from regulators and academics.

U.S. life insurers in our sample do not benefit from falling sovereign CDS spreads, but rather from rising sovereign default probabilities, albeit only to a small degree which is not highly significant (column (3)). A channel through which U.S. insurers may benefit from rising CDS spreads could be higher expected market returns that offset the negative effect of credit deteriorations on existing bonds. We interpret the difference in sensitivities between U.S. and European life insurers as being linked to the relatively low share of U.S. insurers' investments in government bonds[46] and to the large home bias towards U.S. sovereign debt (cf. Table 2) that typically has a high degree of creditworthiness. Based on the measured sensitivities, credit risk is substantially more relevant for European than for U.S. insurers. The latter are better immunized against increasing sovereign default probabilities in terms of stock price reactions.

[45] For the purpose of better comparison, we consider the ceteris paribus average effect of a one SD increase in the underlying variables on the SD of stock returns. For the 10-year hpr, the effect is -0.062, for sovereign CDS spreads -0.043 and for corporate CDS spreads -0.037 SD (column (4)).

[46] The share of corporate bonds is roughly three times larger than that of government bonds for U.S. insurers according to NAIC (2021). This indicates lower sovereign counterparty default risk, but also riskier investments.

For corporate CDS spreads, in line with *H5*, we find that U.S. life insurers significantly suffer from increasing corporate CDS spreads (column (3)). This finding can be explained by the large share of corporate debt held by U.S. life insurers. Standardized beta coefficients show that the impact of a one SD change is twice as large for corporate compared with sovereign CDS spreads. Interest rate risk is by far more relevant for life insurers in the U.S., with an influence that is roughly five times larger than for corporate CDS spreads.

Regarding the size of coefficients, national stock markets have the largest impact on stock returns among all variables. A 1ppt increase in stock indices results in an average life insurer's stock return rise by 0.98ppt in the U.S. and 0.76ppt in Europe (columns (3) and (4)). As for the coefficients of $r_{y10,t}$, the coefficients of $r_{m,o,t}$ are higher for life insurers than for the initial samples in columns (1) and (2). In terms of volatility indices, we find that European insurers significantly suffer from rising rates, while U.S. insures are not affected. We argue that a volatility increase has both advantages and disadvantages for insurers, which have to be compared against each other. On the one hand, market volatility reflects uncertainty in future economic developments which is unfavorable for the insurance industry as it relies on secure cash flows. For European insurers, this uncertainty effect is reflected by the data.[47] On the other hand, insurers may benefit from potentially higher returns when market volatilities and default probabilities of fixed income securities rise. In line with these mechanisms, we find either insignificant or lower sensitivities of U.S. insurers' stock returns to variables reflecting the intensity of crisis periods, such as volatility indices or CDS spreads. Seemingly, U.S. insurers, who did not face a sovereign debt crisis during the sample period, may benefit from potentially higher returns when market volatilities and default probabilities of fixed income securities rise. Due to a lower level of uncertainties and a smaller exposure to equity and credit risk, benefits through higher potential yields may outweigh the downsides. Instead, European insurers are relatively more exposed to indicators of financial crises.

In summary, Model I shows that stock returns are substantially influenced by market risk drivers. Interest rates and stock markets have a highly significant impact on the stock prices of all insurers, while corporate CDS spreads affect all life insurers and sovereign CDS spreads only affect European insurers in the sample.

In Model II, we introduce the insurer-specific binary variables $X_{i,y-1}$ (i.e., $Life_{i,y-1}$ and $Unit_{i,y-1}$), which we interact with the market risk drivers $r_{y10,t}$, $r_{Sov,o,t}$ and $r_{Corp,t}$. Additionally,

[47] On average, a one SD increase in the volatility index (8.84ppt) leads to a 0.02 SD fall in stock returns (0.04ppt). Thus, the effect is roughly half as large as for CDS spread changes.

we introduce the continuous control variables $Y_{i,y-1}$. The coefficients and p-values in Table 6 reveal that insurers' sensitivities towards interest rate changes are significantly linked to insurer-specific balance sheet variables. For the European sample, the influence of $r_{y10,t}$ is only significant for the interaction terms, meaning that we only observe interest rate risk for life and unit-linked insurers, not for non-life insurers. Hypothesis *H2* is supported for both samples, as insurers with a higher share of life insurance reserves suffer significantly more from decreasing interest rates. On average, a hpr within one day of 1ppt (implying a falling interest rate) lowers the stock return of a U.S. (European) life insurer ceteris paribus by 0.22ppt (0.14ppt) more than that of other insurers (column (1)). The result is closely linked to the negative effects of interest rate declines on the balance sheet of life insurers due to duration gaps and the use of guarantees.

	(1)	(2)
Dependent variable:	$r_{i,t}$ (stock return)	
Sample:	U.S.	Europe
$r_{y10,t}$	-0.061*	-0.029
	(0.069)	(0.469)
$r_{y10,t}$ × $\text{Life}_{i,y-1}$ (binary)	-0.215***	-0.141***
	(0.000)	(0.000)
$r_{y10,t}$ × $\text{Unit}_{i,y-1}$ (binary)	-0.710***	-0.196***
	(0.000)	(0.000)
$r_{Sov,o,t}$	0.002	-0.007
	(0.258)	(0.293)
$r_{Sov,o,t}$ × $\text{Life}_{i,y-1}$ (binary)	0.001	-0.018***
	(0.445)	(0.008)
$r_{Sov,o,t}$ × $\text{Unit}_{i,y-1}$ (binary)	-0.001	-0.035***
	(0.629)	(0.000)
$r_{Corp,t}$	0.005	-0.023***
	(0.624)	(0.009)
$r_{Corp,t}$ × $\text{Life}_{i,y-1}$ (binary)	-0.024***	-0.007
	(0.003)	(0.447)
$r_{Corp,t}$ × $\text{Unit}_{i,y-1}$ (binary)	-0.051***	-0.029***
	(0.000)	(0.002)
Insurer Fixed Effects	Yes	Yes
$r_{y1,t}$, $r_{m,o,t}$ and $r_{v,o,t}$	Yes	Yes
$y10_t$ and $CDS_{o,t}$ (levels)	Yes	Yes
Insurer controls (binary) $X_{i,y-1}$	Yes	Yes
Insurer controls (continuous) $Y_{i,y-1}$	Yes	Yes
No. of obs.	104,946	71,405
No. of insurers	72	52
Adj. R^2	0.172	0.219
Adj. R^2 within	0.172	0.219

Note: Fixed effect regressions of insurers' daily stock returns on market risk drivers from 2012 to mid-2018. Binary insurer controls $X_{i,y-1}$ are based on previous year's median of the cross-sectional distribution of life and unit-linked insurance reserve shares. Continuous insurer controls $Y_{i,y-1}$ are the size, leverage and market-to-book ratio at the insurer-year level lagged by one year. Sources: Refinitiv (stock returns, country-level stock and volatility indices), FRED (U.S. interest rates), ECB (interest rates in Europe), Markit (sovereign CDS spreads), Bloomberg (corporate CDS indices), SNL (insurer-level life insurance share, unit-linked business share, leverage, size and market-to-book ratio). Standard errors are clustered at the day level. ***, **, * indicate significance at the 1%, 5% and 10% levels respectively. P-values are in parentheses.

Table 6: Regression results for the empirical Model II

Furthermore, in line with hypothesis *H3*, insurers with a high share of unit-linked business suffer more from falling interest rates than insurers with no or a low share of unit-linked reserves. Presumably due to variable annuities with embedded minimum returns, the effect is particularly large in the U.S., where a 1ppt hpr reduces unit-linked insurers' stock returns by 0.71ppt (column (1)) in addition to the effect of 0.06ppt for all insurers. As outlined in Section 2.4, other reasons for large interest rate risk of unit-linked insurance providers are guarantees within unit-linked trusts and the long duration of liabilities for savings instruments. Moreover, a correlation between insurers with historically high guaranteed returns and those with an increasing share of unit-linked products seems reasonable, as stressed insurers seek to reduce their balance sheets' exposure to interest rate risk. The findings suggest that insurers with large unit-linked portfolios may require an increased attention from their regulators.

In terms of credit risk, Model II reveals that the impact of the interaction term $r_{Sov,o,t} \cdot Life_{i,y-1}$ on stock returns is significantly negative for European insurers (column (2)). This supports hypothesis *H6*, as the stock returns of life insurers are twice as much negatively affected by increasing sovereign CDS spreads than the stock prices of composite or non-life insurers. The main reason is presumably the difference in the investment strategy, as life insurers typically hold a high share of fixed income securities with longer durations, which exposes them more to counterparty credit risk. The stock market reactions to CDS changes are more robust and even larger for the 50% of insurers with the largest unit-linked share. In line with hypothesis *H7*, unit-linked insurance providers suffer significantly more from rising default probabilities of sovereign debt than other insurers. Thus, a 1ppt increase in CDS spreads additionally lowers unit-linked insurers' stock returns by 0.035ppt ceteris paribus (column (2)). The sensitivity to rising default probabilities can be explained by an increased preference of customers for guaranteed insurance products when future market developments seem less predictable. In line with this theory, we observe a significant negative effect for the interaction of changes in corporate CDS spreads and unit-linked insurers $r_{Corp,t} \cdot Unit_{i,y-1}$. Thus, in Europe, unit-linked insurance providers suffer more from a rise in both sovereign and corporate CDS spreads, while traditional life insurers significantly suffer only from rising sovereign CDS spreads.

As U.S. sovereign debt is considered to be very secure during the sample period between 2012 and 2018, the effects of interaction terms of the sovereign credit risk measure $r_{Sov,o,t}$ with insurer-specific variables are not significant in Model II for the U.S. sample (column (1)). We observe, however, that U.S. life and unit-linked insurers suffer significantly from rising corporate CDS spreads. This finding can be explained by the larger share of investments in corporate bonds rather than government bonds in the U.S. These empirical findings also support hypotheses *H6* and *H7* for the U.S. sample.

