The Influence of Negative Interest Rates on Life Insurance Companies

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Abstract

Between 2016 and 2022, life insurers in several European countries experienced negative long-term interest rates, which put pressure on their business models. The aim of this paper is to empirically investigate the impact of negative interest rates on the stock performance of life insurers. To measure the sensitivities, I estimate the level, slope, and curvature of the yield curve using the Nelson-Siegel model and empirical proxies. Panel regressions show that the effect of changes in the level is up to three times greater in a negative interest rate environment than in a positive one. Thus, a 1ppt decline in long-term interest rates reduces the stock returns of European life insurers by up to 10ppt when interest rates are below 0%. I also show that the relationship between the level and the sensitivity to interest rates is convex, and that life insurers benefit from rising interest rates across all maturity types.

Keywords: Life insurance, interest rate risk, negative interest rates

JEL Classification: G01, G18, G22

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1 Introduction

In an effort to stimulate the economy, central banks around the world lowered key interest rates between 2008 and 2022. The monetary policy decisions have resulted in bond yields falling below zero in many countries. In the Euro area, 1-year interest rates turned negative for the first time in mid-2014.[1] The trend has continued, so that 10-year government bond rates were negative in 58% of European countries between 2016 and 2022.[2] In order to protect the economy from the adverse effects of the Covid-19 pandemic, key interest rates were kept at low levels until rising inflation led to a paradigm shift in 2022. The objective of this paper is to empirically examine the relationship between interest rates and the stock performance of insurance companies in a low and negative interest rate environment.

As documented in previous research, low interest rates are putting life insurers globally under severe pressure (cf. Hartley et al. (2017), Koijen and Yogo (2022), Grochola et al. (2023)). Interest rate risk has a manifold impact on insurers' performance, stemming from depreciations and appreciations of bond investments, but also from the insurers' liability portfolios. Life insurers are particularly affected by falling interest rates for two reasons. First, because of ex ante investment guarantees to policyholders. These are annual returns promised at the inception of the contract and paid out at the end.[3] To achieve previously guaranteed returns on capital markets, insurers increase the riskiness of their investments (cf. European Insurance and Occupational Pensions Authority (EIOPA) (2017))[4] and thus have to set aside higher capital requirements. Consistent with this theory, Becker and Ivashina (2015) show that insurers with higher capital reserves tend to "reach for yield". Second, insurers are exposed to interest rate risk due to the longer duration of liabilities compared to assets (cf. EIOPA (2014)). Because of this common negative duration gap, falling interest rates affect the liability side of an insurer's balance sheet more than the asset side. Again, the resulting effect is an increase in regulatory capital requirements and a decrease in solvency ratios.

[1] According to the European Central Bank (ECB), the 1-year interest rate (based on AAA-rated Euro area sovereign debt) was negative for the first time on 11 June 2014. The rate did not turn positive until 6 June 2022.

[2] Long-term interest rates were negative, at least temporarily, in 15 out of 26 European countries and for periods of up to six years, as illustrated in Figures A1 and A2 in Appendix I.

[3] The share of insurance products with guarantees is over 70% in Germany, Sweden, and Denmark (cf. European Systemic Risk Board (ESRB) (2015), and at least 60% in the U.S., Canada, China, Japan, South Korea, France, Italy, Spain, Switzerland, and Norway (cf. Moody's (2015)).

[4] Low-risk, long-term fixed income securities are not yielding high enough returns to cover the annual guarantees promised in the 2000s. While most of the corresponding assets have matured, several policies are still in force. Antolin et al. (2011) call the phenomenon of increasing investment risk "gambling for redemption". Insurers' investment returns are below the average guaranteed rates in many European countries (cf. EIOPA (2019)), thereby leaving no safety margin (cf. Grosen and Jørgensen (2000)).

Related articles have identified several sources of interest rate risk. First, changes in interest rates – typically measured by the holding period return – affect the performance of insurers. Building on Brewer et al. (2007), Grochola et al. (2023) show that U.S. and European insurers suffered significantly from falling interest rates between 2012 and 2018. Second, according to Killins and Chen (2022), changes in the slope of the yield curve lead to fluctuations in insurers' stock prices. U.S. insurers benefited significantly from a negative slope between 2000 and 2019. Third, changes in the curvature of the yield curve affect the sensitivity of insurers' stock returns, as shown by Czaja et al. (2009). Between 1974 and 2002, the level and the curvature are negatively related to German insurers' stock returns, while the slope has no significant effect. Fourth, the level of interest rates significantly influences life insurers' surrender rates (cf. Kubitza et al. (2023)). Akhtaruzzaman and Shamsuddin (2017) combine the last three mentioned sources of interest rate risk and find that Australian insurers' equity returns are affected by changes in the level, slope, and curvature between 1993 and 2011.

This paper's focus on negative interest rates is motivated by the heterogeneous development of interest rates globally[5] and by previous empirical evidence. Klein (2020) shows that the impact of short-term interest rate movements on the net interest rate margin of European banks is 2.7 times larger when yields are negative. For a sample of Japanese life insurers, Lin et al. (2022) find that the sensitivity of the annual return on assets to interest rates is 6.8 times greater in a negative interest rate environment than in a positive one. The question arises how much European insurers can learn from the Japanese sample, where life insurers faced the challenges associated with low interest rates relatively early on (cf. Figure A3). Although U.S. interest rates have never been as low as in Japan, Berends et al. (2013) and Hartley et al. (2017) show that the effect of interest rate changes on U.S. life insurers' stock returns is larger in the low interest rate environment after 2008 than in earlier years. These findings suggest that insurers' sensitivity to interest rates increases as the level of interest rates falls.

In this paper, I combine research on the sources of interest rate risk with an analysis of the impact of negative interest rates on life insurers. I focus on European insurers, for whom negative yields became increasingly common in the late 2010s and early 2020s. The approach is novel in two respects. First, to the best of my knowledge, no previous empirical work analyzing the sensitivity of insurers to the three yield curve factors (level, slope, and curvature)

[5] As shown in Figure A3 in Appendix I, Japanese 10-year government bond rates were already close to 1% in 2001. At that time, 10-year government bond rates in the U.S. and Germany were above 5% and only began to decline after the global financial crisis in 2008. Presumably due to the ECB's asset purchase program, German interest rates have fallen more sharply than U.S. rates and were below Japanese rates in 2019.

has considered a sample period with negative interest rates. Second, there is so far no evidence on the impact of slope and curvature movements on a broad sample of European insurers.

I collect daily interest rate data from January 2006 to March 2022, a period with both positive and negative interest rates. To estimate the yield curve factors, I use two approaches: empirical proxies and the Nelson-Siegel model. Using panel regressions, I examine the impact of changes in the level, slope, and curvature on the stock returns of 60 European insurers, focusing on negative interest rates and on life insurers. Stock returns are used as a measure of insurers' risk exposure, following Brewer et al. (2007) and Carson et al. (2008). I use insurer fixed effects and control for stock markets, inflation, GDP growth, and several firm characteristics.

The regression results show that changes in the entire term structure of interest rates have an impact on the stock returns of European life insurers. Over the sample period, insurers benefit significantly from an increasing level of the yield curve, a falling slope, and a rising curvature. As the yield curve is mostly upward sloping over the sample period, the results suggest that insurers benefit from rising interest rates across all maturity types. Moreover, the sensitivity of insurers' stock returns to changes in the level increases significantly when rates are below 0%. The influence of a 1 percentage point (ppt) overall decline in interest rates is up to three times greater for life insurers in a negative (10.2ppt decline) than in a positive yield environment (3.4ppt decline). Further analysis indicates that the relationship between the level of interest rate and the interest rate sensitivity of life insurers is convex, meaning that the impact of changes in the level increases substantially as the level falls. In terms of the exposure to the slope and curvature factor, there is no additional statistically robust effect of negative interest rates. The results are robust to the use of orthogonalized independent variables and the Svensson model.

Research on negative interest rates is relevant to managers, shareholders, and regulators. At the industry level, asset-liability management (ALM) tools protect insurers from market risks. Since I show that life insurers' interest rate sensitivities are significantly higher when interest rates are negative, it is critical that in some jurisdictions, such as the U.S., insurers' risk management and solvency regulation are not prepared for such scenarios (cf. Alberts (2020)).[6] Indeed, the assumptions of ALM measures such as the Macaulay duration are not valid for negative yields (cf. Lin et al. (2022)). The empirical results of this paper underscore the need to implement ALM measures when dealing with interest rates below 0%. For insurers'

[6] The question of how far interest rates can fall has been discussed in previous papers. Schlütter (2021) introduce an adjustment to the Nelson-Siegel model by setting a lower bound on interest rates, arguing that high negative interest rates are inappropriate from an economic perspective. Earlier, Christensen and Rudebusch (2015) even adjusted the Nelson-Siegel model in a way that excludes the possibility of negative nominal interest rates.

shareholders, such insights are crucial to anticipate the stock market effects of yield curve movements. They can leverage this information when designing investment portfolios or implementing hedging strategies. Regulators also benefit from the research, because authorities can better understand the long-term consequences of monetary policy measures on insurers' performance, as quantitative easing programs lead to lower long-term interest rates (cf. Pelizzon and Sottocornola (2018)). Given the results of this paper, regulators can better design frameworks to protect the industry and policyholders from adverse effects.

Preventive measures are particularly important given the consequences of negative interest rates for banks, as described by Heider et al. (2019) and Eggertsson et al. (2023). The authors show that after 2014, banks increased the riskiness of their loans while lending less overall, because they were unwilling to pass on negative deposit rates to customers. Consistent with this theory, Abadi et al. (2023) argue that monetary policy is less effective when interest rates are negative, while Ulate (2021) quantifies that the effectiveness is indeed only 60 to 90 percent compared to positive interest rates. Altavilla et al. (2022) find that banks transmit negative rates to firms (rather than households), which then reduce the amount of liquid assets they hold. Arguably, a transmission of negative interest rates may not be feasible for life insurers, as negative guaranteed returns would be unattractive to policyholders, even relative to holding cash.

The remainder of this paper is organized as follows. Section 2 describes the methodology by presenting the data, the two approaches to estimating yield curve factors, and the empirical models. Section 3 presents the regression results and robustness tests. Section 4 concludes.

2 Methodology

2.1 Data

To construct the interest rate variables, I use spot rates of AAA-rated Euro area government bonds from the ECB (2023). The spot rates refer to a changing composition of government debt to ensure a consistently high credit quality throughout the sample period. The shortest observed maturities are 3, 6, and 9 months. Thereafter, spot rates are available for maturities of all full years from 1 to 30 years. I collect daily interest rate data for all 33 time series for the period from January 2, 2006 to March 31, 2022, covering 4,152 trading days. Table 1 presents descriptive statistics of interest rates for selected maturities. On average, interest rates are higher as the time to maturity increases, implying an upward sloping yield curve. Notably, long-term rates are more volatile than short-term rates, while the autocorrelation coefficients $\hat{\rho}$ show that long-term rates are more persistent over 1-month and 1-year periods.

	Mean	Median	SD	Min	Max	$\hat{\rho}$(1 day)	$\hat{\rho}$(1 mth)	$\hat{\rho}$(1 yr)	$\hat{\rho}$(10 yr)
Interest rate maturity (years)									
0.25	0.480	0.022	1.506	-0.930	4.325	1.000	0.989	0.734	-0.288
1	0.544	-0.016	1.578	-0.913	4.540	1.000	0.989	0.754	-0.302
2	0.659	0.043	1.610	-0.971	4.714	1.000	0.988	0.790	-0.335
3	0.799	0.199	1.628	-1.002	4.738	1.000	0.989	0.814	-0.362
5	1.116	0.655	1.652	-0.996	4.730	1.000	0.990	0.840	-0.397
10 = Level L_t	1.777	1.751	1.687	-0.815	4.776	1.000	0.990	0.857	-0.429
15	2.126	2.367	1.691	-0.628	4.872	1.000	0.990	0.856	-0.432
20	2.277	2.565	1.670	-0.515	4.985	1.000	0.989	0.851	-0.428
30	2.341	2.468	1.606	-0.432	5.175	0.999	0.986	0.839	-0.414
Yield curve factors (empirical & Nelson-Siegel (NS))									
Slope S_t	1.296	1.105	0.926	-0.073	3.538	0.999	0.975	0.570	-0.292
Curvature C_t	-0.939	-1.003	0.629	-2.186	0.686	0.996	0.938	0.569	-0.147
L_t (NS)	2.849	3.404	1.642	-0.219	5.546	0.999	0.984	0.830	-0.412
S_t (NS)	2.459	2.412	1.329	0.360	5.248	0.999	0.976	0.583	-0.266
C_t (NS)	-1.586	-1.920	1.294	-4.272	1.938	0.995	0.899	0.486	-0.179

Note: The table shows statistics for daily European spot rates of different maturities and for yield curve factors over the sample period from January 2006 to March 2022. The last four columns show the autocorrelation with lags of one day, one month (22 trading days), one year (257 trading days), and 10 years (2570 trading days). Data source: ECB (2023).

Table 1: Descriptive statistics of interest rates and yield curve factors

The historical development of interest rates with selected maturities is plotted in Figure 1. The range between long-term and short-term rates is relatively small at the beginning of the sample period and increases after the financial crisis in 2008. From then on, interest rates fall for the most part (with a temporary rise prior to the European sovereign debt crisis in 2011), until yields begin to rise in 2022 in response to high inflation rates. Interest rates are temporarily negative for all maturities, but for different periods. The 1-year rate has the highest share of observations below 0% (47.26%), while the 30-year rate has the lowest share (4.61%).

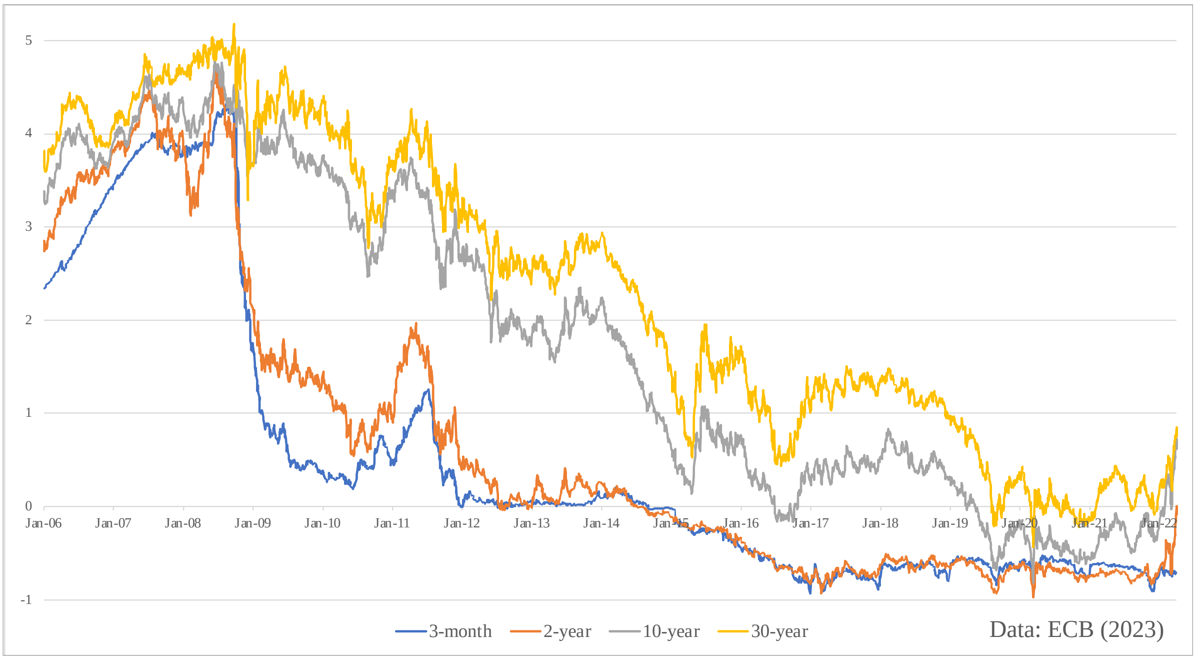

Figure 1: Time series of interest rates with different maturities

Figure 2 depicts the 50% interval of interest rate observations for all maturities in the gray area. While the median yield curve (middle line) is positive for all maturities, the 25th percentile (bottom curve) is negative for maturities up to 7 years. The yield curve is mostly convex and rising at short maturities and concave at long maturities, with little change above 15 years.