Notably, we have tested several product characteristics and asset class specifications, but ultimately only the variables $Life_{i,y-1}$ and $Unit_{i,y-1}$ (with several different definitions) exert robust influences. Other characteristics (cf. Table A8 in Appendix III) lose their statistical significance once we control for binary variables for life or unit-linked insurers and the corresponding interaction terms.[48] For instance, the 50% of insurers with the largest share of government bond investments suffer significantly more from falling interest rates. This effect, however, is seemingly not driven by the asset side of the balance sheet, but by the insurers' product portfolio as it disappears once we control for $r_{y10,t} \cdot Life_{i,y-1}$. Thus, we identify the product lines, and more specifically life and unit-linked insurance, as the dominant channels of market risks.

The results presented are also robust to limiting the sample only to insurers with life insurance reserves (i.e., $Life\ Share_{i,y-1} > 0$, see Appendix V). Previous findings from Model I regarding sensitivities of insurers towards changes of corporate CDS spreads, stock indices and short-term interest rates are robust in terms of the sign of coefficients and their significance.

In Model III, we introduce $Solvency_{i,y}$ as a further insurer-specific binary characteristic to interact with the variables for relative changes in long-term interest rates $r_{y10,t}$ and sovereign CDS spreads $r_{Sov,o,t}$. As outlined in Section 2.5, Model III is limited to a smaller sample period from 2016 to mid-2018 because of the lack of a prominent solvency figure for EU insurers before the introduction of Solvency II in 2016. The coefficients and p-values are illustrated in Table 7. The regression results for the European sample support hypothesis *H4* that less solvent insurers suffer more from falling interest rates (column (2)). For the most solvent 50% of insurers, a 1ppt hpr on average lowers stock prices by 0.215ppt less than for the least solvent 50% of insurers. The sensitivities can be explained by a lesser ability to cope with the challenges caused by interest rate reductions if a company has smaller capital buffers. For the U.S. sample (column (1)), however, the sensitivities of highly solvent insurers do not significantly differ from those of less solvent insurers. Our different results for U.S. insurers and European insurers

[48] We have tested the following further insurer characteristics with binary variables based on a median split: government bond investment share, corporate bond investment share, focus on other investments, historical change in life insurance reserves (increase and decrease) and focus on insurance business. The variable definitions are presented in Table A8. Even though we find significant coefficients for interaction terms with $r_{y10,t}$ and $r_{Sov,o,t}$, these effects disappear once we also interact $r_{y10,t}$ and $r_{Sov,o,t}$ with $Life_{i,y-1}$ and $Unit_{i,y-1}$.

indicate that the RBC ratio is not perceived as strongly by capital market participants as the solvency ratio in Europe.

Moreover, we find that more solvent European insurers suffer less from rising CDS spreads of sovereign debt (column (2)), which tends to confirm hypothesis *H8*. For solvent European insurers, the ceteris paribus negative effect of a 1ppt increase in CDS spreads on stock prices is 0.015ppt smaller than for less solvent insurers. Even though the number of observations in Model III is smaller, the previous findings from Model II are significant.

	(1)	(2)
Dependent variable:	$r_{i,t}$ (stock return)	
Sample:	U.S.	Europe
$r_{y10,t}$	-0.149*	-0.153*
	(0.053)	(0.078)
$r_{y10,t}$ × $Life_{i,y-1}$ (binary)	-0.236***	-0.286***
	(0.000)	(0.000)
$r_{y10,t}$ × $Unit_{i,y-1}$ (binary)	-1.226***	-0.308***
	(0.000)	(0.000)
$r_{y10,t}$ × $Solvency_{i,y}$ (binary)	0.034	0.215***
	(0.465)	(0.003)
$r_{Sov,o,t}$	-0.000	-0.015
	(0.925)	(0.203)
$r_{Sov,o,t}$ × $Life_{i,y-1}$ (binary)	-0.002	-0.027**
	(0.705)	(0.012)
$r_{Sov,o,t}$ × $Unit_{i,y-1}$ (binary)	-0.006	-0.027***
	(0.373)	(0.009)
$r_{Sov,o,t}$ × $Solvency_{i,y}$ (binary)	-0.001	0.015*
	(0.657)	(0.090)
$r_{Corp,t}$	-0.008	-0.035**
	(0.670)	(0.035)
$r_{Corp,t}$ × $Life_{i,y-1}$ (binary)	-0.039**	-0.010
	(0.023)	(0.497)
$r_{Corp,t}$ × $Unit_{i,y-1}$ (binary)	-0.071***	-0.009
	(0.005)	(0.557)
Insurer Fixed Effects	Yes	Yes
$r_{y1,t}$, $r_{m,o,t}$ and $r_{v,o,t}$	Yes	Yes
$y10_t$ and $CDS_{o,t}$ (levels)	Yes	Yes
$Solvency_{i,y}$ (binary)	Yes	Yes
Insurer controls (binary) $X_{i,y-1}$	Yes	Yes
Insurer controls (continuous) $Y_{i,y-1}$	Yes	Yes
No. of obs.	31,735	24,803
No. of insurers	53	43
Adj. R^2	0.153	0.230
Adj. R^2 within	0.153	0.230

Note: Fixed effect regressions of insurers' daily stock returns on market risk drivers from 2012 to mid-2018. Binary insurer controls $X_{i,y-1}$ are based on previous year's median of the cross-sectional distribution of life and unit-linked insurance reserve shares. $Solvency_{i,y}$ is based on the median of current year's corresponding solvency measures (RBC ratio and Solvency II ratio). Continuous insurer controls $Y_{i,y-1}$ are the size, leverage and market-to-book ratio at the insurer-year level lagged by one year. Sources: Refinitiv (stock returns, country-level stock and volatility indices), FRED (U.S. interest rates), ECB (interest rates in Europe), Markit (sovereign CDS spreads), Bloomberg (corporate CDS indices), SNL (insurer-level life insurance share, unit-linked business share, leverage, size and market-to-book ratio), NAIC (RBC ratio) and SFCRs (solvency ratio). Standard errors are clustered at the day level. ***, **, * indicate significance at the 1%, 5% and 10% levels respectively. P-values are in parentheses.

Table 7: Regression results for the empirical Model III

For all samples, we find that insurers with a high share of life and/or unit-linked business have significantly increased market risk sensitivities. Additionally, European insurance companies with low solvency ratios are particularly prone to market risks. In terms of credit risk, we find that U.S. insurers suffer from rising corporate CDS spreads, although to a lower degree than for interest rates. In Europe, the difference in sensitivities to interest rates and CDS spreads is relatively lower. Our paper thus underlines the relevance of taking a closer look at market risks of unit-linked insurance providers and credit risks to ensure an adequate risk management.

The findings are robust to introducing several adjustments relative to the original variable definitions and specifications from the empirical Models I−III. In particular, our findings indicating higher interest rate sensitivities for life, unit-linked and less solvent insurers are confirmed. Moreover, the robustness tests emphasize that capital market investors perceive interest rate risk as a more severe threat for insurers than credit risk, particularly in the U.S. Our results, together with the robustness tests, support that the variable $r_{sov,o,t}$, defined on country-level, is a useful proxy for the insurers' exposures which, in reality, may vary across firms. The variation of insurers' exposures across firms is likely to be larger in the European sample, as these insurers invest in the bonds of different countries. Nevertheless, we observe a significant and robust influence of $r_{sov,o,t}$ on insurers' stock returns especially for Europe. In particular, the influence is robust to country-fixed effects. The robustness tests are presented in Appendix V with regression results illustrated in Table A9. In Appendix VI, we investigate the sensitivity of our model to the time period from 2008 to 2012, when interest rates are closer to their historical averages.

4 Conclusion

In this article, we examine the impact of market risk drivers on the stock returns of insurers in the U.S. and in Europe in a prolonged low yield environment from 2012 to 2018. We design an empirical model that we use to analyze the simultaneous influence of daily changes in interest rates, CDS spreads and stock market indices. We find that market risks are particularly relevant for less solvent firms with a high share of life insurance business. Unit-linked insurance providers are also strongly affected by falling interest rates and rising CDS spreads, signaling that regulators should pay close attention to their market risk sensitivities. In comparison of the market risk types, we find that interest rate changes affect stock returns more strongly than changes in CDS spreads. For U.S. life insurers, interest rate risk is a more dominant risk factor as a one standard deviation decrease in the daily hpr for long-term interest rates (0.43ppt) leads to an increase in the stock return by 0.13 standard deviations (0.36ppt). The effect of a change in interest rates is five times larger than of corporate CDS spreads and 60% larger for U.S. than for European life insurers. Instead, the sensitivity of European life insurers' stock returns to interest rates is only 44% larger than towards rising default probabilities of sovereign debt, signaling a large relevance of credit risk in Europe.

Given that our paper has identified substantial differences between U.S. and European insurers, it would be interesting for future research to extend the empirical analysis to other insurance markets. Moreover, it should be kept in mind that our empirical analysis is based on stock insurers, and the results cannot easily be transferred to companies that are not listed on stock markets, such as mutual insurers. For those companies, however, performance measures such as return on assets are observable only at much longer time intervals.

Appendix

I. Additional motivation

Country	Average duration gap	Spread of investment return over guaranteed rate	Guaranteed products as % of reserves
Germany	10.7 years	-1.6%	75%
Austria	10.09 years	-1.5%	58%
Norway	> 10 years*	1.1%	60% - 80%*
Slovenia	8.34 years		
Netherlands	5.43 years	0.7%	40%
Finland	5.36 years	1.0%	
France	4.82 years	-0.7%	> 80%*
Denmark	4.74 years	-1.9%	74%
Poland	3.44 years	3.0%	
Hungary	3.03 years	-2.8%	
Switzerland	< 2 years*		> 80%*
Greece	1.98 years		
Belgium	1.37 years	-0.1%	
U.S.	< 1 year*		60% - 80%*
Italy	0.81 years	-1.8%	60% - 80%*
Spain	0.75 years	-0.7%	> 80%*
Ireland	-0.63 years	0.0%	< 20%*
U.K.	−1.05 years	-0.5%	19%

Note: The average duration gap is obtained from EIOPA (2014) and the amount of guaranteed products as a share of reserves is obtained from ESRB (2015). For otherwise missing values, the data is collected from Moody's (2015) and marked with the symbol *. The spread of the investment return over the guaranteed rate is obtained from EIOPA (2020b).