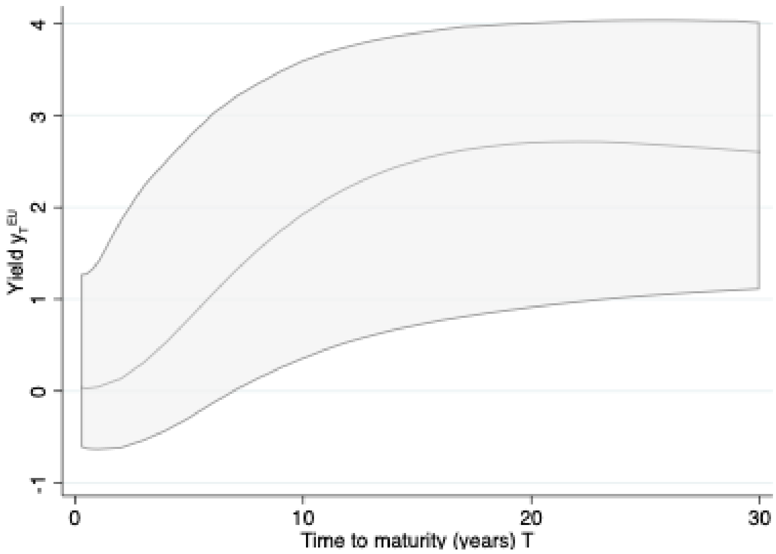

Figure 2: 50% interval of the yield curve

Over the sample period, the yield curve has different shapes, as illustrated by the observations (blue dots) in Figure A4 and by the fitted yield curves (red lines) based on the Nelson-Siegel factors specified in Section 2.3. While the yield curve is mostly concave and rising before the financial crisis (Figure A4a), it is temporarily relatively flat (with a difference between short- and long-term rates below 1ppt) and peaks in September 2008 with rates above 5% for 20-year maturities (A4b). Shortly afterwards, 1-year interest rates fell from above 4% to below 1% in fewer than six months (A4c). In the following years, rates at all maturities have mostly fallen, while the shape is declining at long maturities (A4d). 3-month rates turned negative in December 2011, and by August 2019 yields were negative for all maturities (even below −0.40% in March 2020, see A4e). From early 2022, interest rates started to rise again, leaving only yields for maturities up to two years in negative territory (A4f).

Daily stock data is collected from Refinitiv for 60 European insurers with a market share of 66.5% compared to EIOPA (2023) data.[7] Stock returns are calculated using the total return index (TRI).[8] The sample of insurers from 19 countries is shown in Table A1 in Appendix II.

[7] In the latest EIOPA release which includes U.K. insurers, total assets are reported at €13.125 trillion. Excluding Swiss insurers, which are not part of the EIOPA's releases, total assets in this sample are €8.727 trillion in 2020.
[8] Unlike the stock price, the TRI is not affected by dividends or a changing number of shares outstanding. For the empirical analysis, stock returns and index returns are winsorized at the 0.5% and 99.5% quantiles. Thus, extreme outliers below (above) these quantiles are set to the 0.5% quantile (99.5% quantile). Observations are removed if the stock price is unchanged for at least three consecutive days, as this signals erroneous data.

2.2 Empirical estimation of yield curve factors

By analyzing movements in the term structure of interest rates, Littermann and Scheinkman (1991) and Bliss (1997) show that parallel shifts are the most relevant determinant of changes in the yield curve. However, in addition to the level of interest rates, the authors of both papers find that the slope and the curvature are two other relevant factors. In order to calculate the three components of the yield curve, there are different approaches in the literature, such as empirical proxies and parsimonious models. Figure 3 provides a sketch of an exemplary concave yield curve to illustrate an empirical measure of the level, slope, and curvature.

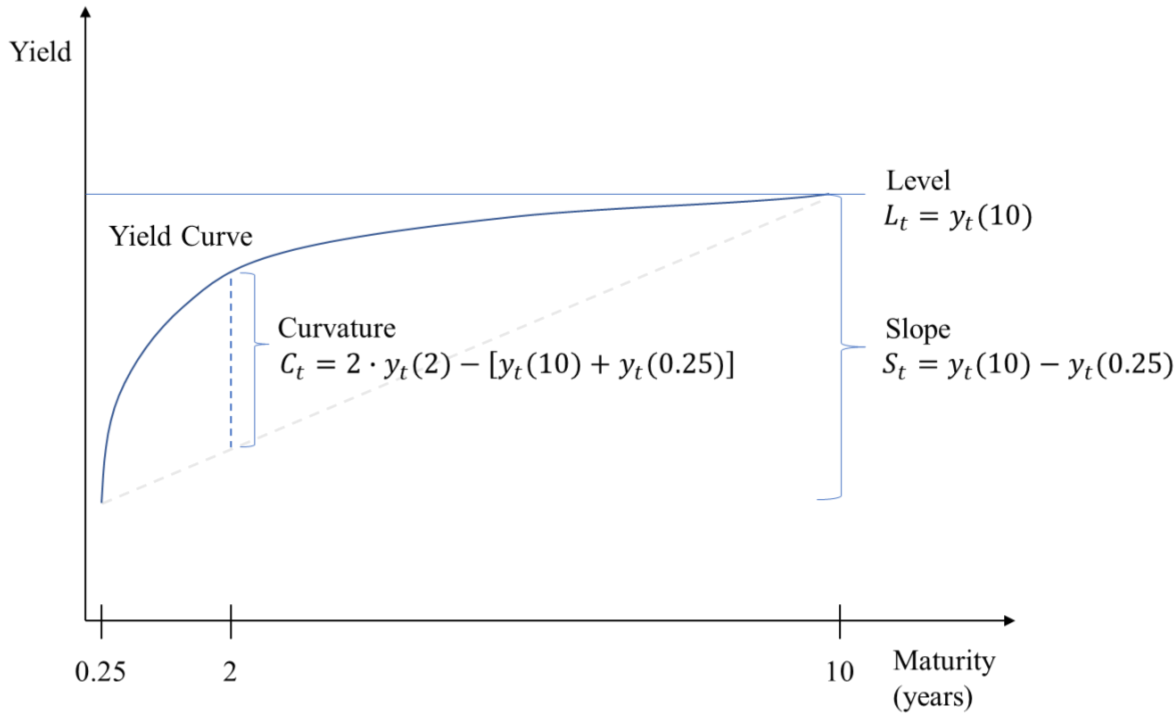

Figure 3: Sketched yield curve with empirical calculations of level, slope, and curvature

First, the level of the term structure is defined as the 10-year interest rate, in line with Diebold and Li (2006) and Kubitza et al. (2023). According to Afonso and Martins (2012), the level reflects the long end of the yield curve and is related to the inflation rate. Second, the slope is measured as the difference between the long-term (here: 10-year) and the short-term (here: 3-month) interest rate. When the level is controlled for in an empirical model (i.e., when the 10-year interest rate is held constant), the slope shows the sensitivity to short-term interest rates. From a macroeconomic perspective, the slope reflects monetary policy rates. Third, the curvature represents the difference between the point at which a concave yield curve begins to flatten and a hypothetical linearly increasing yield curve. Thus, the curvature should be zero if the yield curve is linear. Following Diebold and Li (2006) and Akhtaruzzaman and Shamsuddin (2017), I calculate the curvature as two times the 2-year interest rate minus the sum of the 10-

year and 3-month rates. The empirical proxy for the curvature is large when there is a steep rise in the yield curve for maturities between 3 months and 2 years, followed by a flat or falling yield curve. Economically, the curvature signals whether the market rather values short- or long-term interest rates more, depending on the position of the hump in the yield curve (cf. Afonso and Martins (2012)). The statistics for the empirical proxies are reported in Table 1. The slope is consistently positive, except for five days in the sample. Instead, the curvature is mostly negative (90% of observations), implying that the yield curve is typically convex at short maturities. This is also reflected in the median yield curve in Figure 2. The level factor has the highest standard deviation, followed by the slope and the curvature.

I consider other empirical proxies for the level, slope, and curvature for a robustness test. Since the business model of life insurers is based on long-term policies, they typically have a duration of assets and liabilities exceeding 10 years.[9] Life insurers are also reported to invest in "ultra-long" bonds with maturities over 20 years.[10] Yields above 10 years are therefore relevant to life insurers' business models. Using the full range of interest rate data published by the ECB (2023), I choose 30-year rates as an alternative specification of the interest rate level. The slope is then measured as the difference between 30-year and 3-month rates, which is closer to Frankel and Lown's (1994) definition of the slope as infinite maturity rates minus zero maturity rates. I specify the curvature as twice the 4-year rate minus the sum of the 30-year and 3-month interest rates. The results of this paper are robust to this specification, as well as to other definitions of empirical proxies used in the literature.[11]

2.3 Nelson-Siegel yield curve factors

Theoretical estimates of the level, slope, and curvature have been presented in previous literature. Nelson and Siegel (1987) introduce a parsimonious model to describe non-linear term structures. Diebold and Li (2006) show that the three factors can be interpreted as the level, slope, and curvature of the yield curve. Czaja et al. (2009) argue that the Nelson-Siegel framework provides an appropriate approach to estimating firms' interest rate exposures because the factors take into account the entire shape of the yield curve, unlike the previously

[9] EIOPA (2019) estimates the modified duration of European life insurers' liabilities at 14 years. Using a sample of German life insurers, Möhlmann (2021) estimates an average asset duration of 12.6 years and an average liability duration of 16.9 years in 2018. Domanski et al. (2017) argue that the liability duration of German life insurers even increased to 25.2 years in 2014 due to the ECB's quantitative easing. EIOPA (2014, p. 121) illustrates the average asset and liability duration at the country level, but including non-life insurers.

[10] Insurers hold nearly 40% of all ultra-long bonds in Germany, while banks and other monetary financial institutions hold less than 10% (cf. Shin (2017)).

[11] Killins and Chen (2022) use the 20-year and 3-month interest rate as further proxies for the long and short end of the yield curve. Afonso and Martins (2012) use the 4-year rate instead of the 2-year rate to estimate the curvature.

discussed empirical proxies that are calculated using interest rates at three maturities only. The Nelson-Siegel factors are widely used in practice (cf. Bank for International Settlements (BIS) (2005)) and in theoretical work on measuring insurers' interest rate risk (e.g., Schlütter (2021)). The spot rates y for day t and maturity T are estimated accordingly:

$$y_t(T) = L_t + S_t \frac{1 - e^{-T/\tau_t}}{T/\tau_t} + C_t \left(\frac{1 - e^{-T/\tau_t}}{T/\tau_t} - e^{-T/\tau_t} \right) \quad (1)$$

where L_t, S_t and C_t are the factors (beta coefficients of OLS regressions) defined as level, (negative) slope, and curvature. Following Diebold and Li (2006), the corresponding loadings and their relationship with the time to maturity T are presented in Figure 4 and interpreted below. The level L_t (blue line) has a constant loading of one which is independent of the maturity T. It can be defined as a long-term factor, since it has the only loading not equal to zero as T goes to infinity. The slope S_t (red line) corresponds to a short-term factor, since its loading of $\frac{1-e^{-T/\tau_t}}{T/\tau_t}$ gradually decreases from one to zero as the maturity T increases. Thus, $S_t = y_t(0) - y_t(\infty)$, which can be defined as the slope of the yield curve times -1 (cf. Frankel and Lown (1994)). The curvature C_t (green line) has a loading of $\frac{1-e^{-T/\tau_t}}{T/\tau_t} - e^{-T/\tau_t}$, which is positive only for maturities T between 0 and ∞, and zero otherwise. Thus, the curvature can be interpreted as a medium-term factor. The fourth factor shown in Figure 4 (yellow line) is used in a robustness test for the Svensson model. It is equivalent to a second curvature factor.

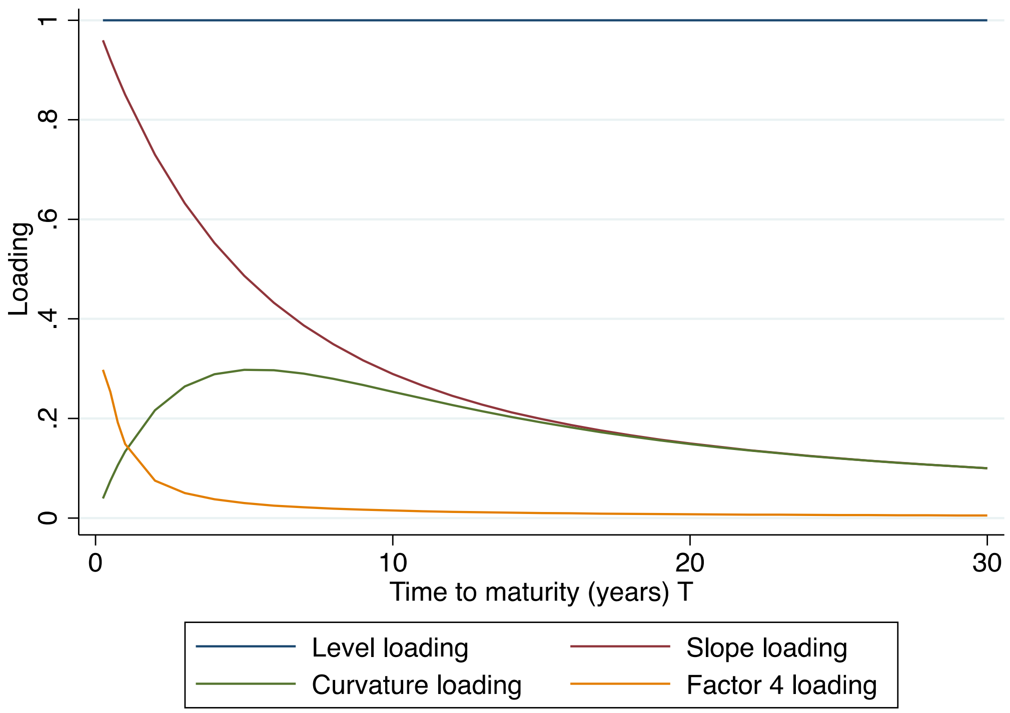

Figure 4: Loadings of the factors in the Nelson-Siegel model from Equation (1)

The rate at which the slope and curvature loadings fall to zero depends on a parameter τ_t. Thus, τ_t is an exponential decay rate. In addition, τ_t determines the maturity at which the curvature loading reaches its maximum (here: 5 years). Since the estimated Nelson-Siegel factors are largely insensitive to the decay parameter τ_t (i.e., spot rates are mainly driven by the beta parameters, cf. Willner (1996)), I choose to fix τ_t at a constant rate of 3, in line with Fabozzi (2005). Fixing τ_t is standard practice and allows for a consistent interpretation of the slope and curvature over the sample period (cf. Czaja et al. (2009)). For each day t in the sample, I run OLS regressions based on Equation (1) with the loadings as independent variables and the ECB spot rates for 33 different maturities as dependent variables. This provides daily Nelson-Siegel estimates of the level, slope, and curvature. Because the gaps between the observed maturities are not equal (cf. Figure A4), short-term interest rates have a slightly larger weight in the estimation of the fitted yield curve (cf. Diebold and Li (2006)).

Descriptive statistics for the Nelson-Siegel estimates are presented in Table 1. The Nelson-Siegel level factor and the empirical proxy for the level move similarly, with a correlation of 96.8%. For both estimation approaches, the slope factor is almost always positive, implying a rising yield curve. Again the correlation is very strong (95.6%). The curvature is negative on average, indicating a slowly increasing yield curve at lower maturities. However, the correlation of the two curvature estimates is only 12.8%, and the Nelson-Siegel factor is typically larger and more volatile than the empirical proxy. Consistent with Akhtaruzzaman and Shamsuddin (2017), I find that the difference between the two measures is strongest at peaks and troughs. The time series of the empirical and Nelson-Siegel estimates of the three yield curve factors over the sample period is plotted in Figure A5, Figure A6, and Figure A7.

A minor criticism of the Nelson-Siegel factors relates to the absence of a second hump in the yield curve, which can occur at maturities of 15 years and above. This can be seen in Figure A4c and A4d, where the fitted yield curve (red line) does not adequately reflect falling interest rates for maturities between 20 and 30 years. The lack of a second hump may be relevant for life insurers, as they invest a larger share of their assets in bonds with maturities at the long end of the yield curve. Nevertheless, for the main part of the paper, I follow the approach of Afonso and Martins (2012), who rely on three factors to describe the term structure of interest rates, instead of introducing a fourth factor. The reason for this is the relatively low liquidity of ultra-long bonds (cf. Afonso and Martins (2012)), the lack of an economic interpretation of a fourth factor due to the correlation with the curvature loading (cf. Gilli et al. (2010)) as well as unstable beta parameters (cf. Fabozzi et al. (2005)).

However, for a robustness check, I use the four-factor model introduced by Svensson (1994). The Svensson model extends the Nelson-Siegel model by a fourth factor with a loading equal to that of the curvature $\frac{1-e^{-T/\upsilon_t}}{T/\upsilon_t} - e^{-T/\upsilon_t}$, but with a different (second) decay parameter υ_t. Notably, when I do not fix the parameters τ_t and υ_t, but estimate them on a daily basis (like L_t, S_t, and C_t), they are almost identical for some days (e.g., τ_t =1.9182 and υ_t=1.9184). Such numerical difficulties are also pointed out by De Pooter (2007). Therefore, I keep the decay parameters constant as in the previous framework in Equation (1). The difference between τ_t and υ_t should then be large in order to avoid multicollinearity issues (cf. Lakhany et al. (2021)). Keeping $\tau_t = 3$ as before, I choose $\upsilon_t = 0.15$ because it provides a good fit to the data.

2.4 Empirical model

The baseline model in Equation (2) extends the empirical work of Czaja et al. (2009) and Akhtaruzzaman and Shamsuddin (2017). In a panel regression, the stock return $r_{i,t}$ of an insurer i on day t is estimated according to the following specification:

$$r_{i,t} = \alpha + \beta_1 \Delta L_t + \beta_2 \Delta S_t + \beta_3 \Delta C_t + \gamma M_{c(i),p} + \eta X_{i,y-1} + u_i + \varepsilon_{i,t} \qquad (2)$$

Where ΔL_t $(= L_t - L_{t-1})$ is the change in the level of interest rates, ΔS_t $(= S_t - S_{t-1})$ is the change in the slope[12], and ΔC_t $(= C_t - C_{t-1})$ is the change in the curvature. $M_{c(i),p}$ are macroeconomic control variables based on an insurer's home country $c(i)$ for returns of stock market indices $r_{m,c(i),t}$ and volatility indices $r_{v,c(i),t}$[13], inflation, GDP growth, and investment growth. The variables are available at different time levels p (either daily, monthly or quarterly) and are lagged if not available on a daily basis. $X_{i,y-1}$ are insurer-specific control variables lagged by one year $(y-1)$ for the share of life insurance and unit-linked business, size, leverage and the market-to-book ratio.[14] The control variables include the three risk factors introduced by Fama and French (1992). Summary statistics for all variables are presented in Table 2. u_i are insurer fixed effects and $\varepsilon_{i,t}$ is the error term. Standard errors are clustered at the time and insurer level to account for correlated shocks and autocorrelation.

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[12] Note that the estimated coefficient S_t from the Nelson-Siegel approach in Equation (1) is equal to the slope of the yield curve times -1 (i.e., the negative slope). For better comparison with the empirical proxies, I change the algebraic sign of the estimated Nelson-Siegel coefficients S_t from Equation (1) before calculating ΔS_t.

[13] For insurers from Slovenia and Malta, I use the Euro Stoxx 50 index due to the lack of daily data on national stock market indices. While I obtain national volatility index data for France, Germany, the Netherlands, Spain, Switzerland, and the U.K, I use the Euro Stoxx 50 Volatility index for the remaining countries. The stock market indices and volatility indices show a highly significant impact on stock returns.

[14] The definitions of all control variables are presented in Table A2 in Appendix II. If one of the insurer-specific control variables is not available in a given insurer-year, it is assumed to be constant with respect to the previous (or, if not available, the following) year. The results are robust to the exclusion of the corresponding observations.

	N	Mean	Median	SD	p1	p5	p95	p99
Insurer characteristics (insurer-day level in ppt)								
$r_{i,t}$ (stock return)	189,707	0.04	0.00	2.36	-6.15	-3.08	3.15	6.51
Insurer characteristics (insurer-year level)								
Life $\text{Share}_{i,y-1}$ (ratio)	863	0.37	0.41	0.27	0.00	0.00	0.81	0.88
Unit-linked $\text{Share}_{i,y-1}$ (ratio)	863	0.18	0.11	0.23	0.00	0.00	0.79	0.90
$\text{Leverage}_{i,y-1}$ (ratio)	863	0.94	0.39	2.51	0.00	0.00	3.45	12.23
$\text{Market-to-Book}_{i,y-1}$ (ratio)	863	1.75	1.13	2.10	0.21	0.46	4.79	8.74
$\ln(\text{Size}_{i,y-1})$	863	16.81	17.25	2.57	10.77	11.42	20.30	20.80
Macroeconomic characteristics (country level in ppt)								
$r_{m,c(i),t}$ (daily market return)	66,401	0.01	0.05	1.61	-4.48	-2.26	2.10	3.86
$r_{v,c(i),t}$ (daily volatility return)	20,854	0.29	-0.40	8.25	-14.37	-9.20	12.07	22.44
$\text{Inflation}_{c(i),mth-1}$ (monthly)	3,440	1.56	1.47	1.63	-2.11	-0.85	4.45	5.90
GDP $\text{growth}_{c(i),q-1}$ (quarterly)	1,160	0.37	0.47	2.46	-9.22	-2.07	2.38	11.31
Investment $\text{growth}_{c(i),q-1}$ (qtly.)	1,160	2.07	1.94	17.15	-30.21	-14.58	14.53	42.74
Interest rate variables (day level)								
ΔLevel_t (change in ppt)	4,152	-0.00	-0.00	0.04	-0.09	-0.06	0.06	0.10
ΔSlope_t (change in ppt)	4,152	0.00	-0.00	0.04	-0.10	-0.06	0.07	0.11
$\Delta\text{Curvature}_t$ (change in ppt)	4,152	-0.00	0.00	0.05	-0.14	-0.07	0.07	0.14
ΔLevel NS_t (change in ppt)	4,152	-0.00	-0.00	0.05	-0.15	-0.08	0.08	0.13
ΔSlope NS_t (change in ppt)	4,152	0.00	-0.00	0.05	-0.13	-0.08	0.09	0.15
ΔCurvature NS_t (change in ppt)	4,152	0.00	0.00	0.13	-0.34	-0.18	0.19	0.38
Negative_t (binary)	4,152	0.19	0.00	0.39	0.00	0.00	1.00	1.00
Low_t (binary)	4,152	0.17	0.00	0.37	0.00	0.00	1.00	1.00

Note: The stock return is at the insurer-day level and retrieved from Refinitiv. Other insurer characteristics are at the insurer-year level and obtained from SNL. Macroeconomic characteristics are partly at the country-day level and retrieved from Refinitiv (stock and volatility indices), partly at the country-month level and retrieved from the BIS (inflation), partly at the country-quarter level and retrieved from the OECD (GDP and investment growth), and partly at the day level and computed from ECB (2023) data (interest rate variables). The sample starts in January 2006 and ends in March 2022. It includes 60 European insurance companies.

Table 2: Descriptive statistics for insurer-level data and macroeconomic characteristics

To analyze how insurers' sensitivities to interest rate movements change when yields are negative, I introduce a binary variable N_t in Equation (3). N_t equals one if the level $L_t < 0$ on day t according to the empirical level proxy (i.e., the 10-year interest rate), and zero otherwise. By interacting N_t with ΔL_t, I test whether changes in the level of interest rates have a significantly stronger effect on insurers' stock returns when the level is negative. In this way, I combine the baseline model from Equation (2) with the ideas introduced by Lin et al. (2022), who distinguish the interest rate sensitivities of Japanese insurers in negative and positive interest rate environments. Similarly, I interact N_t with ΔC_t and ΔS_t to measure the additional effect of changes in the slope and the curvature of the yield curve when the level is negative. I control for the main effect N_t to measure ceteris paribus effects. This ensures that, for instance, β_4 in Equation (3) is driven by the interaction of ΔL_t and N_t and not just by the fact that the interest rate environment is negative. It follows:

$$r_{i,t} = \alpha + \beta_1 \Delta L_t + \beta_2 \Delta S_t + \beta_3 \Delta C_t + \beta_4 (\Delta L_t \cdot N_t) + \beta_5 (\Delta S_t \cdot N_t) + \beta_6 (\Delta C_t \cdot N_t) \quad (3)$$
$$+ \beta_7 N_t + \gamma M_{c(i),p} + \eta X_{i,y-1} + u_i + \varepsilon_{i,t}$$

I further adjust the model from Equation (3) by introducing the binary variable Low_t in Equation (4). Low_t equals one when the level is $0 \leq L_t < 0.5$ppt and zero otherwise. By interacting Low_t with the change in the level ΔL_t, I test whether insurers' sensitivity to interest rates already increases as soon as interest rates fall below 0.5%, and are thus close to being negative. I then observe how large the marginal effect of Low_t is relative to being in a negative interest rate environment (when $N_t = 1$). This approach of using another threshold in addition to 0% provides insight into whether negative interest rate movements have a greater impact on insurers than very low interest rates according to the perception of stock market participants.[15]

$$r_{i,t} = \alpha + \beta_1 \Delta L_t + \beta_2 \Delta S_t + \beta_3 \Delta C_t + \beta_4 (\Delta L_t \cdot N_t) + \beta_5 (\Delta S_t \cdot N_t) + \beta_6 (\Delta C_t \cdot N_t) + \beta_7 N_t + \beta_8 (\Delta L_t \cdot Low_t) + \beta_9 Low_t + \gamma M_{c(i),p} + \eta X_{i,y-1} + u_i + \varepsilon_{i,t} \quad (4)$$

As a robustness check, I run auxiliary regressions to obtain orthogonalized independent variables in line with Czaja et al. (2009). The main reason is that ΔL_t, ΔS_t and ΔC_t are correlated (cf. Table A5), and thus the effect of a single yield curve factor on stock returns cannot be completely ruled out. Even though the variance inflation factors (VIFs) for ΔL_t, ΔS_t and ΔC_t never exceed a value of 10, I follow the insights of Littermann and Scheinkman (1991) to address the potential econometric concern. The authors rank the relevance of yield curve factors for changes in the term structure of interest rates, describing the level as the most important, the slope as the second most, and the curvature as the least important of the three factors. Using auxiliary regressions, I first regress ΔS_t on ΔL_t to exclude the effect that a change in the level has on the slope of the yield curve. Then, I use the residuals ΔS_t^* as the orthogonalized variable instead of ΔS_t in Equation (3). Similarly, ΔC_t is replaced by ΔC_t^*, i.e., the residuals of an auxiliary regression of ΔC_t on ΔL_t and ΔS_t. Thus, ΔC_t^* excludes the effect of level and slope movements on the curvature. As a consequence, the preceding variables (here ΔL_t and ΔS_t) are weighted more heavily and their regression coefficients change. I also remove the effects of ΔL_t, ΔS_t and ΔC_t on the macro controls for stock market returns $r_{m,c(i),t}$ and volatility index returns $r_{v,c(i),t}$, because these variables are available on a daily basis and their effects on stock returns are highly significant. Equation (5) reads:

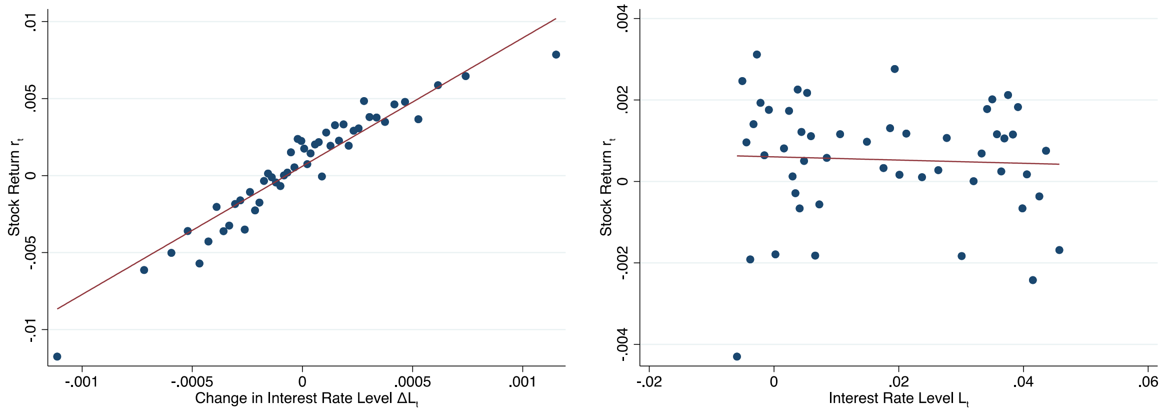
$$r_{i,t} = \alpha + \beta_1 \Delta L_t + \beta_2 \Delta S_t^* + \beta_3 \Delta C_t^* + \beta_4 (\Delta L_t \cdot N_t) + \beta_5 (\Delta S_t^* \cdot N_t) + \beta_6 (\Delta C_t^* \cdot N_t) + \beta_7 N_t + \gamma M_{c(i),p}^* + \eta X_{i,y-1} + u_i + \varepsilon_{i,t} \quad (5)$$

[15] Using higher thresholds in future research would allow for the inclusion of countries where interest rates have never been negative. For example, the U.S. Treasury Constant Maturity Rate has never been negative for any maturity, but the 1-month rate was 0% on 61 out of 2503 trading days between 2012 and 2022. Instead, the U.S. real (inflation-adjusted) interest rate was negative in January 2022 for all available maturities from 1 year to 30 years, according to Federal Reserve Economic Data (FRED).