Table A1: Characteristics of interest rate risk channels in life insurance markets

	Browne et al. (1999)	Brewer et al. (2007)	Carson et al. (2008)	Berends et al. (2013)	Hartley et al. (2017)	Killins and Chen (2020)	Möhlmann (2021)
Sample	U.S. life-health insurers	Publicly-traded U.S. life insurance companies (60)	U.S. life (17-37), health (5-11), and property and casualty (21-46) insurers	Publicly-traded U.S. life insurance companies (26)	• Publicly-traded U.S. and U.K. life and non-life insurers • Sample of continental European insurers for robustness check	U.S. insurers (95) and Canadian insurers (8)	German life insurers (83)
Main Data Sources	Best's Review: Life/Health Editions, A.M. Best, Federal Reserve Bulletin, Life Insurance Fact Book, U.S. Dept. of Labor	Center for Research in Securities Prices (CRSP)	CRSP	Compustat, French (2013), Haver Analytics, SNL Financial, CRSP	SNL Financial	DataStream, AQR, FRED	Federal Financial Supervisory Authority (BaFin)
Period	Q1/1972 - Q4/1994	01/1975 - 12/2000	01/1991 - 12/2001	08/2002 - 12/2012	01/2002 - 07/2015	01/2000 - 06/2019	01/2014 - 12/2014
Data frequency	quarterly	monthly	daily	weekly	weekly	monthly	yearly
Model	• Poisson regression presented as a log-linear model - dependent variable (DV): no. of insolvencies by quarter - independent variables (IV): average bond rate, slope of yield curve, change in T-bill rate, disposable personal income per capita, rate of unemployment, returns on real estate, S&P 500, unanticipated inflation, total number of insurers - control variable (CV): no. of quarters, seasonal variation	• Generalized autoregressive conditionally heteroskedastic in the mean (GARCH–M) model - return equation that includes the market return, the interest rate index, and the volatility measure - volatility equation that includes the ARCH and GARCH factors	• 8-equation System-GARCH model of stock return movements for portfolios - 3 return equations which include a market facor, an interest rate factor, and two return spillover factors across insurer segments - 3 volatility equations which include the ARCH and GARCH factors, risk spillover factors across different insurer categories, and a variable for the passage of the GLBA	• Two - factor model (panel regression) - DV: insurer stock returns - IV: return on a Treasury bond with a 10-year constant maturity - CV: return on a value-weighted stock market portfolio	• Two - factor model (panel regression) - DV: insurer stock returns - IV: return on U.S./U.K. government bonds with a 10-year constant maturity - CV: value-weighted stock market index • Building on the two-factor model, two-stage difference-in-difference approach	• Two - factor model (panel regression) - DV: insurer equity returns with different measures (e.g. 10Y - 3M rates) - IV: slope of the yield curve - CV: Fama and French (1993) factors for market, size and value • U.S. and Canadian sample • Pooled OLS and models with fixed and random effects	• Estimation of the historical modified duration gap using accounting data • Cross-sectional regression as well as panel regression: - DV: historical duration gap - IV: planned premium growth, run-off, size, subsidiary of a group, mutual insurance company, public ownership, interest rate derivatives • Robust-to-outliers regression of investment duration on liability duration
Extension of the basic model		• Smaller subsamples sorted by risk and asset size • Subsample periods based on changes in the monetary policy strategy of the FED	• Smaller subsamples sorted by market capitalization and geographic and product diversification	• Three subsample periods • Division into small and large firms • Firm level and portfolio level	• Division into life and non-life insurers • Division into insurers with high and low exposures to the German and U.S. insurance market	• Lagged impact of the yield curve • Subsamples sorted by insurer type • Tests for asymmetric sensitivities	• Subsection using robust-to-outliers regression to examine effect of insurers' duration gap on the Solvency II capital ratio
Hypotheses	• Relationship between the rate of insolvency and exogenous factors, e.g., rate of insolvency is either positively or negatively realted to long-term interest	• No interest rate effects • Interest rate sensitivity does not change across varying interest rate environments	• Significance of interest rate sensitivity of insurers • Equality of systematic risk and interest rate sensitivity across insurer segments	• Higher interest rate risk as interest rates decrease • Lower stock returns as interst rates decrease	• U.S. life insurers should be more sensitive to interest rates compared to U.K. life insurers as interest rates decrease	• The yield curve has a direct and lagged influence on the equity returns of insurance companies • Heterogeneity in effect of yield curve changes across insurers	• Presence of interest rate risk for life insurers • Interest rate risk differs significantly between insurers with different attributes
Results							
Effect of interest rate decrease	• Decrease in the rate of insolvency	• Increase in the stock returns of life insurers • Affects equity values of life insurers • Stronger effect on life insurers with low market betas	• Rising stock returns of insurers • Life insurers with largest sensitivities • Lower interest rate sensitivities for insurance companies who have higher geographic and product diversification	• Increase in the interest rate risk stronger for firms holding more assets • Risk exposure varies for large firms • Risk exposure remains balanced for small firms	• Increase in the interest rate risk for U.S. life insurers • Interest rate risk for U.K. life insurers remained roughly unchanged	• Falling yield curve slope (e.g., through a decrease in long-term rates) significantly increases equity returns • Larger sensitivities for life insurers	• Significant effect on insurers • Interest rate movements are negatively related to insurers' size, growth rate and solvency ratios
Effect of different monetary policy regimes		• Interest rate sensitivity of life insurer stock returns varies across regimes				• Asymmetric sensitivities towards changes in the yield curve slope	

Table A2: Overview of chosen empirical literature on the interest rate risk of insurance companies

II. Descriptive statistics

Name	Country	Obser-vations	Mean stock returns	SD of stock returns	Min. stock return	Max. stock return
Aetna Inc New	U.S.	1623	0.11%	1.47%	-8.20%	11.54%
Affirmative Insurance Hldgs Inc	U.S.	664	1.83%	26.98%	-75.00%	200.00%
Aflac Inc	U.S.	1621	0.06%	1.13%	-7.36%	7.76%
Alleghany Corp De	U.S.	1623	0.05%	1.05%	-4.56%	6.79%
Allstate Corp	U.S.	1623	0.09%	1.04%	-10.15%	6.12%
Ambac Financial Group	U.S.	1290	0.03%	2.54%	-16.61%	18.28%
American Equity Invt Life Hldg C	U.S.	1621	0.10%	1.96%	-15.34%	11.23%
American Financial Group Inc New	U.S.	1623	0.08%	0.94%	-4.61%	6.31%
American Independence Corp	U.S.	902	0.26%	3.46%	-15.75%	42.03%
American National Ins Co	U.S.	1623	0.05%	1.24%	-8.39%	9.13%
Ameriprise Financial Inc	U.S.	1623	0.09%	1.56%	-10.22%	12.42%
Amerisafe Inc	U.S.	1617	0.08%	1.55%	-12.00%	11.94%
Amtrust Financial Services Inc	U.S.	1619	0.06%	2.35%	-19.23%	25.03%
Anthem Inc	U.S.	1623	0.10%	1.47%	-12.07%	7.68%
Assurant Inc	U.S.	1623	0.07%	1.33%	-13.41%	7.59%
Atlantic American Corp	U.S.	1445	0.06%	2.66%	-14.69%	22.07%
Atlas Financial Holdings Inc	U.S.	1321	0.06%	2.38%	-40.96%	16.34%
Berkley Wr Corp	U.S.	1623	0.06%	0.96%	-4.65%	5.54%
Berkshire Hathaway Inc Del	U.S.	1623	0.06%	0.95%	-5.89%	3.90%
Cigna Corp	U.S.	1617	0.06%	1.15%	-6.91%	6.93%
Cincinnati Financial Corp	U.S.	1623	0.10%	1.46%	-11.45%	11.74%
Citizens Inc	U.S.	1623	0.07%	1.03%	-6.65%	4.70%
CNO Financial Group	U.S.	1623	0.09%	1.70%	-8.75%	7.70%
Conifer Holdings Inc	U.S.	681	-0.03%	2.99%	-16.20%	10.71%
Danielson Holding Corp	U.S.	1603	0.04%	1.49%	-12.41%	11.11%
Donegal Group Inc	U.S.	1623	0.02%	1.48%	-9.27%	10.78%
Emc Insurance Group Inc	U.S.	1623	0.07%	1.66%	-10.03%	8.92%
Employers Holdings Inc	U.S.	1623	0.07%	1.71%	-15.35%	18.70%
Erie Indemnity Co	U.S.	1623	0.05%	1.17%	-8.99%	5.86%
FBL Financial Group Inc	U.S.	1623	0.08%	1.50%	-7.29%	9.61%
Fidelity National Finl Inc New	U.S.	1623	0.10%	1.21%	-4.65%	6.17%
First Acceptance Corp	U.S.	1551	0.07%	3.96%	-24.02%	23.21%
First American Finl Corp New	U.S.	1621	0.11%	1.35%	-6.97%	6.49%
Fortegra Financial Corp	U.S.	710	0.08%	2.22%	-8.45%	40.60%
Foundation Health Systems Inc	U.S.	1190	0.21%	4.76%	-27.66%	95.33%
Gainsco Inc	U.S.	486	0.47%	5.14%	-20.00%	20.00%
Genworth Financial Inc	U.S.	1615	0.04%	3.44%	-38.45%	27.63%
Hallmark Financial Services Inc	U.S.	954	0.13%	1.42%	-3.71%	36.44%
Hartford Financial Svcs Grp Inc	U.S.	1612	0.04%	1.77%	-8.38%	10.21%
HCC Insurance Holdings Inc	U.S.	1622	0.09%	1.45%	-9.29%	7.64%
Heritage Insurance Holdings Inc	U.S.	1026	0.07%	2.51%	-16.96%	21.56%
Horace Mann Educators Corp New	U.S.	1619	0.09%	1.38%	-6.15%	6.89%
Humana Inc	U.S.	1623	0.09%	1.65%	-12.69%	20.31%
Independence Holding Co New	U.S.	1623	0.12%	2.07%	-8.26%	15.15%
Investors Title Co	U.S.	1582	0.12%	1.84%	-9.07%	12.10%
Kansas City Life Ins Co	U.S.	1530	0.03%	1.43%	-11.57%	11.00%
Kemper Corp De	U.S.	1623	0.08%	1.63%	-19.21%	14.85%
Kingstone Companies Inc	U.S.	1546	0.14%	2.41%	-13.84%	20.79%
Kinsale Capital Group Inc	U.S.	481	0.25%	1.89%	-6.01%	9.44%
Lincoln National Corp	U.S.	1623	0.09%	1.82%	-13.30%	9.21%
Loews Corp	U.S.	1623	0.02%	0.98%	-5.18%	4.90%
Lorillard Inc	U.S.	859	0.10%	1.38%	-10.49%	10.40%