3 Results

3.1 Relevance of yield curve factors

To show the relevance of the individual yield curve factors for stock returns, I refer to binned scatterplots and the empirical proxies for the level, slope, and curvature. Figure 5a) shows a strong positive linear relationship between changes in 10-year interest rates ΔL_t and insurers' stock returns $r_{i,t}$. The rising red line illustrates the predicted fit of a univariate OLS regression without controlling for other variables (i.e., in contrast to Equations (2)–(5)). It implies that, on average, stock returns are higher when interest rates rise. Figure 5b) depicts a much weaker correlation between the level of interest rates L_t (rather than changes) and insurers' stock returns $r_{i,t}$. Thus, Figure 5 emphasizes that changes in the level of interest rates are a more relevant source of interest rate risk than the actual level of interest rates.

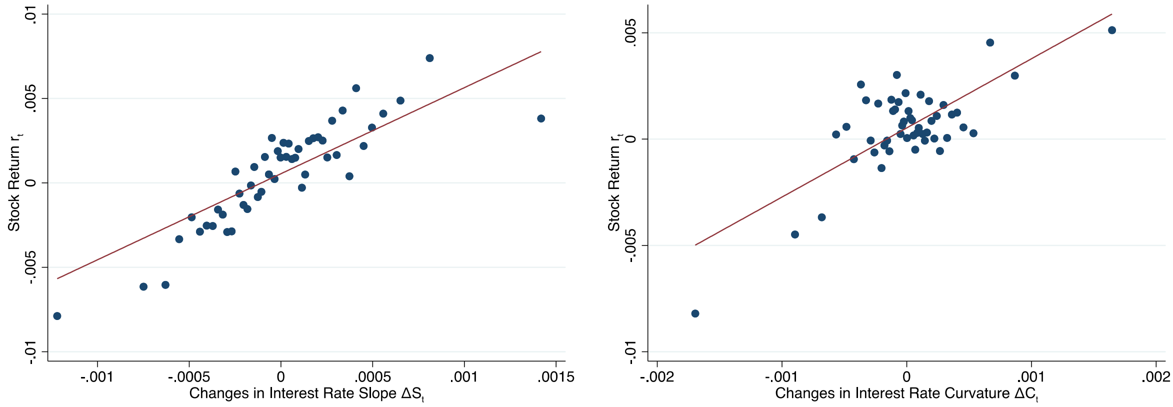


a) Changes in level *b) Level of interest rates*

Note: All observations of the variables on the x-axis are grouped into 50 equally sized bins. Each point represents the mean of the variable on the x-axis and the conditional mean of the insurers' stock returns r_t within each bin. The red line shows the best fit from a univariate linear OLS model.

Figure 5: Binned scatterplots of stock returns and interest rate levels

Moreover, Figure 6 plots the relationship between stock returns $r_{i,t}$ and changes in slope ΔS_t and curvature ΔC_t. At first glance, the red regression line in Figure 6a) suggests that insurers' stock returns are higher as the slope increases, i.e., when the spread between long- and short-term interest rates rises. However, as Section 3.2 will show, this is only true for a univariate OLS regression that does not include ΔL_t. Here, the positive relationship indicates that insurers value increases in long-term interest rates more than increases in short-term interest rates. Figure 6b) shows that, on average, stock returns are higher when the curvature of the yield curve increases. However, the fit of a univariate linear OLS regression model is less accurate compared to the level in Figure 5a) and the slope in Figure 6a). Also, the coefficient is smaller, suggesting that the curvature is less relevant for insurers' stock returns. Thus, the binned scatterplots confirm Littermann and Scheinkman's (1991) ranking of yield curve factors, with the level being the most relevant term structure component, followed by the slope and the curvature.



a) Changes in slope *b) Changes in curvature*

Note: All observations of the variables on the x-axis are grouped into 50 equally sized bins. Each point represents the mean of the variable on the x-axis and the conditional mean of the insurers' stock returns r_t within each bin. The red line shows the best fit from a univariate linear OLS model.

Figure 6: Binned scatterplots of stock returns and interest rate slopes and curvatures

3.2 Baseline model

The results for the panel regression model from Equation (2) are shown for two different approaches to estimating yield curve factors: the empirical proxies and the Nelson-Siegel model. For both approaches, I consider the influence of changes in the level, slope, and curvature on insurers' stock returns. The empirical results are also presented for two samples: First, a full sample of 60 stock listed insurers from 19 European countries. Second, a sample of 37 life insurers with at least 40% of their liabilities derived from life and health insurance reserves in the previous year. The second sample allows me to emphasize that the interest rate sensitivities of the full sample are mainly driven by firms that focus on life insurance business. Table 3 shows the regression coefficients and p-values (in parentheses) for the two different yield curve estimators and for both samples. As expected, the independent variables explain a larger share of the stock variation for life insurers (R^2=0.29) than for all insurers (R^2=0.24). This suggests that interest rates are perceived as a more relevant driver of the performance of life insurers than of non-life insurers, in line with the findings of Carson et al. (2008).

The results for the two samples show similar and highly significant regression coefficients for the influence of the yield curve factors on insurers' stock returns. For the level factor, a 1ppt increase (e.g., from 0% to 1% or from 2% to 3%) corresponds to a parallel upward shift of the yield curve, holding all other variables constant. It leads to an increase in stock returns of 3.4ppt for the full sample in columns (1) and (3) and up to 4.2ppt for life insurers in columns (2) and

(4). The level coefficients ΔL_t differ from those of Czaja et al. (2009) and Akhtaruzzaman and Shamsuddin (2017), who find a negative relationship between the level and insurers' stock returns. However, their analyses cover sample periods prior to the low interest rate environment starting in 2008,[16] after which the sensitivity of U.S. and European insurers' stock returns to interest rates begins to change, as shown by Hartley et al. (2017). In addition, Czaja et al. (2009) and Akhtaruzzaman and Shamsuddin (2017) argue that insurers have positive duration gaps (i.e., a larger average duration of assets relative to liabilities), while in 2013 the opposite is true for all European countries except the U.K. and Ireland (cf. EIOPA (2014)).

	(1)	(2)	(3)	(4)
Dependent variable:	$r_{i,t}$ (stock return)			
Yield curve estimation:	Empirical		Nelson-Siegel	
Sample:	Full	Life	Full	Life
ΔLevel_t	3.389***	4.189***	3.390***	4.101***
	(0.000)	(0.000)	(0.000)	(0.000)
ΔSlope_t	-1.561***	-1.829***	-2.062***	-2.335***
	(0.000)	(0.001)	(0.000)	(0.001)
$\Delta \text{Curvature}_t$	0.849***	0.865***	0.606***	0.710***
	(0.000)	(0.005)	(0.000)	(0.000)
Macro controls	Yes	Yes	Yes	Yes
Insurer controls	Yes	Yes	Yes	Yes
Insurer fixed effects	Yes	Yes	Yes	Yes
No. of obs.	189,707	102,690	189,707	102,690
No. of insurers	60	37	60	37
R^2	0.2368	0.2932	0.2366	0.2930
Adj. R^2	0.2365	0.2928	0.2363	0.2927

Note: Fixed effect regressions of insurer stock returns on yield curve factors from January 2006 to March 2022. Sources: Refinitiv (insurer-level daily stock returns measured using total return indices (TRI), country-level stock and volatility indices), ECB (daily interest rates), BIS (country-level monthly inflation), OECD (country-level quarterly GDP and investment growth), and SNL (insurer-level yearly life share, unit-linked share, leverage, size, and market-to-book ratio). Standard errors are clustered at insurer and day level. ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively. P-values are in parentheses.

Table 3: Regression results for Equation (2)

Consistent with the findings of Killins and Chen (2022) for U.S. insurers, I observe a negative relationship between European insurers' stock returns and changes in the slope of the yield curve ΔS_t. Holding the level – which reflects long-term interest rates – constant, insurers prefer rising short-term yields.[17] As the empirical proxy for the slope is negative on only 5 out of 4152 trading days, insurers benefit from a lower steepness, i.e., they prefer a relatively flat yield curve. A 1ppt increase in the slope factor significantly reduces insurers' stock returns by between 1.6ppt and 2.1ppt (columns (1) and (3)) and life insurers' stock returns by between 1.8ppt and 2.3ppt (columns (2) and (4)). An economic explanation is that short-term yields have

[16] Czaja et al. (2009) study the interest rate risk of insurers over the period from 1974 to 2002, while Akhtaruzzaman and Shamsuddin (2017) use a sample period from July 1993 to March 2011.

[17] Note that this finding underscores that changes in the level are more relevant than changes in the slope. Without controlling for the level, I find a positive relationship between the slope and stock returns (cf. Figure 6a)).

an effect on insurers that is similar to, but less impactful than that of long-term interest rates. Since insurers hold assets and contracts with all kinds of remaining maturities, they are also affected by movements in short-term rates. Killins and Chen (2022) explain the negative coefficients of the slope with a valuation effect due to lower capital reserve requirements and lower risk premiums associated with flat yield curves. Both channels should increase the stock returns of insurance companies. Another reason for the relevance of short-term interest rates presented by Akhtaruzzaman and Shamsuddin (2017), who however find a positive regression coefficient for the slope factor, is the use of interest rate derivatives to manage the duration gap.

In terms of the curvature, the regression coefficients ΔC_t show a significantly positive relationship with stock returns. Thus, insurers benefit from a steep rise in short-term interest rates followed by a relatively flat continuation of the yield curve at the long end. In other words, insurers prefer a yield curve that peaks at a relatively low maturity, thereby increasing the markets' emphasis on long-term rates. Since the yield curve is typically upward sloping over the sample period, the positive coefficient implies that insurers prefer a more concave shape of the yield curve. A 1ppt increase in the curvature factor increases European insurers' stock returns by between 0.61ppt and 0.85ppt (columns (1) and (3)). The average effects are slightly larger for life insurers. Again, the findings differ from the empirical results of Czaja et al. (2009) and Akhtaruzzaman and Shamsuddin (2017), who find negative or insignificant curvature coefficients. Because the level factor reflects long-term interest rates and the slope factor reflects short-term interest rates, the curvature factor shows the influence of medium-term interest rates. Thus, the coefficients of the three yield curve factors in Table 3 indicate that insurers benefit from rising interest rates across all maturity types: short, medium, and long.

3.3 Negative interest rate environment

In this section, I interact changes in the yield curve factors ΔL_t, ΔS_t, and ΔC_t with binary variables for negative (N_t) and very low interest rate environments (Low_t). Over the sample period (January 2006 to March 2022), 10-year interest rates are negative on 780 out of 4152 trading days. Thus, N_t equals one for 18.79% of all observations. As 10-year interest rates are between 0% and 0.5% for 687 trading days, Low_t equals one for 16.55% of all observations.

The results of the panel regressions based on Equation (3) and (4) are presented in Table 4. Two insights can be gained. First, the coefficients on the level factor have declined slightly relative to the results from Equation (2) in Table 3, so that in general, a 1ppt rise in the level increases insurers' stock returns by about 2.9% on average for the full sample and by 3.5% for life insurers (instead of 3.4% and 4.1%, respectively). Second, when long-term interest rates are negative, a change in the level has a significantly larger effect on stock returns. This can be seen from the coefficients of the interaction $\Delta L_t \cdot N_t$. The incremental effect on stock returns in the full sample is between 5ppt and 5.6ppt (columns (1) and (4)), implying that a 1ppt overall increase in interest rates in a negative yield environment leads to an average increase in stock returns of up to 8.5ppt (sum of 2.868 and 5.598). Presumably due to the consequences of negative duration gaps and guaranteed returns to policyholders, the effect is larger for life insurers. A 1ppt decrease in the level factor reduces life insurers' stock returns by up to 10.2ppt on average when 10-year interest rates are negative, holding other variables constant (column (5)). The empirical results confirm the findings of Lin et al. (2022) for Japanese insurers that interest rate sensitivity is higher in a negative than in a positive interest rate environment. However, the effect is relatively smaller in my regression model with the European sample, as the sensitivities are not 6.8 times higher when yields are negative, but between 2.58 and 2.99 times higher.[18]

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable:	$r_{i,t}$ (stock return)					
Yield curve estimation:	Empirical			Nelson-Siegel		
Sample:	Full	Life	Life	Full	Life	Life
ΔLevel_t	2.987***	3.675***	3.360***	2.868***	3.407***	3.231***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)
$\Delta\text{Level}_t \times \text{Negative}_t$	5.039*	5.814*	6.127**	5.598**	6.766**	6.945**
	(0.067)	(0.058)	(0.049)	(0.048)	(0.036)	(0.033)
ΔSlope_t	-1.433***	-1.618***	-1.670***	-1.797***	-1.919***	-1.954***
	(0.001)	(0.009)	(0.008)	(0.000)	(0.006)	(0.005)
$\Delta\text{Slope}_t \times \text{Negative}_t$	-2.883	-3.601	-3.548	-4.044	-5.120*	-5.088*
	(0.215)	(0.169)	(0.175)	(0.118)	(0.082)	(0.084)
$\Delta\text{Curvature}_t$	0.813***	0.813**	0.884***	0.586***	0.681***	0.675***
	(0.000)	(0.012)	(0.007)	(0.000)	(0.000)	(0.000)
$\Delta\text{Curvature}_t \times \text{Negative}_t$	1.963	2.017	1.946	0.199	0.290	0.297
	(0.138)	(0.203)	(0.219)	(0.646)	(0.520)	(0.511)
$\Delta\text{Level}_t \times \text{Low}_t$			2.061**			1.062*
			(0.017)			(0.058)
Negative_t (binary)	Yes	Yes	Yes	Yes	Yes	Yes
Low_t (binary)	No	No	Yes	No	No	Yes
Macro controls	Yes	Yes	Yes	Yes	Yes	Yes
Insurer controls	Yes	Yes	Yes	Yes	Yes	Yes
Insurer fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
No. of obs.	189,707	102,690	102,690	189,707	102,690	102,690
No. of insurers	60	37	37	60	37	37
R^2	0.2371	0.2936	0.2938	0.2371	0.2936	0.2937
Adj. R^2	0.2368	0.2932	0.2934	0.2368	0.2932	0.2933

Note: Fixed effect regressions of insurer stock returns on yield curve factors from January 2006 to March 2022. Sources: Refinitiv (insurer-level daily stock returns measured using TRI, country-level stock and volatility indices), ECB (daily interest rates), BIS (country-level monthly inflation), OECD (country-level quarterly GDP and investment growth), and SNL (insurer-level yearly life share, unit-linked share, leverage, size, and market-to-book ratio). Standard errors are clustered at the insurer and day level. ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively. P-values are in parentheses.