Table A3: Descriptive stock return statistics of 94 U.S. insurers in the sample (first part)

Name	Country	Obser-vations	Mean stock returns	SD of stock returns	Min. stock return	Max. stock return
Markel Corp	U.S.	1621	0.03%	3.20%	-23.44%	45.37%
MBIA Inc	U.S.	1619	0.13%	3.44%	-64.08%	27.76%
Meadowbrook Insurance Group Inc	U.S.	1621	0.06%	1.01%	-10.25%	6.22%
Mercury General Corp New	U.S.	848	0.01%	2.17%	-20.66%	18.66%
Metlife Inc	U.S.	1623	0.03%	1.28%	-12.39%	8.84%
MGIC Investment Corp Wis	U.S.	1623	0.05%	1.61%	-10.71%	7.10%
Molina Healthcare Inc	U.S.	1623	0.13%	2.57%	-31.02%	26.40%
National General Holdings Corp	U.S.	1074	0.07%	1.58%	-7.27%	15.08%
National Interstate Corp	U.S.	1209	0.06%	2.16%	-17.67%	30.85%
National Security Group Inc	U.S.	1304	0.10%	3.10%	-12.38%	18.66%
National Western Life Ins Co	U.S.	1622	0.06%	1.36%	-6.97%	6.29%
Old Republic International Corp	U.S.	1621	0.08%	1.32%	-12.05%	8.29%
Phoenix Cos Inc	U.S.	1610	0.00%	1.92%	-11.29%	11.51%
PICO Holdings Inc	U.S.	1105	0.11%	5.48%	-22.23%	149.49%
Primerica Inc	U.S.	1621	0.11%	1.56%	-7.58%	12.45%
Principal Financial Group Inc	U.S.	1623	0.07%	1.47%	-10.24%	6.25%
Proassurance Corporation	U.S.	1619	0.03%	1.07%	-12.55%	8.03%
Progressive Corp Oh	U.S.	1622	0.09%	1.03%	-4.96%	5.79%
Protective Life Corp	U.S.	766	0.17%	1.56%	-7.27%	18.12%
Prudential Financial Inc	U.S.	1623	0.06%	1.58%	-10.06%	6.97%
Radian Group Inc	U.S.	1622	0.07%	1.26%	-12.00%	7.34%
Reinsurance Group Of America Inc	U.S.	1623	0.15%	2.64%	-15.83%	22.42%
RLI Corp	U.S.	1623	0.07%	1.16%	-10.83%	5.06%
Safety Insurance Group Inc	U.S.	1619	0.07%	1.16%	-6.74%	5.59%
Selective Insurance Group Inc	U.S.	1621	0.09%	1.33%	-7.86%	8.38%
Stancorp Financial Group Inc	U.S.	1042	0.13%	1.92%	-11.03%	47.93%
State Auto Financial Corp	U.S.	1621	0.08%	2.03%	-11.02%	26.53%
Stephan Company	U.S.	673	0.22%	5.78%	-29.03%	54.55%
Stewart Information Svcs Corp	U.S.	1620	0.10%	1.70%	-10.23%	16.05%
Symetra Financial Corp	U.S.	1013	0.15%	1.47%	-7.10%	10.27%
Torchmark Corp	U.S.	1623	0.07%	0.99%	-4.92%	3.97%
Travelers Ppty Casualty Corp New	U.S.	1623	0.06%	1.00%	-6.05%	4.96%
Triple S Management Corp	U.S.	1621	0.07%	2.32%	-17.86%	23.81%
Unico American Corp	U.S.	1275	0.01%	2.60%	-13.56%	21.88%
United Fire Group Inc	U.S.	1619	0.09%	1.88%	-11.86%	15.13%
United Insurance Holdings Corp	U.S.	1469	0.15%	2.81%	-23.98%	33.33%
Unitedhealth Group Inc	U.S.	1623	0.11%	1.29%	-5.65%	6.90%
Universal American Financial Cor	U.S.	1296	0.04%	2.16%	-19.28%	14.05%
Universal Insurance Holdings Inc	U.S.	1618	0.20%	2.72%	-30.73%	16.74%
Unum Group	U.S.	1623	0.05%	1.47%	-16.95%	7.69%
Voya Financial Inc	U.S.	1291	0.08%	1.70%	-10.55%	11.19%
Wellcare Health Plans Inc	U.S.	1623	0.12%	2.09%	-19.83%	18.42%

Table A3: Descriptive stock return statistics of 94 U.S. insurers in the sample (second part)

Name	Country	Obser-vations	Mean stock returns	SD of stock returns	Min. stock return	Max. stock return
UNIQA Insurance Group AG	Austria	1603	0.02%	1.59%	-10.10%	9.84%
Vienna Insurance Group AG	Austria	1607	0.01%	1.58%	-17.93%	7.15%
Ageas SA	Belgium	1658	0.11%	1.53%	-9.75%	10.65%
KBC Groep NV	Belgium	1658	0.15%	2.21%	-13.88%	10.71%
Jadransko Osiguranje dd	Croatia	494	0.15%	4.23%	-29.83%	47.19%
Atlantic Insurance Company	Cyprus	525	0.29%	3.85%	-10.00%	11.61%
Alm Brand A/S	Denmark	1472	0.17%	1.74%	-7.17%	14.08%
Topdanmark A/S	Denmark	1604	0.08%	1.19%	-7.03%	8.92%
Tryg A/S	Denmark	1604	0.08%	1.23%	-6.63%	7.75%
Sampo Plc	Finland	1627	0.08%	1.17%	-9.40%	4.86%
April SA	France	1633	0.03%	1.57%	-6.38%	10.03%
Axa SA	France	1658	0.08%	1.75%	-15.48%	7.55%
CNP Assurances SA	France	1654	0.08%	1.58%	-8.49%	11.73%
Coface SA	France	1024	0.03%	2.05%	-29.73%	8.87%
Scor SE	France	1655	0.06%	1.25%	-6.93%	5.61%
Allianz SE	Germany	1644	0.08%	1.29%	-10.17%	6.04%
Muenchener Rueckvers. AG	Germany	1644	0.07%	1.15%	-7.05%	4.94%
Nuernberger Beteiligungs AG	Germany	1527	0.04%	1.22%	-6.17%	7.31%
Rheinland Holding AG	Germany	1063	0.11%	3.44%	-12.34%	16.36%
Talanx AG	Germany	1451	0.06%	1.38%	-5.59%	5.23%
Wuestenrot & Wuerttemberg. AG	Germany	1612	0.04%	1.64%	-7.87%	7.48%
European Reliance Gen. Ins. C. SA	Greece	1337	0.23%	3.29%	-16.43%	19.90%
CIG Pannonia EletBiztosito Nyrt	Hungary	1503	0.02%	2.44%	-12.83%	14.99%
Vatryggingafelag Islands hf	Iceland	1192	0.06%	1.19%	-5.49%	9.22%
FBD Holdings Plc	Ireland	1605	0.06%	2.04%	-20.54%	14.84%
Permanent TSB Group Hldgs plc	Ireland	1528	0.15%	5.66%	-25.70%	39.16%
Assicurazioni Generali SpA	Italy	1645	0.04%	1.79%	-16.77%	9.35%
Societa Cattolica di Assic. Sc	Italy	1638	0.02%	1.94%	-17.43%	17.30%
UnipolSai Assicurazioni SpA	Italy	1643	0.15%	5.20%	-58.82%	119.81%
Vaudoise Assurances Holding SA	Italy	1607	0.06%	1.26%	-5.05%	8.52%
Vittoria Assicurazioni SpA	Italy	1628	0.12%	1.52%	-8.14%	19.73%
Mapfre Middlesea Plc	Malta	388	0.34%	3.38%	-16.25%	14.93%
Aegon NV	Netherlands	1658	0.07%	1.98%	-11.37%	13.32%
ASR Nederland NV	Netherlands	526	0.14%	1.37%	-7.43%	6.76%
Delta Lloyd NV	Netherlands	371	0.03%	5.38%	-32.72%	47.89%
NN Group NV	Netherlands	1018	0.08%	1.40%	-8.03%	8.77%
Gjensidige Forsikring ASA	Norway	1624	0.08%	1.22%	-8.15%	12.28%
Insr Insurance Group ASA	Norway	1001	-0.11%	3.89%	-54.56%	22.42%
Protector Forsikring ASA	Norway	1484	0.16%	2.02%	-9.91%	15.61%
Storebrand ASA	Norway	1627	0.07%	2.15%	-14.25%	12.36%
Powszechny Zaklad Ubezp. SA	Poland	1614	0.05%	1.51%	-6.59%	7.13%
Pozavarovalnica Sava dd	Slovenia	1382	0.12%	2.09%	-10.47%	12.39%
Zavarovalnica Triglav dd	Slovenia	1559	0.12%	1.61%	-7.94%	8.91%
Grupo Catalana Occidente SA	Spain	1652	0.09%	1.70%	-7.94%	13.26%
Mapfre SA	Spain	1656	0.04%	1.88%	-9.30%	14.14%
Baloise Holding Ltd	Switzerland	1623	0.08%	1.12%	-7.41%	4.57%
Chubb Ltd	Switzerland	1625	0.05%	0.99%	-4.83%	4.54%
Helvetia Holding AG	Switzerland	1619	0.06%	1.16%	-6.96%	5.65%
Swiss Life Holding AG	Switzerland	1621	0.11%	1.38%	-8.10%	8.73%
Swiss Re AG	Switzerland	1620	0.07%	1.10%	-5.63%	4.26%
Zurich Insurance Group AG	Switzerland	1627	0.05%	1.13%	-10.82%	6.57%
Admiral Group PLC	U.K.	1634	0.09%	1.43%	-7.68%	10.00%
Aon PLC	U.K.	1632	0.08%	1.07%	-5.76%	6.11%
Aviva PLC	U.K.	1634	0.06%	1.63%	-15.68%	8.13%
Beazley PLC	U.K.	1632	0.13%	1.39%	-8.96%	6.85%
Chesnara PLC	U.K.	1624	0.09%	1.77%	-14.51%	8.85%
Direct Line Insurance Group PLC	U.K.	1436	0.08%	1.23%	-7.16%	12.62%
esure Group PLC	U.K.	1317	0.04%	1.74%	-21.02%	9.82%
Hansard Global PLC	U.K.	1632	0.01%	2.37%	-14.36%	13.67%
Hastings Group Holdings PLC	U.K.	682	0.08%	1.53%	-12.03%	6.82%
Legal & General Group PLC	U.K.	1633	0.09%	1.48%	-20.26%	7.88%
Old Mutual PLC	U.K.	1634	0.05%	1.65%	-10.83%	6.92%
Personal Group Holdings PLC	U.K.	1079	0.10%	1.44%	-6.98%	11.56%
Phoenix Group Holdings PLC	U.K.	1607	0.07%	1.43%	-11.54%	11.17%
Prudential PLC	U.K.	1632	0.09%	1.60%	-10.53%	9.33%
RSA Insurance Group PLC	U.K.	1633	0.05%	1.49%	-20.84%	18.43%
Saga PLC	U.K.	1029	-0.01%	1.60%	-21.41%	10.78%
St. James's Place PLC	U.K.	1630	0.10%	1.63%	-16.18%	7.24%
Standard Life Aberdeen PLC	U.K.	1634	0.06%	1.59%	-17.30%	8.07%