Table 4: Regression results for Equations (3) and (4)

[18] Column (5) of Table 4 shows that in a positive (vs. negative) yield environment, the effect of a 1ppt change in the level on life insurers' stock returns is 3.41ppt (vs. 3.41+6.77=10.18ppt). Thus, the effect is 2.99 times larger.

The interaction of N_t with the change in the slope ΔS_t and curvature factor ΔC_t does not provide robust coefficients. For life insurers, the effect of $\Delta S_t \cdot N_t$ is only significant in the Nelson-Siegel model, with a p-value of 0.082 and a coefficient of -5.12 (column (5)), indicating that the effect of changes in the slope on stock returns is 3.66 times larger in a negative yield environment. Similarly, the regression coefficients for the curvature factor suggest that sensitivities are greater when 10-year interest rates are negative. Due to the lack of statistical significance, further research is needed to investigate these relationships. However, the findings underscore that the level is the most relevant yield curve factor.

The regression results presented in columns (3) and (6) in Table 4 extend the previous model by introducing the interaction $\Delta L_t \cdot Low_t$ and the main effect of the binary variable Low_t, which is equal to one when the level $0 \leq L_t < 0.5$ppt (cf. Equation (4)). The negative and significant coefficients on the interaction term show that the sensitivity of life insurers' stock returns increases even before 10-year interest rates are negative. This finding suggests that falling interest rates lead to a continuous change in the stock return sensitivity. However, when rates fall below the 0% threshold, there is a more pronounced increase in risk exposure. For the empirical proxies (column (3)), a 1ppt decrease in the level lowers stock returns by 5.4ppt (3.36+2.061) when 10-year interest rates are between 0% and 0.5%, and by 9.5ppt (3.36+6.127) when they are negative. For the Nelson-Siegel estimators (column (6)), the difference is even larger at 4.3ppt for low interest rates and 10.2ppt for negative ones. Thus, negative yields substantially increase the interest rate risk exposure of life insurers in the eyes of stock market participants. One explanation could be the existence of a "reversal interest rate" along the lines of banks, as described by Abadi et al. (2023). Thus, below a certain interest rate, the positive effect of increased economic growth due to stimulative monetary policy disappears. For banks, this leads to more restrictive lending. Analogously, negative interest rates can affect the supply and demand of guaranteed life insurance policies, as the business model of life insurers appears to be at risk. In addition, insurers' reinvestment risk increases further as interest rates fall.

The theory of gradually increasing interest rate sensitivity of life insurers at falling interest rates is supported by the results in Table 5. Here, the sample is divided into four groups with different interest rate environments that have a similar number of observations: below 0% (negative), between 0% and 1% (low), between 1% and 3% (medium-high), and above 3% (high interest rate environment). The regression results are based on the model in Equation (2), with the yield curve factors estimated using the Nelson-Siegel model. The results are similar when using the empirical proxies as regressors (cf. Table A6 in Appendix IV).

	(1)	(2)	(3)	(4)
Dependent variable:	$r_{i,t}$ (life insurers' stock return)			
Yield curve estimation:	Nelson-Siegel			
Interest rate level (in %):	$L_t < 0$	$1 > L_t \geq 0$	$3 > L_t \geq 1$	$L_t \geq 3$
$\Delta Level_t$	9.449***	4.932***	3.291**	2.423**
	(0.001)	(0.000)	(0.019)	(0.022)
$\Delta Slope_t$	-6.512**	-2.489***	-1.436	-1.836**
	(0.011)	(0.005)	(0.180)	(0.044)
$\Delta Curvature_t$	0.926**	0.996***	0.324	0.453**
	(0.034)	(0.000)	(0.112)	(0.017)
Macro controls	Yes	Yes	Yes	Yes
Insurer controls	Yes	Yes	Yes	Yes
Insurer fixed effects	Yes	Yes	Yes	Yes
No. of obs.	22,793	31,274	24,449	24,174
No. of insurers	34	36	31	27
R^2	0.3341	0.2423	0.2716	0.3273
Adj. R^2	0.3327	0.2411	0.2703	0.3262

Note: Fixed effect regressions of insurer stock returns on yield curve factors from January 2006 to March 2022. Sources: Refinitiv (insurer-level daily stock returns measured using TRI, country-level stock and volatility indices), ECB (daily interest rates), BIS (country-level monthly inflation), OECD (country-level quarterly GDP and investment growth), and SNL (insurer-level yearly life share, unit-linked share, leverage, size, and market-to-book ratio). Standard errors are clustered at the insurer and day level. ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively. P-values are in parentheses.

Table 5: Regression results for Equation (2) with different interest rate levels

Column (1) of Table 5 shows the coefficients and p-values when 10-year interest rates are negative ($L_t < 0$). Accordingly, a 1ppt reduction in the level leads to a 9.5ppt decrease in life insurers' stock prices. As the level of interest rates increases, the impact of ΔL_t systematically decreases. The coefficients on the slope factor are also largest in column (1). When 10-year interest rates are between 0% and 1% (column (2)), the effect of the level factor is only about half as large (4.9ppt) and the coefficient of the slope factor falls by even 62% relative to negative interest rates (6.5ppt vs. 2.5ppt in absolute terms). The sensitivities to the three yield curve factors decrease by a further 30–70% when the interest rate level is between 1% and 3% (column (3)). For the level factor, there is another substantial decrease in the coefficient of 26% when interest rates are above 3% (cf. column (4)). Overall, the interest rate sensitivity for the level is 290% higher in a negative interest rate environment in column (1) than in a high positive yield environment in column (4). In terms of the slope and curvature factor, the sensitivities are greater at the high interest rate level above 3% than at the medium-high level between 1–3%, while they mainly decrease until the 1% level is reached.

The substantially diminishing effects of ΔL_t with rising interest rates are illustrated in Figure 7. The dots represent the regression coefficients of ΔL_t for the different interest rate environments in Table 5, estimated using Equation (2). The blue line suggests that the relationship between the level of interest rates and the sensitivity of stock returns to that level is not linear, but convex.[19] Notably, the graph is reminiscent of (Macaulay) duration and convexity as measures of an increasing interest rate sensitivity as yields fall. In Appendix III, I use a stylized cash flow model to show that the balance sheet effects measured by duration and convexity account for only a small fraction of the observed interest rate sensitivities of life insurers in Figure 7. In the most extreme case (interest rates fall from 5% to -1%), the duration gap would increase by 28.5% and the convexity gap by 53.5%, which are substantially smaller effects than those observed in Table 5 (290% when comparing the coefficient of ΔL_t in columns (1) and (4)). The main difference is that the Macaulay duration and convexity capture only direct balance sheet effects and do not take into account other relevant drivers of interest rate sensitivity at negative rates, such as guaranteed annual returns, increased reinvestment risk, changes in the supply and demand for life insurance policies, higher opportunity costs for policyholders as holding cash becomes more attractive, and psychological effects on the shareholder side.

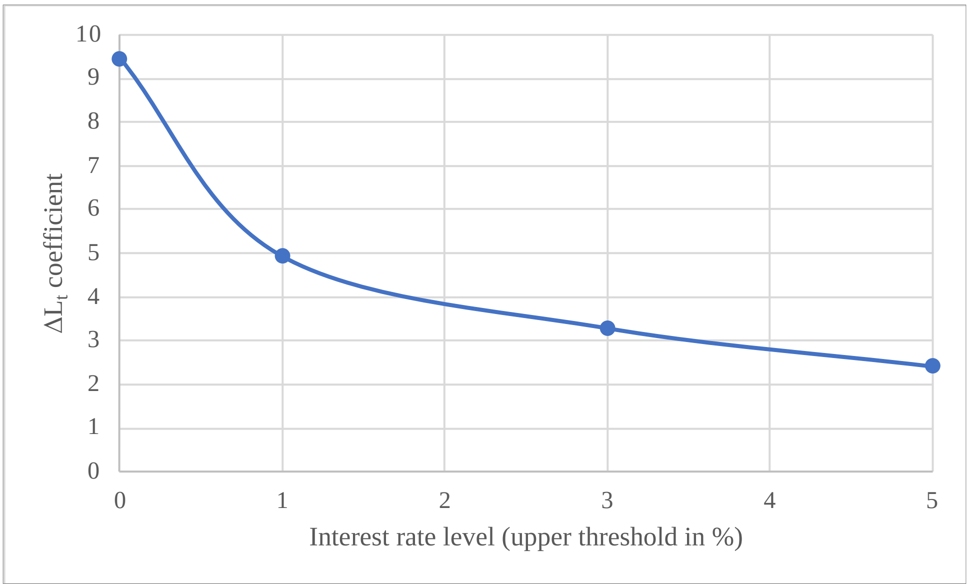


Figure 7: Convexity of life insurers' interest rate sensitivity (based on Table 5)

3.4 Robustness: Orthogonalization

Notably, the VIFs do never exceed a value of 10 for the variables ΔL_t, ΔS_t and ΔC_t in any of the previous models based on Equations (2), (3), and (4). Nevertheless, there is a strong positive correlation between the estimated level and slope factors, with coefficients of 0.8 for the empirical proxies and 0.9 in the Nelson-Siegel model (cf. Table A5 in Appendix IV).[20] Using the residuals from an auxiliary regression of the slope on the level factor removes any correlation between the two variables. Analogously, I re-

[19] Note that the OLS coefficients in Table 5 are estimated using fewer observations than in Table 4. This provides an explanation why the impact of changes in the level factor for negative yields is only 9.45ppt instead of 10.18ppt.
[20] Using the Svensson model, the correlation coefficient for the two yield curve factors is only 0.4.

estimate the curvature factor as well as the stock market and volatility index return. Table 6 presents the regression results for the model using orthogonalized variables according to Equation (5), i.e., after removing the effects of preceding independent variables.

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable:	$r_{i,t}$ (stock return)					
Yield curve estimation:	Empirical			Nelson-Siegel		
Sample:	Full	Life	Life	Full	Life	Life
ΔLevel_t	8.297***	9.230***	8.867***	4.268***	4.826***	4.623***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$\Delta\text{Level}_t \times \text{Negative}_t$	2.379**	2.490**	2.852**	1.625**	1.703**	1.907***
	(0.039)	(0.038)	(0.024)	(0.015)	(0.012)	(0.008)
ΔSlope^*_t	-1.788***	-2.049***	-2.064***	-3.546***	-3.711***	-3.756***
	(0.000)	(0.002)	(0.002)	(0.000)	(0.000)	(0.000)
$\Delta\text{Slope}^*_t \times \text{Negative}_t$	-1.838	-2.499	-2.485	-3.750	-4.646*	-4.604*
	(0.339)	(0.242)	(0.245)	(0.101)	(0.077)	(0.079)
$\Delta\text{Curvature}^*_t$	3.097***	3.245***	3.317***	2.371***	2.579***	2.572***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$\Delta\text{Curvature}^*_t \times \text{Negative}_t$	1.974	2.015	1.944	0.205	0.290	0.296
	(0.136)	(0.204)	(0.219)	(0.638)	(0.520)	(0.512)
$\Delta\text{Level}_t \times \text{Low}_t$			2.060**			1.062*
			(0.017)			(0.058)
Negative_t (binary)	Yes	Yes	Yes	Yes	Yes	Yes
Low_t (binary)	No	No	Yes	No	No	Yes
Macro controls (with $r^*_{m,t}$ & $r^*_{v,t}$)	Yes	Yes	Yes	Yes	Yes	Yes
Insurer controls	Yes	Yes	Yes	Yes	Yes	Yes
Insurer fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
No. of obs.	189,707	102,690	102,690	189,707	102,690	102,690
No. of insurers	60	37	37	60	37	37
R^2	0.2371	0.2936	0.2938	0.2371	0.2936	0.2937
Adj. R^2	0.2368	0.2932	0.2934	0.2368	0.2932	0.2933

Note: Fixed effect regressions of insurer stock returns on yield curve factors from January 2006 to March 2022. Sources: Refinitiv (insurer-level daily stock returns measured using TRI, country-level stock and volatility indices), ECB (daily interest rates), BIS (country-level monthly inflation), OECD (country-level quarterly GDP and investment growth), and SNL (insurer-level yearly life share, unit-linked share, leverage, size, and market-to-book ratio). Standard errors are clustered at the insurer and day level. ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively. P-values are in parentheses.

Table 6: Regression results for Equation (5)

The regression results confirm previous findings in terms of the significance of the effects of the variables of interest and the signs of their coefficients. Thus, insurers benefit significantly from rising interest rates across all maturity types (long, short, and medium), and the level is the most dominant yield curve factor. Also, the interaction term $\Delta L_t \cdot N_t$ is significant at least at the 5% level in all models tested in Table 6, suggesting that sensitivities increase when 10-year interest rates are below 0%. The incremental effect of level changes is still larger for negative than for low interest rates (columns (3) and (6)).

There are, however, changes in the regression coefficients compared to Table 4 and larger differences between the empirical proxies and the Nelson-Siegel factors. The level factor appears to have a stronger effect, as a 1ppt rise leads to an increase in life insurers' stock returns of 9.2ppt according to the empirical proxies (column (2) in Table 6) and 4.8ppt according to the Nelson-Siegel estimates (column (5)). Instead, the effects before orthogonalization are only 3.7ppt and 3.4ppt, respectively (columns (2) and (5) in Table 4). The slope also seems to be more relevant after orthogonalization, as a 1ppt increase reduces stock returns by almost 4ppt in column (5) (before orthogonalization: 2ppt). When 10-year interest rates are negative, the incremental effect of a 1ppt change in the level is only 2.5ppt (instead of 5.8ppt) for life insurers according to the orthogonalized empirical proxies (column (2)) and 1.7ppt (instead of 6.8ppt) according to the Nelson-Siegel factors (column (5)). This suggests a smaller and thus more conservative effect of negative interest rates compared to previous models.

Notably, the changes in the coefficients can be explained by the specifications of Equation (5). The level is defined ex ante as the most relevant driver of stock returns, while the variables ΔS_t^*, ΔC_t^*, $r_{m,c(i),t}^*$, and $r_{v,c(i),t}^*$ are based only on residuals from auxiliary regressions that include ΔL_t as an independent variable. Thus, the level absorbs some of the effects of other variables (including stock market indices) and is per se the most dominant factor in the multivariate regression model, followed by the slope. This approach results in larger beta coefficients for the three yield curve factors in Equation (5) compared to previous models, and a seemingly smaller impact of interest rate changes when yields are negative. The use of auxiliary regressions also complicates the interpretation of the regression coefficients.

Overall, while the orthogonalization confirms the robustness of the results to multicollinearity concerns, the regression coefficients for the yield curve factors in the previous sections can be considered more reliable. They also better reflect the estimated effects of negative interest rates measured by Klein (2020) and Lin et al. (2022).

3.5 Further robustness tests

To test the robustness of the results beyond orthogonalization, I conduct additional regression analyses. The empirical results for all models presented in Equations (3)–(5) are robust to an alternative definition of the empirical proxies, where the level is specified as the 30-year interest rate, the slope as the 30-year minus the 3-month interest rate, and the curvature as the 4-year minus the sum of the 30-year and 3-month interest rates. These definitions arguably better reflect the long duration of life insurers' assets and liabilities, as explained in Section 2.2. The corresponding coefficients and p-values are shown in Table A7 in Appendix IV and are consistent with the results of the previous models.

Moreover, the regression results for the Svensson model, explained in Section 2.3, are closely related to the Nelson-Siegel model. They are presented in Table A8 and confirm the findings of this paper. The Svensson model introduces a fourth factor reflecting the curvature in the very short run (cf. Figure 4). It has a positive coefficient that is significant at the 5% level for the full sample, implying that insurers also benefit from rising interest rates at very short maturities.

The empirical results are also robust to several other changes in the model specifications:[21] First, to different definitions of a life insurer, such as having at least 30% or 50% (instead of 40%) of liabilities arising from life and health insurance business. Second, to the omission of the winsorization of stock returns. Third, to different definitions of the binary variable N_t, such as whether 5-year or 15-year (instead of 10-year) interest rates are below 0%. Fourth, to the introduction of year fixed effects. Fifth, to the exclusion of micro-cap firms (with total assets below $250 million), as these may have different risk profiles than large insurers. Sixth, to the exclusion of insurers from countries with currencies other than the Euro, countries not subject to Solvency II regulation, and to the exclusion of all insurers from each individual country in the sample. The latter ensures that the empirical results are not driven by the risk profiles of insurance companies from a single country.

4 Conclusion

This paper empirically analyzes the sources of interest rate risk for life insurers, focusing on the effects of negative interest rates. To this end, the three yield curve factors level, slope, and curvature are estimated using the Nelson-Siegel model and empirical proxies. For the period from 2006 to 2022 and a sample of 60 listed European insurers, I find that the firms benefit significantly from a greater level and curvature of the yield curve, while having a negative relationship with the slope. Since the yield curve is almost continuously upward sloping throughout the sample period, the results imply that life insurers benefit from rising interest rates across all types of maturities (short, medium, and long).

As negative long-term interest rates first appeared in Europe in the late 2010s, relatively little is known about their impact on the risk profiles of life insurers. To fill this gap, I show that life insurers are up to three times more sensitive to interest rates in a negative yield environment. A 1ppt decline in the level of interest rates reduces stock returns by more than 10ppt, compared to 3.4ppt in a positive interest rate environment. Insurers' risk exposure is already perceived to be significantly higher at interest rates below 0.5%, but the additional effect of negative 10-

[21] All corresponding regression tables are available upon request.

year interest rates is highly significant. More specifically, I find that the relationship between the level of interest rates and the sensitivity of life insurers' stock returns to changes in that level is convex. The results are confirmed by yield curve factors calculated using the Svensson model and by empirical models with orthogonalized independent variables. For the slope and curvature factors, an incremental effect caused by yield curve changes in a negative interest rate environment is not robust and leaves room for further research.

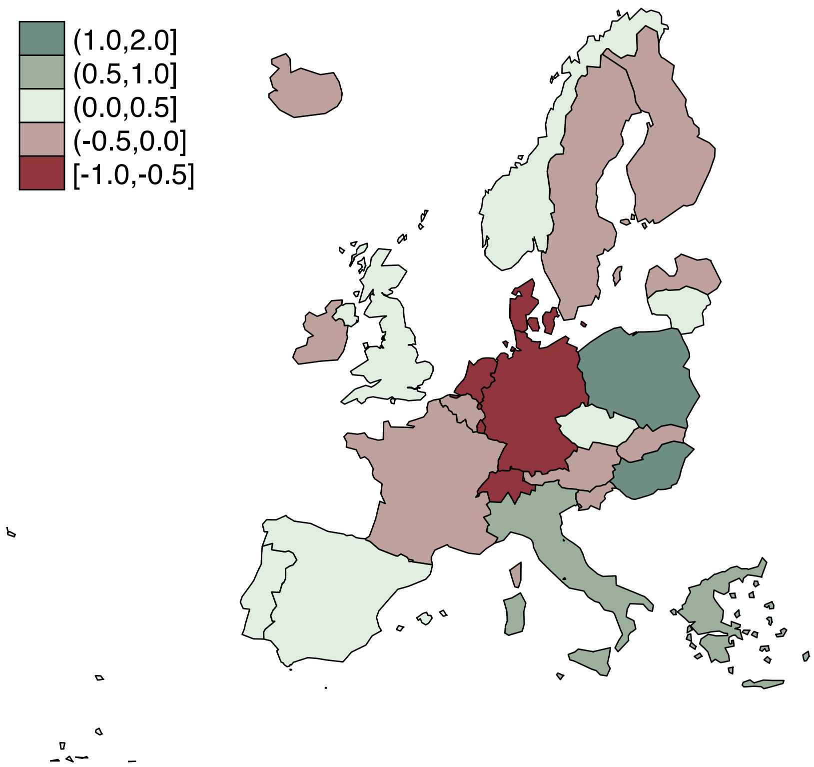
The findings of this paper suggest that stock market participants perceive the interest rate risk of life insurers to be particularly high for interest rates below 0%. There are several reasons for this. First, insurers face higher reinvestment risk because they have negative duration gaps and must pay contractually guaranteed returns on maturing policies. In addition, capital reserves increase. Thus, the lower interest rates fall, the more stressed life insurers are. Second, psychological effects (in the sense of mental accounting) play a role when interest rates are negative, as market participants pay more attention to the situation of business models that depend on interest rates. A long-term change from low but positive to negative interest rates could be perceived as a potentially disruptive event for life insurers offering policies with guaranteed annual returns. A third reason for the high sensitivity to negative interest rates is the higher opportunity cost. When interest rates are negative, potential policyholders have a higher incentive to hold cash rather than purchase a life insurance policy, since the nominal return is zero. This is closely related to Heider et al.'s (2019) argument for why banks avoid passing on negative deposit rates to customers.

Analogous to the role of banks as lenders to the real economy, the business model of life insurers as pension providers is at risk if interest rates are negative for a prolonged period. On the asset side, investments in safe fixed income securities become less attractive as they do not generate profit. In the long run, traditional life insurers may have to pass on negative interest rates to policyholders in the form of non-existent or even negative guarantees. While this transfer of negative interest rates may work for banks and corporate depositors (cf. Altavilla et al. (2022)), policyholders are arguably less dependent on insurers than corporations are on banks. Thus, potential new policyholders may be unwilling to accept these negative returns, leading to a missing link between central bank policy rates and guaranteed interest rates, similar to the findings of Eggertsson et al. (2023) for banks. Consistent with this theory, Inhoffen et al. (2021) predict a decline in the demand for life insurance policies during a prolonged period of negative interest rates.

Managers and regulators benefit from the findings of this paper by learning that the entire term structure of interest rates has a significant impact on the stock performance and thus the risk perception of life insurers. The substantial effect of negative interest rates has implications for risk management and asset-liability management purposes, as well as for monetary policy decisions and regulatory schemes. Shareholders also benefit from new insights into the relationship between bond and equity markets, as they can adjust their investment portfolios and hedging strategies to reflect the fact that stocks of life insurance companies become more interest rate sensitive when interest rates turn negative.

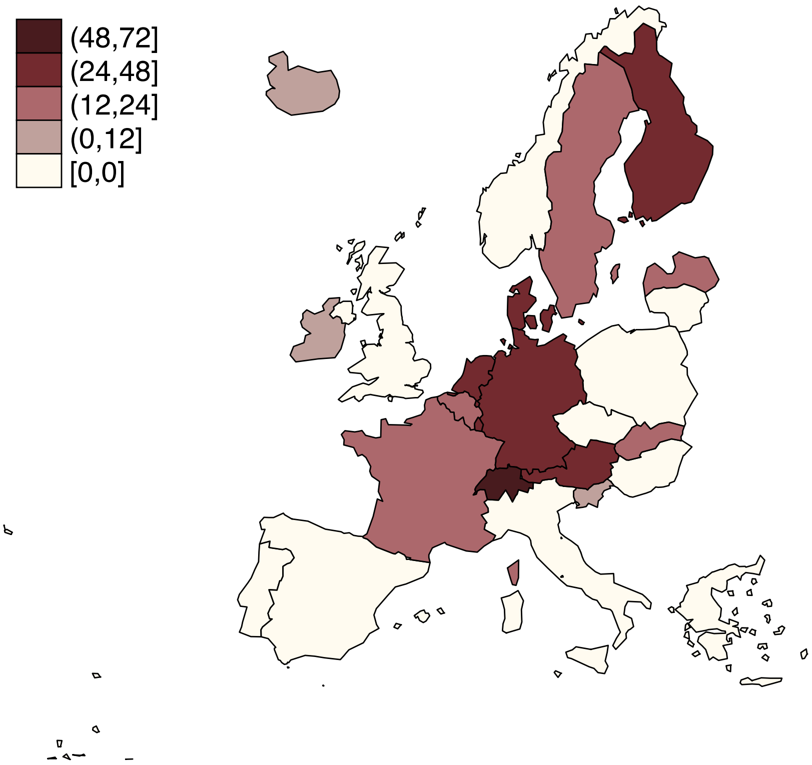
Appendix

I. Additional motivation



Note: The figure shows the lowest levels of 10-year government bond rates (in %) across European countries, with data starting in 1960. All historical lows were between August 2019 and January 2021 (with the exception of the Czech Republic in July 2016). The red colors show 15 countries where interest rates were negative. Five of these countries even had rates below -0.5%. Typically, the respective central banks (the ECB, and the central banks of Denmark, Sweden, and Switzerland) have set negative policy rates, while the Bank of England, for example, did not (cf. Heider et al. (2019)). Data source: FRED.

Figure A1*: Lowest 10-year interest rates in European countries*



<u>Note</u>: The figure illustrates the number of months with negative 10-year government bond rates across European countries, with data starting in 1960. Long-term interest rates were negative for the first time in January 2015 in Switzerland, and for the last time in January 2022 in Germany, the Netherlands, and Luxembourg. The different shades of red color show the heterogeneity in the persistence of negative interest rates. While Iceland had negative interest rates for only one month, Switzerland had them for 71 months (almost six years). Data source: FRED.

Figure A2: Months with negative 10-year interest rates

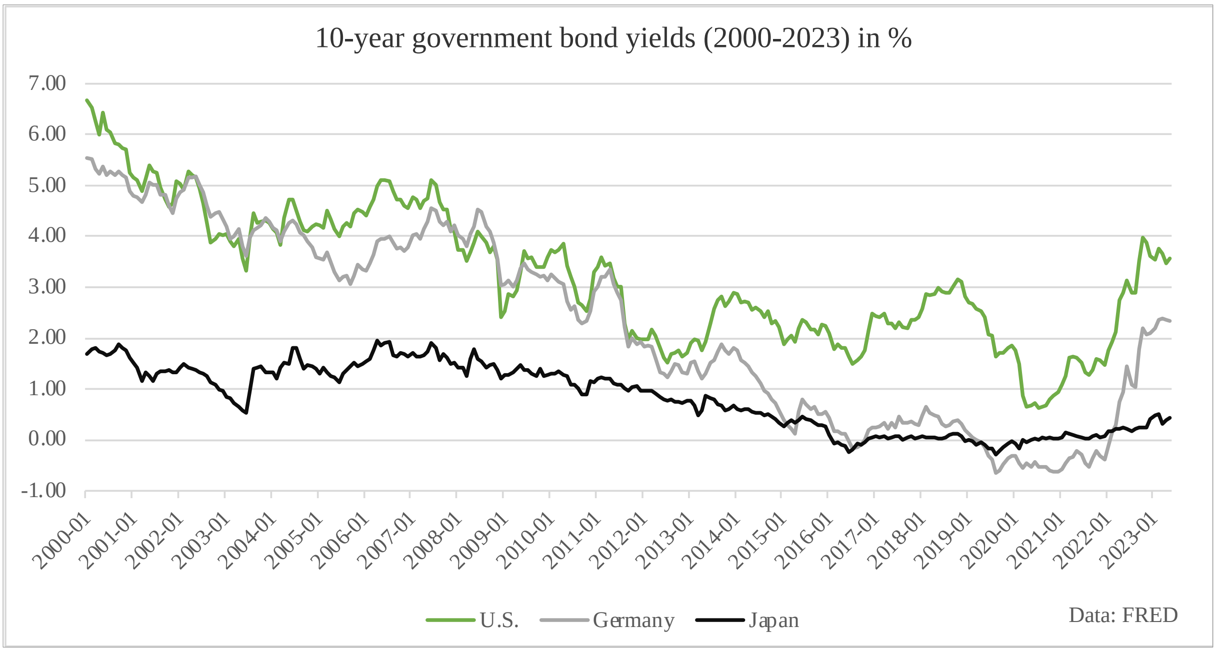
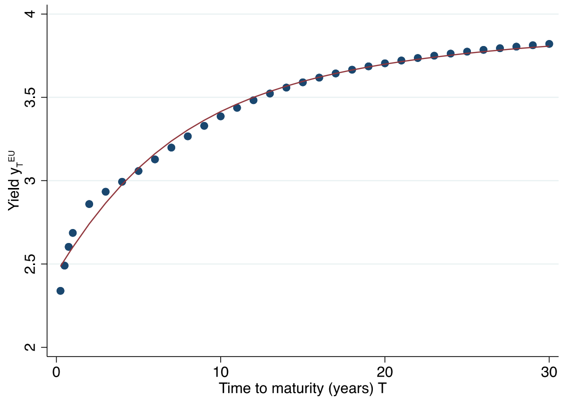
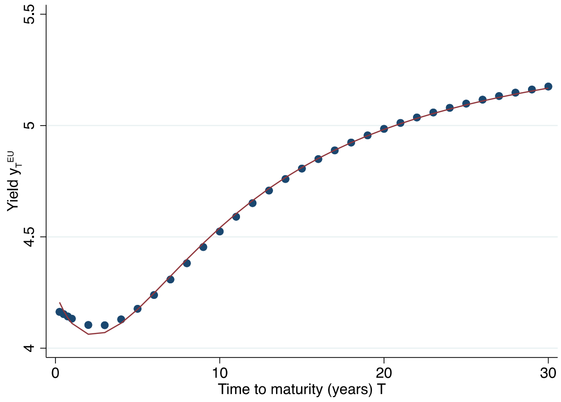