Table A4: Descriptive stock return statistics of 69 European insurers in the sample

Country	Mean CDS return	SD of CDS returns	Min. CDS return	Max. CDS return
Austria	-0.09%	3.69%	-89.27%	53.93%
Belgium	-0.14%	2.89%	-75.37%	31.95%
Denmark	-0.09%	3.45%	-72.49%	39.26%
Finland	-0.12%	3.05%	-26.19%	34.71%
France	-0.11%	2.97%	-82.49%	33.01%
Germany	-0.14%	3.18%	-60.16%	41.14%
Greece	-0.10%	2.96%	-83.96%	13.89%
Hungary	-0.06%	1.94%	-12.51%	25.26%
Iceland	-0.10%	1.62%	-10.19%	12.88%
Ireland	-0.07%	4.45%	-93.66%	65.55%
Italy	-0.14%	1.76%	-11.26%	13.12%
Netherlands	-0.12%	2.92%	-26.10%	36.00%
Norway	-0.16%	2.42%	-15.86%	32.09%
Poland	-0.09%	1.43%	-14.55%	9.69%
Slovenia	-0.07%	1.68%	-24.58%	25.67%
Spain	-0.09%	1.77%	-19.46%	19.60%
Switzerland	-0.09%	1.83%	-10.37%	18.05%
U.K.	-0.08%	2.43%	-13.39%	39.81%
U.S.	0.14%	7.07%	-31.49%	106.19%

Table A5: Descriptive statistics of insurers' CDS exposures per country

Variable	$r_{m,o,t}$ (market return)				$r_{v,o,t}$ (volatility return)			
Country	Mean	SD	Min	Max	Mean	SD	Min	Max
Austria	0.04%	1.13%	-7.04%	4.79%	-	-	-	-
Belgium	0.04%	0.95%	-6.40%	3.87%	-	-	-	-
Denmark	0.06%	1.04%	-6.56%	5.28%	-	-	-	-
Croatia	0.00%	0.57%	-3.06%	3.45%	-	-	-	-
Cyprus	-0.06%	2.23%	-14.38%	17.19%	-	-	-	-
Finland	0.05%	1.11%	-8.38%	4.32%	-	-	-	-
France	0.04%	1.11%	-8.04%	4.75%	0.20%	7.04%	-39.68%	71.43%
Germany	0.04%	1.11%	-6.82%	4.97%	0.15%	6.12%	-30.93%	50.81%
Greece	0.03%	2.07%	-16.23%	11.27%	-	-	-	-
Hungary	0.05%	1.05%	-6.07%	5.09%	-	-	-	-
Iceland	0.05%	0.75%	-3.77%	4.88%	-	-	-	-
Ireland	0.06%	1.02%	-9.89%	4.55%	-	-	-	-
Italy	0.03%	1.48%	-12.48%	6.59%	-	-	-	-
Netherlands	0.04%	0.97%	-5.70%	4.05%	0.19%	6.75%	-27.53%	54.61%
Norway	0.05%	1.02%	-5.20%	4.51%	-	-	-	-
Poland	0.03%	0.88%	-5.66%	3.05%	-	-	-	-
Slovenia	0.03%	0.85%	-5.18%	3.53%	-	-	-	-
Spain	0.01%	1.31%	-12.35%	6.06%	-	-	-	-
Switzerland	0.03%	0.89%	-8.67%	3.42%	0.15%	5.79%	-27.42%	43.63%
U.K.	0.02%	0.84%	-4.67%	3.58%	0.03%	0.95%	-5.19%	5.33%
Europe	0.03%	1.06%	-7.66%	4.61%	0.19%	6.82%	-35.26%	60.05%
U.S.	0.05%	0.77%	-4.10%	3.90%	0.28%	8.10%	-25.91%	115.60%

Table A6: Descriptive statistics of variables measuring stock index returns

	Life $Share_{i,y-1}$		Unit-linked $Share_{i,y-1}$		RBC $Ratio_{i,y}$	Solvency $Ratio_{i,y}$
Sample	U.S.	Europe	U.S.	Europe	U.S.	Europe
2012	0.533	0.419	0.15	0.087	-	-
2013	0.537	0.399	0.137	0.102	-	-
2014	0.502	0.407	0.15	0.124	-	-
2015	0.499	0.401	0.185	0.111	-	-
2016	0.485	0.396	0.174	0.122	6.989	1.943
2017	0.475	0.394	0.099	0.118	6.624	2.022
2018	0.564	0.417	0.111	0.075	6.497	2.069

Table A7: Medians from insurer-specific balance sheet variables

III. Other variables

Variable	Definition
$Gov\ Bond\ Share_{i,y}$	$\frac{Government\ Bond\ Investments\ and\ Similar_{i,y}}{Total\ Investments_{i,y} - Separate\ Account\ Assets_{i,y}}$
$Corp\ Bond\ Share_{i,y}$	$\frac{Corporate\ Bonds\ Investments_{i,y}}{Total\ Investments_{i,y} - Separate\ Account\ Assets_{i,y}}$
$Investment\ Focus_{i,y}$	$max \left\{ \begin{matrix} Gov\ Bond\ Share_{i,y};\ Corp\ Bond\ Share_{i,y}; Loan\ Inv\ Share_{i,y}; \\ Equity\ Inv\ Share_{i,y};\ Real\ Estate\ Inv\ Share_{i,y}; \\ Derivatives\ Inv\ Share_{i,y};\ Share\ Other\ Inv_{i,y} \end{matrix} \right\}$
$Life\ Change_{i,y}$	$Life\ Share_{i,2018} - Life\ Share_{i,2008}$
$Insurance\ Focus_{i,y}$	$\frac{Total\ Policy\ Reserves_{i,y}}{Total\ Liabilities_{i,y}}$

Table A8: Further balance sheet variables tested empirically

IV. Interest rate exposure of unit-linked insurance providers

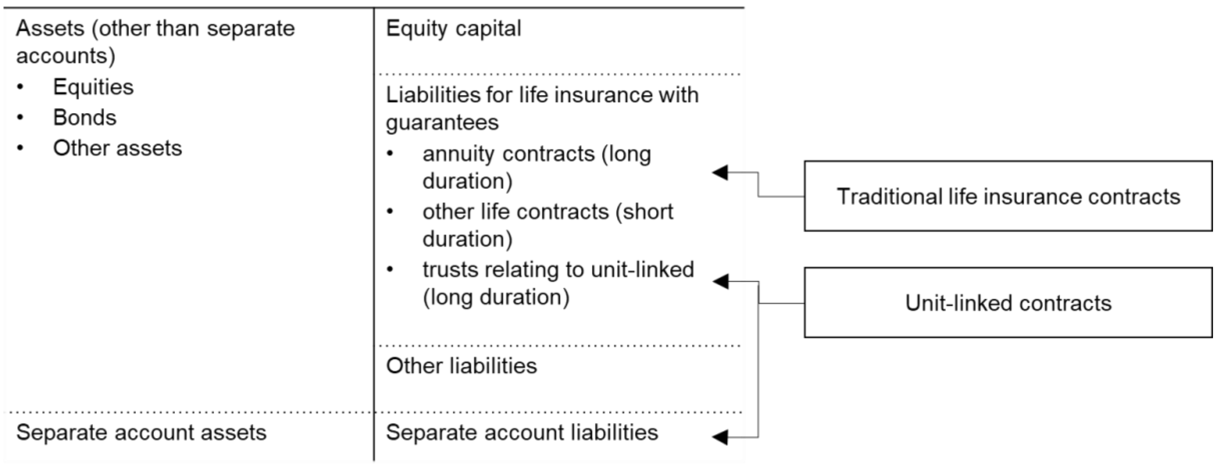


Figure A1: Stylized balance sheet with liabilities for traditional life and unit-linked contracts

V. Robustness

To test the robustness of the findings, we consider several changes in the empirical models and variable definitions. Table A9 shows whether the hypotheses set out in Section 2.4 are supported by the regression results after implementing the following thirteen individual adjustments to the original specifications for the empirical Models I−III:[49]