Figure A3: Performance of selected 10-year interest rates from 2000 to 2023

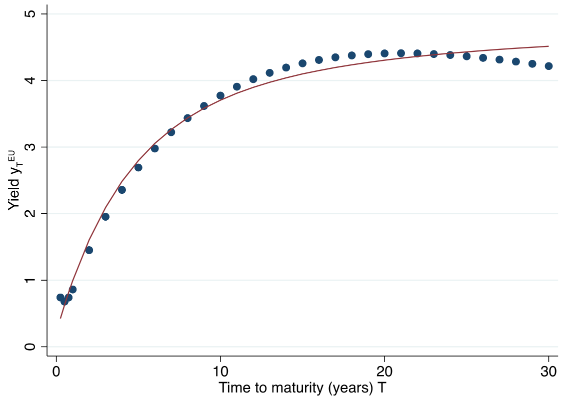
II. Data



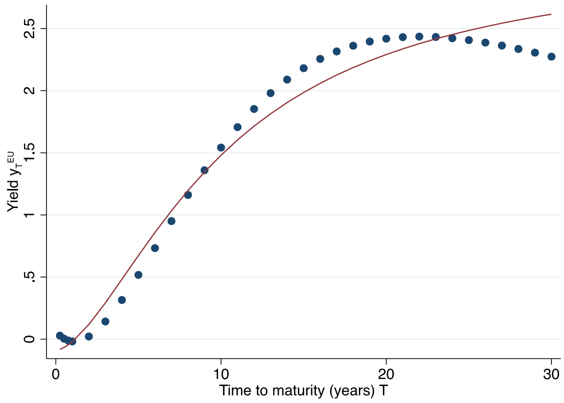
a) 02.01.06 (first day in sample)



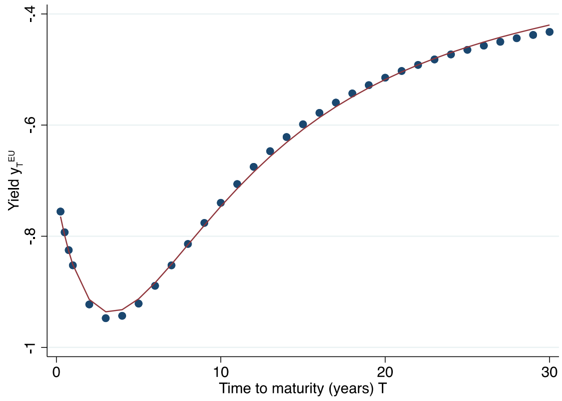
b) 22.09.08 (highest level)



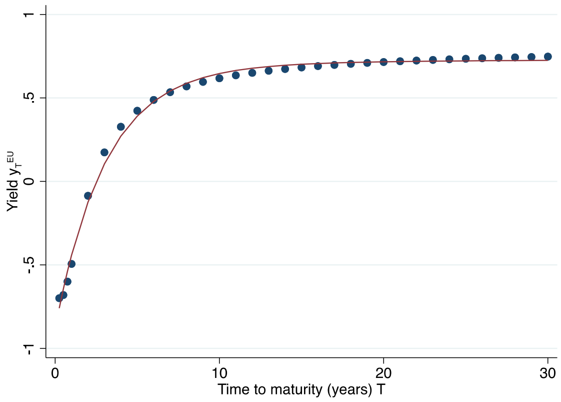
c) 01.04.09 (after financial crisis)



d) 02.05.13 (partly convex and falling curve)



e) 10.03.20 (lowest level)



f) 31.03.22 (last day in sample)

Figure A4: Yield curves on selected days

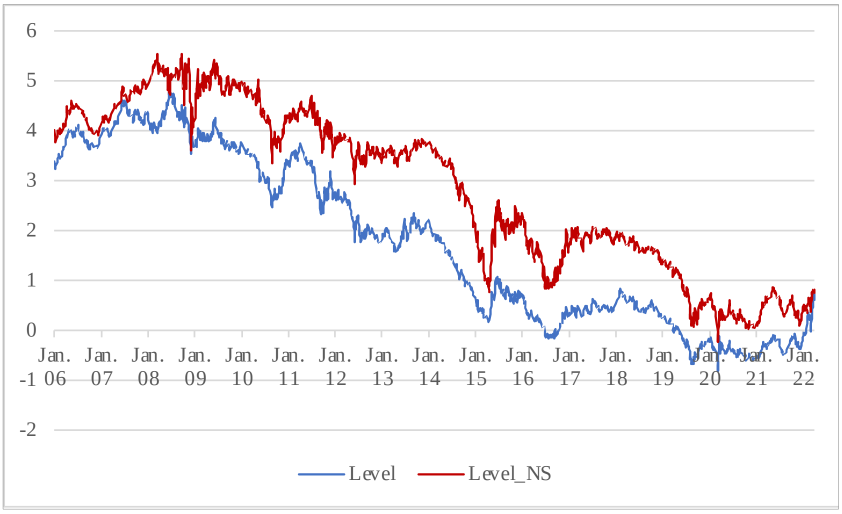


Figure A5: Estimates for the level

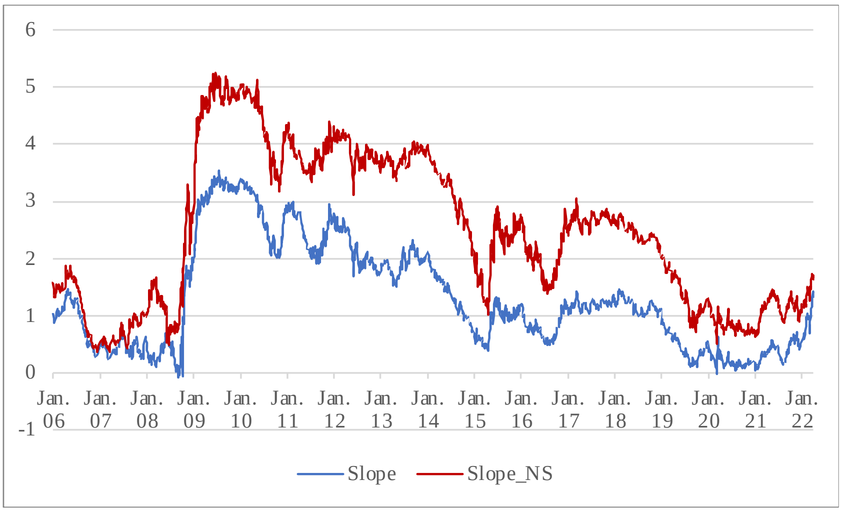


Figure A6: Estimates for the slope

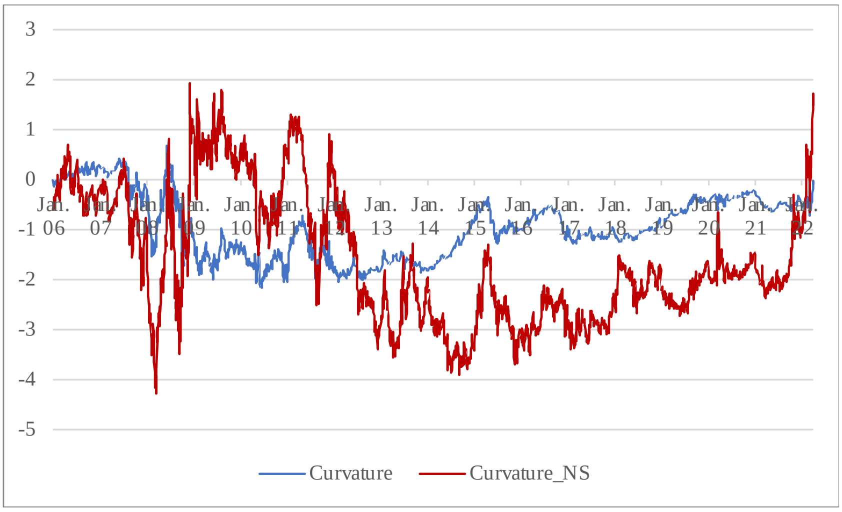


Figure A7: Estimates for the curvature

Name	Country	Obser-vations	Mean stock returns	SD of stock returns	Min. stock return	Max. stock return	Life insurer in 2022
UNIQA Insurance Group AG	Austria	3,777	0.00%	1.70%	-15.88%	9.96%	Yes
Vienna Insurance Group AG	Austria	3,785	0.01%	2.10%	-17.93%	16.26%	Yes
Ageas SA	Belgium	4,141	0.03%	2.95%	-78.05%	29.54%	No
Atlantic Insurance Company	Cyprus	1,412	0.18%	3.58%	-23.07%	17.39%	No
Cosmos Insurance PCL	Cyprus	383	-0.19%	7.74%	-39.80%	68.13%	No
Alm Brand A/S	Denmark	3,587	0.01%	2.24%	-21.17%	28.30%	No
Topdanmark A/S	Denmark	3,794	0.06%	1.57%	-11.84%	15.11%	Yes
Tryg A/S	Denmark	3,790	0.05%	1.47%	-12.73%	7.75%	No
Sampo Plc	Finland	3,831	0.06%	1.67%	-16.67%	16.07%	Yes
April SA	France	3,204	0.01%	1.98%	-37.91%	16.18%	Yes
Axa SA	France	4,150	0.05%	2.40%	-18.41%	21.87%	Yes
CNP Assurances SA	France	4,139	0.05%	2.08%	-21.92%	34.99%	Yes
Coface SA	France	1,973	0.04%	2.33%	-29.73%	14.31%	No
Scor SE	France	4,139	0.05%	1.92%	-19.82%	19.83%	No
Allianz SE	Germany	4,122	0.05%	1.90%	-12.99%	19.49%	Yes
Muenchener Rueckv. Ges.	Germany	4,122	0.05%	1.59%	-14.56%	16.95%	Yes
Nürnberger Beteiligungs AG	Germany	3,142	0.04%	1.77%	-14.72%	25.40%	Yes
Rheinland Holding AG	Germany	1,961	0.11%	3.37%	-30.17%	28.00%	Yes
Talanx AG	Germany	2,397	0.06%	1.61%	-15.81%	13.82%	Yes
Wuestenrot & Wuerttemb. AG	Germany	3,760	0.03%	1.79%	-13.24%	13.86%	Yes
European Reliance Gen. Ins. C.	Greece	3,308	0.09%	3.02%	-17.14%	19.90%	No
CIG Pannonia EletBizt. Nyrt	Hungary	2,704	0.00%	2.53%	-14.87%	36.75%	Yes
FBD Holdings Plc	Ireland	3,819	0.01%	2.33%	-25.08%	22.04%	No
Assicurazioni Generali SpA	Italy	4,123	0.02%	1.71%	-16.77%	13.10%	Yes
Societa Cattolica di Assic. Sc	Italy	3,857	0.00%	2.11%	-17.43%	38.09%	Yes
UnipolSai Assicurazioni SpA	Italy	3,862	0.01%	3.88%	-58.82%	119.81%	Yes
Vittoria Assicurazioni SpA	Italy	2,934	0.05%	1.67%	-10.80%	19.73%	No
Mapfre Middlesea Plc	Malta	703	0.12%	4.09%	-28.16%	16.04%	Yes
Aegon NV	Netherlands	4,150	0.03%	2.84%	-24.18%	35.28%	Yes
ASR Nederland NV	Netherlands	1,479	0.09%	1.73%	-16.06%	13.33%	Yes
NN Group NV	Netherlands	1,969	0.07%	1.62%	-17.95%	10.81%	Yes
Gjensidige Forsikring ASA	Norway	2,830	0.08%	1.31%	-10.31%	12.28%	Yes
Insr Insurance Group ASA	Norway	1,900	-0.11%	5.67%	-58.26%	68.00%	No
Protector Forsikring ASA	Norway	3,016	0.13%	2.78%	-22.39%	24.98%	No
Storebrand Livsforsikring AS	Norway	3,827	0.05%	2.81%	-19.55%	27.95%	Yes
Powszechny Zaklad Ubezp. SA	Poland	2,965	0.04%	1.62%	-11.14%	8.57%	No
KD Group dd	Slovenia	2,140	0.17%	6.50%	-39.32%	190.56%	Yes
Pozavarovalnica Sava dd	Slovenia	2,959	0.04%	2.23%	-12.97%	14.91%	Yes
Zavarovalnica Triglav dd	Slovenia	3,235	0.03%	1.75%	-10.20%	10.00%	Yes
Grupo Catalana Occidente SA	Spain	3,858	0.03%	2.04%	-13.83%	13.26%	Yes
Mapfre SA	Spain	4,131	0.03%	2.10%	-12.58%	19.97%	Yes
Baloise Holding Ltd	Switzerland	3,827	0.04%	1.63%	-11.17%	20.82%	Yes
Swiss Life Holding AG	Switzerland	4,076	0.06%	1.93%	-20.05%	20.64%	Yes
Vaudoise Assurances Hold. SA	Switzerland	3,663	0.05%	1.60%	-16.48%	11.49%	Yes
Zurich Insurance Group AG	Switzerland	4,082	0.05%	1.64%	-13.79%	15.70%	Yes
Admiral Group PLC	UK	3,834	0.06%	1.85%	-25.61%	25.50%	No
Aviva PLC	UK	4,090	0.04%	2.40%	-33.37%	25.10%	No
Chesnara PLC	UK	3,798	0.07%	2.17%	-14.51%	33.48%	Yes
Direct Line Insurance Gr. PLC	UK	2,378	0.05%	1.41%	-9.98%	12.62%	No
esure Group PLC	UK	1,422	0.06%	1.87%	-21.02%	30.98%	No
Hansard Global PLC	UK	3,825	0.01%	2.44%	-17.34%	20.10%	No
Hastings Group Holdings PLC	UK	1,266	0.07%	1.81%	-13.66%	18.00%	Yes
Legal & General Group PLC	UK	4,086	0.07%	2.47%	-28.88%	27.51%	No
Personal Group Holdings PLC	UK	2,531	0.06%	1.68%	-13.02%	11.56%	No
Phoenix Group Holdings	UK	3,015	0.05%	1.62%	-11.82%	19.27%	No
Prudential PLC	UK	817	0.04%	2.57%	-16.69%	17.87%	Yes
RSA Insurance Group PLC	UK	3,863	0.04%	1.91%	-20.84%	45.75%	No
Saga PLC	UK	1,971	-0.06%	3.29%	-37.03%	33.93%	No
St. James's Place PLC	UK	3,827	0.07%	2.21%	-16.18%	27.05%	No
Standard Life Aberdeen PLC	UK	3,958	0.04%	2.22%	-17.31%	20.51%	No