1. **Continuous variables for interaction terms instead of binaries in Model II and III**: While we initially chose binary variables $X_{i,y-1}$ to allow for an easier interpretation of coefficients, an alternative specification with the continuous variables $Life\ Share_{i,y-1}$, $Unit\text{-}linked\ Share_{i,y-1}$ and $Solvency\ Ratio^{x}_{i,y}$ instead of $Life_{i,y-1}$, $Unit_{i,y-1}$ and $Solvency^{x}_{i,y}$ is also reasonable from an econometric point of view. Again, we include the main effects of these continuous insurer-specific characteristics in the model and interact them with $r_{y10,t}$, $r_{Sov,o,t}$ and $r_{Corp,t}$ analogously to the original Models II−III. The empirical results of these alternative models (see corresponding columns in Table A9) confirm previous findings in terms of the sign of the coefficients for the variables of interest. Only regarding the influence of the interaction term $r_{Sov,o,t} \cdot Solvency_{i,y}$ relating to hypothesis *H8*, the robustness test does not show significant coefficients for the restricted sample period in Model III. One reason is the smaller number of observations (data only from 2016 to mid-2018). Similarly, the effect of $r_{Sov,o,t} \cdot Unit_{i,y-1}$ on European insurers' stock returns is only significant for the larger sample in Model II including all observations from 2012 to mid-2018.
2. **Standard errors clustered at day and firm level**: While most of the empirical literature investigating the market risks of insurance companies does not include clustered standard errors, we cluster standard errors at the day level to handle correlated shocks in line with Düll et al. (2017). However, previous finance-related literature has shown that stock returns and their variance display autocorrelation (see Mech (1993), Campbell et al. (1997) and Kim et al. (2011)). To handle this issue and to ensure the obtaining of heteroskedasticity-robust coefficients, we additionally cluster standard errors on an insurer and day level in a robustness check. The summarized empirical results illustrated in Table A9 indicate that the majority of coefficients are significant. Only the interaction term $r_{Corp,t} \cdot Life_{i,y-1}$ is insignificant for the U.S. sample after

[49] Regression tables including the coefficients and p-values of the empirical models used for the alternative specifications in Appendix V are available upon request.

additionally clustering standard errors at the firm level, which can be explained by opposing effects of rising CDS spreads on life insurers (see Section 2.4).

3. **Weekly data**: We test whether the elaborated hypotheses are supported by significant regression coefficients after adjusting the data frequency to weekly data in line with Berends et al. (2013) and Hartley et al. (2017). For this robustness test, we use end-of-week data for stock returns and all market risk variables. The adjustment results in a lower power of empirical testing. Presumably because of the resulting decrease in the number of observations,[50] the positive effect of the interaction term $r_{Sov,o,t} \cdot Solvency_{i,y}$ disappears and corporate CDS spreads $r_{Corp,t}$ have no significant effect on U.S. insurers. The majority of effects, particularly for interest rate risk, is still highly significant.
4. **Without winsorizing**: In order to deal with outliers, we initially winsorize the highest and lowest 0.5% of stock returns and continuous independent variables in each sample in the specifications for Models I−III. As a robustness check, we estimate our models without winsorizing the data. Compared with the results from the original models, all hypotheses are still supported.
5. **Considering the number of days passed**: For this robustness check, we use an alternative specification for variables measuring daily stock returns and changes in market risk drivers. We consider the number of days that has passed since the last stock price of an insurer was observed. For instance, we define the stock return as $r_{i,t} = \left(\frac{TRI_{i,t}}{TRI_{i,t_{previous}}}\right)^{\frac{1}{t-t_{previous}}} - 1$ instead of $r_{i,t} = \frac{TRI_{i,t}}{TRI_{i,t_{previous}}} - 1$. Therefore, if an insurer's stock price is missing for a certain trading day (where stock markets globally are trading), but available for the following trading day, then $t - t_{previous} = 2$ applies. We adjust the calculations for the independent variables analogously. The regression results with this alternative specification are consistent with previous findings.
6. **Only observations where exactly one day has passed**: We test whether we find different market risk sensitivities when removing all stock return observations for an insurer i after a missing $r_{i,t}$. Thus, this limited sample only considers changes in stock prices within one trading day. The approach allows a reduction of concerns regarding distortions from national public holidays differing across countries. Although some observations are removed (1,439 in the U.S. and 2,778 in the European sample), the coefficients for all variables of interest are still significant across all samples.

[50] For instance, the number of observations in the European sample in Model III falls from 24,803 to 4,970.

Hypothesis	Variable of interest	Robustness check	Original models		1. Continuous insurer		2. Firm & day level cluster		3. Weekly data		4. Without winsorizing		5. With nr. of days passed		6. With one day passed	
		Sample	U.S.	Europe	U.S.	Europe	U.S.	Europe	U.S.	Europe	U.S.	Europe	U.S.	Europe	U.S.	Europe
H1	$r_{y10,t}$	Model I	√***	√***	√***	√***	√***	√***	√***	√***	√***	√***	√***	√***	√***	√***
H2	$r_{y10,t} \cdot Life_{i,y-1}$	Model II	√***	√***	√***	√***	√**	√**	√***	√*	√***	√***	√***	√***	√***	√***
		Model III	√***	√***	√***	√***	√′	√***	√**	√***	√***	√***	√***	√***	√***	√***
H3	$r_{y10,t} \cdot Unit_{i,y-1}$	Model II	√***	√***	√***	√**	√***	√***	√***	√**	√***	√***	√***	√***	√***	√***
		Model III	√***	√***	√***	√′	√***	√***	√***	√***	√***	√***	√***	√***	√***	√***
H4	$r_{y10,t} \cdot Solvency_{i,y}$	Model III	-	√***	-	√**	-	√*	-	√′	-	√***	-	√***	-	√***
H5	$r_{CDS,o,t}$	Model I	√**	√***	√**	√***	√***	√*	√	√**	√'	√***	√**	√***	√**	√***
H6	$r_{CDS,o,t} \cdot Life_{i,y-1}$	Model II	√***	√***	√**	√***	√′	√′	√	√′	√*	√*	√***	√***	√***	√***
		Model III	√**	√**	√**	√**	√	√**	√	√	√**	√′	√**	√**	√**	√**
H7	$r_{CDS,o,t} \cdot Unit_{i,y-1}$	Model II	√***	√***	√***	√***	√***	√**	√	√**	√*	√***	√***	√***	√***	√***
		Model III	√***	√***	√***	√	√**	√**	√	√	√***	√***	√***	√***	√***	√***
H8	$r_{Sov,o,t} \cdot Solvency_{i,y}$	Model III	-	√*	-	√	-	√′	-	X	-	√**	-	√'	-	√'

Hypothesis	Variable of interest	Robustness check	7. Life insurers only		8. St. market interactions		9. Interactions with size		10. 60th percentile		11. 40th percentile		12. European median		13. Mean threshold	
		Sample	U.S.	Europe	U.S.	Europe	U.S.	Europe	U.S.	Europe	U.S.	Europe	U.S.	Europe	U.S.	Europe
H2	$r_{y10,t} \cdot Life_{i,y-1}$	Model II	√***	√***	√***	√***	√***	√**	√***	√***	√***	√***	√***	√***	√***	√***
		Model III	√**	√***	√***	√***	√***	√**	√*	√***	√***	√***	√***	√***	√**	√***
H3	$r_{y10,t} \cdot Unit_{i,y-1}$	Model II	√***	√***	√***	√***	√***	√***	√***	√***	√***	√***	√***	√***	√***	√***
		Model III	√***	√***	√***	√***	√***	√***	√***	√***	√***	√***	√***	√***	√***	√***
H4	$r_{y10,t} \cdot Solvency_{i,y}$	Model III	-	√***	-	√***	-	√**	-	√***	√***	√*	-	√***	√***	√***
H6	$r_{CDS,o,t} \cdot Life_{i,y-1}$	Model II	√**	√***	√*	√	√*	√	√***	√*	√***	√***	√***	√***	√**	√***
		Model III	√*	√'	√**	√	√**	√	√***	√**	√***	√***	√***	√**	√	√**
H7	$r_{CDS,o,t} \cdot Unit_{i,y-1}$	Model II	√***	√***	√*	√	√***	√***	√***	√*	√**	√**	√***	√***	√**	√***
		Model III	√***	√*	√	√	√***	√*	√***	√*	√**	√'	√*	√***	√***	√*
H8	$r_{Sov,o,t} \cdot Solvency_{i,y}$	Model III	-	√	-	√	-	√'	-	√	-	√*	-	√*	-	√′

Note: Each robustness test stands for an adjustment compared with the original empirical Models I–III. ***, **, *, ', ´ indicate significance at the 1%, 5%, 10%, 15% and 20% levels respectively. The checkmark symbol implies that under the given specification, the coefficient of the variable of interest from the panel regression analysis has a sign that is in line with the hypothesis formulated in Section 2.4. In contrast, X implies that the sign is not in line with the given hypothesis. For U.S. insurers, the displayed sensitivities towards $r_{CDS,o,t}$ reflect corporate credit risk based on $r_{Corp,t}$ and for European insurers, sovereign credit risk based on $r_{Sov,o,t}$.

Table A9: Overview of regression results for robustness tests

7. **Life insurers only**: In the original sample, we include all types of listed insurance companies, i.e., also non-life insurers. The chosen approach enables an analysis of how market risk sensitivities are linked to the product portfolio of an insurer. In this robustness test, we only keep insurers in the sample when their share of life insurance reserves is above 20%, i.e., where the requirement $Life\ Share_{i,y-1} > 0.2$ is fulfilled. Thus, for the insurers in the sample, life insurance business accounts for a substantial

part of their liabilities.[51] The sign of all coefficients is in line with previous findings. The influence of the variables of interest is significant on the 10% level apart from two interaction terms with CDS changes in the European sample in Model III, which only uses a subset of the initial observations.

8. **Stock market interactions included**: In their empirical models, Hartley et al. (2017) include the interaction of life insurance business with stock market returns as a control variable. Based on their approach, we additionally introduce the interactions of the stock index return $r_{m,o,t}$ with the binary variables $Life_{i,y-1}$, $Unit_{i,y-1}$ and $Solvency_{i,y}^{x}$ in a robustness check. By doing so, we test whether previously observed sensitivities related to market risk drivers might be influenced by overall economic conditions. This specification considers a wider range of independent variables (22 in total in Model II and 25 in Model III). In terms of interest rate sensitivities, the empirical results are significantly in line with the hypotheses *H1* - *H4*. Only regarding European insurers' stock price reactions to CDS spread, the model does not show significant effects in terms of hypothesis *H6* - *H8*. We assume these insignificant coefficients to be driven by the large set of variables with counteracting effects on stock returns. For U.S. insurers, all findings from the original models are still significant on a 10% level.
9. **Interactions with size included**: Previous research articles have analyzed market risk sensitivities depending on the size of insurance companies. Brewer et al. (2007) find that life insurers with a larger asset size react less sensitively to stock market movements than to interest rates. In the original models, we control for the size of insurers using the continuous variable $Size_{i,y-1}$. For a robustness check, we use a binary variable instead, which we define analogously to other dummy variables $X_{i,y-1}$, i.e., based on the previous year's median in the cross-sectional distribution. We interact the binary variable for size with the measures for relative changes of interest rates $r_{y10,t}$ and CDS spreads $r_{Sov,o,t}$ and $r_{Corp,t}$ in the same way as other insurer-specific indicators, such as $Life_{i,y-1}$. The results are robust and only regarding hypothesis *H6* and the credit risk of European life insurers, the coefficients are insignificant.

10.-13. **Adjustments to the binary thresholds**: In these four specifications, we use alternative definitions for the binary variables $Life_{i,y-1}$, $Unit_{i,y-1}$ and $Solvency_{i,y}^{x}$ compared with the definitions illustrated in Table 4. Initially, the dummy variables are set to be equal

[51] Please note that the binary variable $Life_{i,y-1}$ still accounts for the 50% of insurers with the largest share of life insurance reserves in the given sample. Compared to the original sample including pure non-life insurers, the threshold for defining a life insurer is higher in this robustness test.

to one when the respective continuous share $Life\ Share_{i,y-1}$, $Unit\text{-}linked\ Share_{i,y-1}$ or $Solvency\ Ratio_{i,y}^{x}$ is above the median for a given sample. For the robustness tests, we use the following four uniform requirements across all samples for defining thresholds for the respective binary variables to be equal to one:

10. 60^{th} percentile of all observations where $X_{i,y-1} > 0$,
11. 40^{th} percentile of all observations where $X_{i,y-1} > 0$,
12. the median of all observations in the European sample[52],
13. mean (i.e., the average) of all observations.

The results of the robustness tests illustrated in Table A9 show that for all given adjustments for the definitions of the binary variables, the coefficients of the variables of interest are in line with previous findings. Excluding hypotheses *H7* and *H8*, the influence on the stock returns is always significant at least at a 10% level. Notably, in line with hypothesis *H4*, which is very robust for European insurers, we find that more solvent U.S. insurers significantly suffer less from falling interest rates under the adjustments 11. and 13. Arguably, only U.S. insurers with low RBC ratios are affected by falling interest rates as they are closer to undergo additional regulatory monitoring.

In summary, the results from the thirteen alternative specifications to the empirical models indicate that the vast majority of initial findings can be confirmed by significant coefficients supporting the hypotheses. Regarding the interaction term $r_{Sov,o,t} \cdot Solvency_{i,y}$ and hypothesis *H8*, which implies higher credit risk sensitivities for less solvent insurers, one adjustment shows contradicting and four adjustments show insignificant coefficients. *H6* (*H7*) regarding the credit risk of life insurers (unit-linked insurers) is insignificant in at least one of the samples for three (two) specifications. One reason for the lack of significance could be the existence of a positive effect of rising CDS spreads on the demand for secure pension planning and potentially higher future investment returns. In contrast, we observe that previous findings indicating higher interest rate sensitivities for life insurers, unit-linked insurers and less solvent firms are very robust. Therefore, the robustness tests emphasize that capital market investors perceive interest rate risk as a more severe threat for insurers than credit risk, however with a more important role of credit risk in Europe.

[52] The European sample has a substantially larger share of insurers offering life insurance and unit-linked products compared with the U.S. sample. The adjustment only applies to the variables $Life_{i,y-1}$, $Unit_{i,y-1}$. The varying definitions of the solvency measures for European and U.S. insurers (i.e., the solvency ratio and RBC ratio) result in a different scaling of the corresponding observations (cf. Table 1).

VI. Supplementary analysis

We have adapted our regression tables (Table 5 and Table 6) to focus on the period from 2008 to 2012, which covers the financial crisis and its immediate aftermath. Our updated analysis (Table A10 and Table A11) shows that European insurers are less sensitive to declining interest rates compared to the initial sample period from 2012 to 2018. For life insurers, the impact of interest rate changes is not significantly larger, unlike unit-linked insurers, where the effect of the interaction term $r_{y10,t} \cdot Unit_{i,y-1}$ is significant (cf. Table A11, column (2)). In contrast, corporate CDS spreads play a relatively more significant role in the European market during this period, illustrated by the large standardized beta coefficients compared with other market risk factors (cf. Table A10, columns (2) and (4)).

Regarding the U.S. market, our empirical results for the period from 2008 to 2012 show that, in general, insurers benefit from declining interest rates, except for traditional life and unit-linked insurers (cf. Table A11, column (1)). These findings suggest that the sensitivity of insurers to interest rates varies across different types of insurers and markets, highlighting the importance of considering market-specific factors in analyzing the impact of interest rates on insurance companies.

	(1)	(2)	(3)	(4)
Dependent variable:	$r_{i,t}$ (stock return)			
Sample:	U.S.	Europe	U.S. life	Europe life
$r_{y10,t}$ (10-year interest rate hpr)	0.058	-0.136**	0.035	-0.115
	(0.330)	(0.024)	(0.689)	(0.139)
$r_{y1,t}$ (1-year interest rate hpr)	0.217**	-0.093	0.377**	-0.107
	(0.047)	(0.193)	(0.020)	(0.198)
$r_{Sov,o,t}$ (sovereign CDS return)	0.000	-0.020***	-0.004	-0.011**
	(0.990)	(0.000)	(0.302)	(0.048)
$r_{Corp,t}$ (corporate CDS return)	-0.012	-0.095***	-0.014	-0.095***
	(0.519)	(0.000)	(0.593)	(0.000)
$r_{m,o,t}$ (market return)	1.253***	0.688***	1.705***	0.844***
	(0.000)	(0.000)	(0.000)	(0.000)
$r_{v,o,t}$ (volatility return)	0.016***	-0.010***	0.033***	-0.004
	(0.009)	(0.002)	(0.001)	(0.238)
Insurer Fixed Effects	Yes	Yes	Yes	Yes
$y10_t$ and $CDS_{o,t}$ (levels)	Yes	Yes	Yes	Yes
No. of obs.	115,159	66,652	22,378	28,992
No. of insurers	110	64	22	28
Adj. R^2	0.290	0.239	0.464	0.357
Adj. R^2 within	0.291	0.239	0.464	0.357
Standardized beta coefficients				
10-year interest rate	.012	-.021	.007	-.019
Sovereign CDS	0	-.028	-.01	-.016
Corporate CDS	-.006	-.066	-.006	-.071

Table A10: Regression results for the empirical Model I for the years 2008 to 2012

	(1)	(2)
Dependent variable:	$r_{i,t}$ (stock return)	
Sample:	U.S.	Europe
$r_{y10,t}$	0.203***	0.077
	(0.001)	(0.248)
$r_{y10,t} \times Life_{i,y-1}$ (binary)	-0.348***	-0.037
	(0.000)	(0.509)
$r_{y10,t} \times Unit_{i,y-1}$ (binary)	-0.367***	-0.377***
	(0.000)	(0.000)
$r_{Sov,o,t}$	0.002	-0.013*
	(0.557)	(0.069)
$r_{Sov,o,t} \times Life_{i,y-1}$ (binary)	-0.002	0.017**
	(0.534)	(0.023)
$r_{Sov,o,t} \times Unit_{i,y-1}$ (binary)	-0.011***	-0.048***
	(0.004)	(0.000)
$r_{Corp,t}$	0.036*	-0.017
	(0.068)	(0.224)
$r_{Corp,t} \times Life_{i,y-1}$ (binary)	-0.087***	-0.030**
	(0.000)	(0.033)
$r_{Corp,t} \times Unit_{i,y-1}$ (binary)	-0.183***	-0.094***
	(0.000)	(0.000)
Insurer Fixed Effects	Yes	Yes
$r_{y1,t}$, $r_{m,o,t}$ and $r_{v,o,t}$	Yes	Yes
$y10_t$ and $CDS_{o,t}$ (levels)	Yes	Yes
Insurer controls (binary) $X_{i,y-1}$	Yes	Yes
Insurer controls (continuous) $Y_{i,y-1}$	Yes	Yes
No. of obs.	76,656	45,750
No. of insurers	67	47
Adj. R^2	0.305	0.248
Adj. R^2 within	0.305	0.248

Table A11: Regression results for the empirical Model II for the years 2008 to 2012

Literature

Acharya, V., Drechsler, I., Schnabl, P. (2014), 'A Pyrrhic Victory? Bank Bailouts and Sovereign Credit Risk', *The Journal of Finance,* 69 (6): 2689-2739.

Angrist J. D., Pischke J.-S. (2009), '*Mostly Harmless Econometrics: An Empiricist's Companion*', Economics Books, Princeton University Press, edition 1, April.

Becker, B., Ivashina, V. (2015), 'Reaching for Yield in the Bond Market', *The Journal of Finance,* 70 (5): 1863-1902.

Becker, B., Opp, M., Saidi, F. (2022),'Regulatory Forbearance in the U.S. Insurance Industry: The Effects of Eliminating Capital Requirements', *The Review of Financial Studies,* 35 (12): 5438–5482.

Bégin, J. F., Boudreault, M., Doljanu, D. A., Gauthier, G. (2019), 'Credit and Systemic Risks in the Financial Services Sector: Evidence From the 2008 Global Crisis', *Journal of Risk and Insurance,* 86 (2): 263-296.

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.

Bertrand, M., Morse, A. (2011), 'Information Disclosure, Cognitive Biases, and Payday Borrowing', *The Journal of Finance*, 66 (6): 1865-1893.

Billio, M., Getmansky, M., Gray, D., Lo, A.W., Merton, R.C., Pelizzon, L., (2014), 'Sovereign, Bank, and Insurance Credit Spreads: Connectedness and System Networks', SYRTO Working Paper Series, 8.

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., Mondschean, T. H., Strahan, P. E. (1993), 'Why the life insurance industry did not face an 'S&L-type' crisis', *Federal Reserve Bank of Chicago Economic Perspectives,* 17 (5): 12-24.

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.

Caballero, R. J., Farhi, E., Gourinchas P.-O. (2017), 'The Safe Assets Shortage Conundrum', *Journal of Economic Perspectives*, 31 (3): 29-46.

Campbell, J. Y., Lo, A. W., MacKinlay, A. C. (1997), '*The Econometrics of Financial Markets*', Princeton University Press, Princeton, NJ.

Carson, J. M., Hoyt, R. (2000), 'Evaluating the risk of life insurer insolvency: implications from the US for the European Union', *Journal of Multinational Financial Management*, 10 (3/4): 297-314.

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.

Chen, H., J. D. Cummins, K. S. Viswanathan, and M. A. Weiss, (2014), 'Systemic Risk and the Interconnectedness Between Banks and Insurers: An Econometric Analysis', *Journal of Risk and Insurance*, 81: 623- 652.

Czaja, M. G., Scholz, H., Wilkens, M. (2009), 'Interest rate risk of German financial institutions: The impact of level, slope, and curvature of the term structure', *Review of Quantitative Finance and Accounting*, 33: 1-26.

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.

Eckert, J., Gatzert, N., & Martin, M. (2016). 'Valuation and risk assessment of participating life insurance in the presence of credit risk.' *Insurance: Mathematics and Economics*, 71: 382-393.

EIOPA (2014), 'EIOPA Insurance stress test 2014', November 2014, https://www.eiopa.europa.eu/insurance-stress-test-2014_en.

EIOPA (2016), '2016 EIOPA Insurance Stress Test Report', December 2016, https://www.eiopa.europa.eu/insurance-stress-test-2016_en.

EIOPA (2017), 'Investment behavior report', November 2017, https://register.eiopa.europa.eu/Publications/Reports/Investment_behaviour_report.pdf.

EIOPA (2018), 'Failures and near misses in insurance - Overview of the causes and early identification', July 2018, https://www.eiopa.europa.eu/media/news/eiopa-examines-causes-of-insurers%E2%80%99-failures-and-near-misses_en.

EIOPA (2019), 'Report on insurers' asset and liability management in relation to the illiquidity of their liabilities', December 2019, https://www.eiopa.europa.eu/publications/insurers-asset-and-liability-management-relation-illiquidity-their-liabilities_en.

EIOPA (2020a), 'European Insurance Overview 2020', October 2020, https://www.eiopa.europa.eu/publications/european-insurance-overview-2020_en.

EIOPA (2020b), 'EIOPA Financial Stability Report December 2019', January 2020, https://www.eiopa.europa.eu/publications/eiopa-financial-stability-report-december-2019_en.

EIOPA (2021), 'Insurance statistics', https://www.eiopa.europa.eu/tools-and-data/insurance-statistics_en.

Eling, M., Holder, S. (2013a), 'Maximum Technical Interest Rates in Life Insurance in Europe and the United States: An Overview and Comparison', *The Geneva Papers on Risk and Insurance - Issues and Practice*, 38 (2): 354-375.

Eling, M., Holder, S. (2013b), 'The value of interest rate guarantees in participating life insurance contracts: Status quo and alternative product design', *Insurance: Mathematics and Economics*, 53 (3): 491-503.

ESRB (2015), 'Issues note on risks and vulnerabilities in the EU financial system', ESRB Issues Note / June 2015, European Systemic Risk Board.

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.

Fama, E., French, K. (1992), 'The Cross-Section of Expected Stock Returns', *The Journal of Finance*, 47 (2): 427-465.

Flannery, M. J., James, C. M. (1984), 'The effect of interest rate changes on the common stock returns of financial institutions', *The Journal of Finance,* 39 (4): 1141–1153.

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.

Frydman, C.,Wang, B. (2020), 'The Impact of Salience on Investor Behavior: Evidence from a Natural Experiment', *The Journal of Finance*, 75 (1): 229-276

Gatzert, N., Heidinger, 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.

Giot, P. (2005), ‘Relationship Between Implied Volatility Indexes and Stock Index Returns’, *The Journal of Portfolio Management,* 31 (3): 92-100.

Greenwood, R., Vayanos, D. (2010) ‘Price pressure in the government bond market’, *American Economic Review,* 100 (2): 585-590.

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.

Holsboer, J. H. (2000), ‘The Impact of Low Interest Rates on Insurers’, *The Geneva Papers on Risk and Insurance - Issues and Practice,* 25 (1): 38-58.

Holzmüller, I. (2009), ‘The United States RBC standards, Solvency II and the Swiss Solvency Test: a comparative assessment’, *The Geneva Papers on Risk and Insurance - Issues and Practice,* 34 (1): 56-77.

Hombert, J., Lyonnet, V. (2017), ‘Intergenerational risk sharing in life insurance: Evidence from France’, Working Paper, HEC Paris.

Insurance Europe (2019), ‘European Insurance in Figures – 2017 data’, Brussels, March 2019, https://www.insuranceeurope.eu/publications/464/european-insurance-in-figures-2017-data/.

Kablau, A. and M. Weiß (2014) ‘How is the low-interest-rate environment affecting the solvency of German life insurers?’, Deutsche Bundesbank Discussion Paper 27/2014.

Kessler, D., de Montchalin, A., Thimann, C. (2017), ‘The Macroeconomic Role of Insurance’, in: Hufeld, F., Koijen, R. S. J., Thimann, C. (Eds.)*, The Economics, Regulation, and Systemic Risk of Insurance Markets,* Oxford University Press, Oxford, Ch. 2: 20-54.

Killins, R. N., and Chen, H. (2022), ‘The impact of the yield curve on the equity returns of insurance companies’, *International Journal of Finance & Economics*, 27 (1): 1134-1153.

Kim J. H., Shamsuddin A., Lim K.-P. (2011), ‘Stock return predictability and the adaptive markets hypothesis: Evidence from century-long U.S. data’, *Journal of Empirical Finance,* 18 (5): 868-879.

Koijen, R. S. J., & Yogo, M. (2015). The cost of financial frictions for life insurers, *American Economic Review*, 105 (1): 445-475.

Koijen, R. S. J., Yogo, M. (2022). 'The fragility of market risk insurance', *The Journal of Finance*, 77 (2): 815-862.

Kubitza, C., Grochola, N., Gründl, H. (2023), 'Life insurance convexity', ECB Working Paper Series No. 2829.

Liu, H. H., Chang, A., Shiu, Y. M. (2020), 'Interest rate derivatives and risk exposure: Evidence from the life insurance industry', *The North American Journal of Economics and Finance*, 51.

Lorson, J., Schmeiser, H., Wagner, J. (2012), Evaluation of Benefits and Costs of Insurance Regulation – A Conceptual Model for Solvency II, *Journal of Insurance Regulation*, 31 (1): 125-156.

Mech, T. (1993), 'Portfolio return autocorrelation', *Journal of Financial Economics*, 34 (3): 307-344.

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

Moody's (2015), 'Low Interest Rates are Credit Negative for Insurers Globally, but Risks Vary by Country', Global Insurance Themes, Moody's Investors Service, March 2015.

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.

NAIC (2013), 'Update on Insurance Industry Investment Portfolio Asset Mixes', Capital Markets Special Report, https://naic.soutronglobal.net/Portal/Public/en-US/RecordView/Index/23705.

NAIC (2016a), 'Year-End 2015 Foreign Exposure in the U.S. Insurance Industry', Capital Markets Special Report, https://content.naic.org/sites/default/files/capital-markets-special-report-foreign-exposure-2015.pdf.

NAIC (2016b), 'U.S. Insurance Industry Cash and Invested Assets at Year-End 2015', Capital Markets Special Report, https://content.naic.org/sites/default/files/capital-markets-special-report-cash-invested-assets-2015.pdf.

NAIC (2017a), 'Year-End 2016 U.S. Insurance Industry's Exposure to the Financial Sector', Capital Markets Special Report, https://content.naic.org/sites/default/files/capital-markets-special-report-industy-exposure-financial-sector.pdf.

NAIC (2017b), 'U.S. Insurance Industry Cash and Invested Assets at Year-End 2016', Capital Markets Special Report, https://content.naic.org/sites/default/files/capital-markets-special-report-cash-invested-assets-2016.pdf.

NAIC (2021), 'U.S. Insurance Industry's Cash and Invested Assets Continue to Grow Amid the Pandemic', Capital Markets Special Report, https://content.naic.org/sites/default/files/capital-markets-asset-mix-ye-2020-final.pdf.

Ozdagli, A. and Wang, Z. K. (2019), 'Interest rates and insurance company investment behavior', Working Paper.

Park, J., Choi, P. B. (2011), 'Interest rate sensitivity of US property/liability insurer stock returns', *Managerial Finance,* 37: 134-150.

Siglienti, S. (2000), 'Consequences of the reduction of interest rates on insurance', *The Geneva Papers on Risk and Insurance - Issues and Practice,* 25: 63–77.

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

Zimmer, A., Schade, C., Gründl, H. (2009), 'Is Default Risk Acceptable When Purchasing Insurance? Experimental Evidence for Different Probability Representations, Reasons for Default, and Framings', *Journal of Economic Psychology,* 30 (1): 11-23.

Zimmer, A., Gründl, H., Schade, C., Glenzer, F. (2018), 'An Incentive-Compatible Experiment on Probabilistic Insurance and Implications for an Insurer's Solvency Level', *Journal of Risk and Insurance*, 85 (1): 245-273.