Table A1: Descriptive statistics for daily stock returns

Variable	Definition	Source
$r_{m,c(i),t}$	$\frac{Stock\ \ Market\ Index_{c(i),t}}{Stock\ \ Market\ Index_{c(i),t-1}} - 1$	Refinitv
$r_{v,c(i),t}$	$\frac{Volatility\ Index_{c(i),t}}{Volatility\ Index_{c(i),t-1}} - 1$	Refinitv
$Inflation_{c(i),mth}$	$\frac{Consumer\ Price\ Index\ (CPI)_{c(i),mth}}{CPI_{c(i),mth-1}} - 1$	Bank for International Settlements (BIS)
$GDP_{c(i),q}$	$\frac{Gross\ Domestic\ Product\ (GDP)_{c(i),q}}{GDP_{c(i),q-1}} - 1$	Organization for Economic Cooperation and Development (OECD)
$Investment_{c(i),q}$	$\frac{Gross\ fixed\ capital\ formation\ (GFCF)_{c(i),q}}{GFCF_{c(i),q-1}} - 1$	
$Life\ Share_{i,y}$	$\frac{Life\ and\ Health\ Insurance\ Reserves_{i,y}}{Total\ Liabilities_{i,y}}$	SNL
$Unit\text{-}linked\ Share_{i,y}$	$\frac{Separate\ Account\ Liabilities_{i,y}}{Total\ Liabilities_{i,y}}$	SNL
$Size_{i,y}$	$ln\ (Total\ Assets_{i,y})$	SNL
$Leverage_{i,y}$	$\frac{Total\ Debt_{i,y}}{Total\ Equity_{i,y}}$	SNL
$Market\text{-}to\text{-}Book_{i,y}$	$\frac{Stock\ Price_{i,y}}{Book\ Value\ per\ Share_{i,y}}$	SNL

Table A2: Definitions of control variables

III. Duration and convexity

In the main part of this paper, stock performance is used as a measure of the interest rate risk exposure of life insurers in a top-down approach. Traditional alternative measures of interest rate sensitivity are the Macaulay duration and convexity. Arguably, Figure 7, which illustrates the substantially diminishing impact of ΔL_t as interest rates rise, reminds of the Macaulay duration and convexity. This is because, by definition, when expected cash flows are positive, a falling interest rate leads to an increase in both duration and convexity. At the same time, a 1ppt change in interest rates has a greater effect on duration and convexity for smaller interest rates. These relationships can be derived using the definitions in Equations A1 and A2 below, where y is the year, CF_y is the cash flow in year y, i is the interest rate (which is held constant across different maturities), and P is the price (of either the sum of assets or liabilities).

$$Duration = \frac{\sum_{y=1}^{Y} \frac{y \cdot CF_y}{(1+i)^y}}{\sum_{y=1}^{Y} \frac{CF_y}{(1+i)^y}} = \frac{\sum_{y=1}^{Y} y \cdot PV(CF_y)}{P} \tag{A1}$$

$$Convexity = \frac{\sum_{y=1}^{Y} \frac{y(y+1) \cdot CF_y}{(1+i)^{y+2}}}{\sum_{y=1}^{Y} \frac{CF_y}{(1+i)^y}} = \frac{\sum_{y=1}^{Y} y(y+1) \cdot PV(CF_y)}{P \cdot (1+i)^2} \tag{A2}$$

The relationship between the duration, convexity, and interest rates is relevant to life insurers because they hold assets and liabilities with long maturities. The cash flows of life insurers are usually not perfectly matched, which exposes them to interest rate risk. For insurers in most European countries, the duration of liabilities exceeds the duration of assets (cf. EIOPA (2014)). Thus, falling interest rates have a stronger impact on the duration of liabilities than on assets, leading to a wider duration gap and higher interest rate risk. As a result, the Macaulay duration and convexity provide a potential explanation for higher interest rate risk due to falling interest rates from a balance sheet perspective.

To estimate the magnitude of the balance sheet effects, I use a simplified cash flow model for a stylized life insurer. The firm's expected cash flows in Table A3 are chosen to meet the following criteria. First, the insurer has a duration of assets and liabilities that closely reflects the estimates of the EIOPA (2014) stress test. The stress test was conducted using balance sheet data from the end of 2013, when 10-year interest rates were around 2%. The observed average duration gap was 4.21 years (cf. EIOPA (2014, p. 17)). I use this combination (2% interest rate and 4.21 years duration gap) as a benchmark for designing the cash flow structure. Second, the present value of assets exceeds the present value of liabilities at least for scenarios with interest rates 1ppt above and below 2%. Third, while the cash flows of the liabilities are assumed to be constant, the cash flows of the assets decrease over time, reflecting the relatively lower proportion of investments with very long maturities. Thus, the expected cash flows on the asset side are insufficient to cover the expected liabilities from year $y = 11$ onwards.

year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
CF Assets	100	80	80	80	80	60	60	60	60	60	10	10	10	10	10	5	5	5	5	5
CF Liabilit.	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40

Table A3: Cash flows of stylized life insurer

In the next step, I estimate the Macaulay duration and convexity of the stylized life insurer for different interest rate environments. Interest rates ranging from -1% to 5% yield the present values (PV), Macaulay durations, and convexities of assets and liabilities shown in Table A4. Relative to a scenario with very high interest rates (5% level), the duration gap increases from 3.68 years to 4.73 years, when interest rates are negative (-1% level). In this most extreme case, the relative increase in the duration gap is 28.5%. This effect is due to a smaller increase in the duration of assets (from 5.22 years to 6.1 years) compared to that of liabilities (from 8.9 years to 10.83 years). The estimated maximum increase in the convexity gap is 53.5% (from 67.21 to 103.19), which is higher than for the duration gap.

Interest rate level	-1%	0%	1%	2%	3%	4%	5%
PV(Assets)	844.58	795.00	749.99	709.01	671.60	637.36	605.93
PV(Liabilities)	890.53	800.00	721.82	654.06	595.10	543.61	498.49
Duration(Assets)	6.10	5.94	5.78	5.63	5.49	5.35	5.22
Duration(Liabilities)	10.83	10.50	10.17	9.84	9.52	9.21	8.90
Duration Gap	4.73	4.56	4.39	4.21	4.04	3.86	3.68
Convexity(Assets)	61.48	57.41	53.68	50.25	47.10	44.20	41.53
Convexity(Liabilities)	164.67	154.00	143.88	134.30	125.26	116.74	108.74
Convexity Gap	103.19	96.59	90.20	84.05	78.15	72.54	67.21

Table A4: Characteristics of stylized life insurer

The various measures of interest rate sensitivity presented in Table A4 show a much smaller effect of falling interest rates than in the main body of the paper. This is the case for the duration and convexity gap, as well as for the Macaulay duration and convexity of assets and liabilities. The largest effect observed when comparing a negative to a high interest rate environment is

53.5%. Instead, the regression results of Equation (2) in Table 5 show an effect of 290% for the coefficients of ΔL_t, which measures the sensitivity of life insurers' stock returns to changes in the level of interest rates. Figure A8 illustrates the relative change in three measures of interest rate sensitivity (the coefficients of ΔL_t in Table 5, the duration gap, and the convexity gap) as the level of interest rates falls. The graphs highlight that the magnitude of the direct balance sheet effects, as measured by the changes in the duration gap and the convexity gap, is only a fraction of the interest rate risk observed by the regression coefficients of ΔL_t.[22]

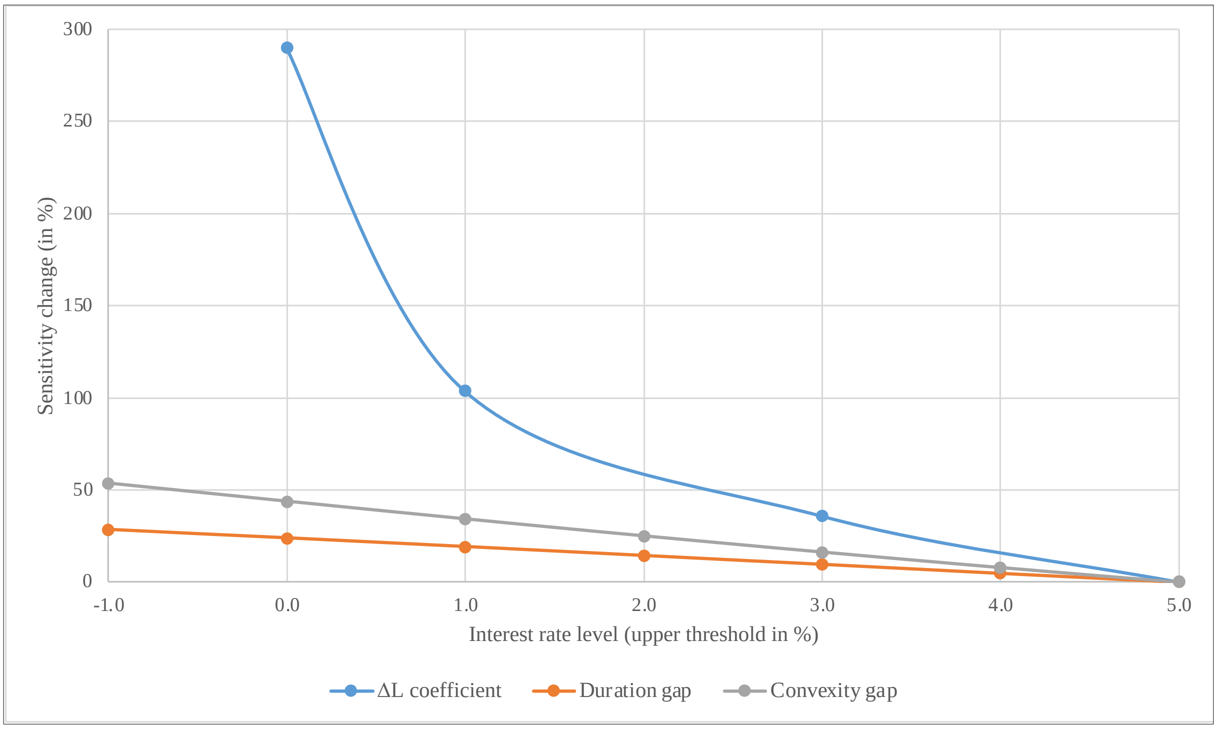


Figure A8: Percentage change in interest rate sensitivities at falling interest rates

The substantial differences between the interest rate sensitivities measured by duration and convexity, on the one hand, and the coefficients of ΔL_t, on the other, can be explained by several factors. First, the duration and convexity are estimated using theoretical cash flow data, while the regression coefficients are estimated using historical stock data. Second, and more importantly, the duration and convexity only consider balance sheet effects and do not take into account other factors that influence the risk of negative interest rates: higher reinvestment risk due to guaranteed annual returns, consequences for the supply and demand of life insurance policies, higher incentives for policyholders to hold cash, and investor perceptions.

[22] Note that each dot in the blue graph reflects regression coefficients estimated using a range of interest rate observations. For instance, the blue dot at 0% reflects the coefficient of ΔL_t for the sample of observations when interest rates are negative (i.e., with 0% as the upper threshold).

IV. Further results and robustness tests

Correlation: Empirical	ΔL_t	ΔS_t	ΔC_t	$r_{m,c(i),t}$	$r_{v,c(i),t}$
$\Delta Level_t$ (ΔL_t)	1				
$\Delta Slope_t$ (ΔS_t)	0.80	1			
$\Delta Curvature_t$ (ΔC_t)	-0.01	0.16	1		
$r_{m,c(i),t}$	0.27	0.20	0.10	1	
$r_{v,c(i),t}$	-0.23	-0.19	-0.09	-0.63	1
Correlation: Nelson-Siegel	ΔL_t	ΔS_t	ΔC_t	$r_{m,c(i),t}$	$r_{v,c(i),t}$
$\Delta Level_t$ (ΔL_t)	1				
$\Delta Slope_t$ (ΔS_t)	0.90	1			
$\Delta Curvature_t$ (ΔC_t)	-0.38	0.21	1		
$r_{m,c(i),t}$	0.21	0.15	0.08	1	
$r_{v,c(i),t}$	-0.18	-0.15	-0.06	-0.63	1

Table A5: Correlation matrix for independent variables with daily data before orthogonalization

	(1)	(2)	(3)	(4)
Dependent variable:	$r_{i,t}$ (life insurers' stock return)			
Yield curve estimation:	Empirical			
Interest rate level (in %):	$L_t < 0$	$1 > L_t \geq 0$	$3 > L_t \geq 1$	$L_t \geq 3$
$\Delta Level_t$	8.713***	4.789***	2.884**	2.751***
	(0.002)	(0.000)	(0.031)	(0.006)
$\Delta Slope_t$	-4.742**	-1.242	-1.003	-2.118***
	(0.039)	(0.127)	(0.301)	(0.007)
$\Delta Curvature_t$	2.593*	1.085*	-0.024	0.896**
	(0.055)	(0.086)	(0.965)	(0.011)
Macro controls	Yes	Yes	Yes	Yes
Insurer controls	Yes	Yes	Yes	Yes
Insurer fixed effects	Yes	Yes	Yes	Yes
No. of obs.	22,793	31,274	24,449	24,174
No. of insurers	34	36	31	27
R^2	0.3334	0.2421	0.2712	0.3281
Adj. R^2	0.3320	0.2410	0.2699	0.3270

Note: Fixed effect regressions of insurer stock returns on yield curve factors from January 2006 to March 2022. Sources: Refinitiv (insurer-level daily stock returns measured using TRI, country-level stock and volatility indices), ECB (daily interest rates), BIS (country-level monthly inflation), OECD (country-level quarterly GDP and investment growth), and SNL (insurer-level yearly life share, unit-linked share, leverage, size, and market-to-book ratio). Standard errors are clustered at the insurer and day level. ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively. P-values are in parentheses.

Table A6: Regression results for Equation (2) with different interest rate levels based on empirical proxies

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable:	$r_{i,t}$ (stock return)					
Yield curve estimation:	Alternative empirical proxies					
Sample:	Full	Life				
ΔLevel$_t$	3.224***	3.983***	3.481***	3.233***	6.493***	6.196***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
ΔSlope$_t$	-1.916***	-2.238***	-2.062***	-2.108***		
	(0.000)	(0.001)	(0.004)	(0.004)		
ΔCurvature$_t$	0.938***	1.031***	1.019***	1.036***		
	(0.000)	(0.001)	(0.001)	(0.001)		
ΔLevel$_t$ $\times$ Negative$_t$			4.699*	4.955*	2.193**	2.490***
			(0.085)	(0.073)	(0.015)	(0.009)
ΔSlope$_t$ $\times$ Negative$_t$			-2.655	-2.614		
			(0.264)	(0.271)		
ΔCurvature$_t$ $\times$ Negative$_t$			0.191	0.174		
			(0.820)	(0.835)		
ΔLevel$_t$ $\times$ Low$_t$				1.765**		1.765**
				(0.011)		(0.011)
ΔSlope$^*_t$					-2.126***	-2.158***
					(0.002)	(0.002)
ΔSlope$^*_t$ $\times$ Negative$_t$					-2.492	-2.465
					(0.240)	(0.246)
ΔCurvature$^*_t$					3.818***	3.834***
					(0.000)	(0.000)
ΔCurvature$^*_t$ $\times$ Negative$_t$					0.190	0.174
					(0.821)	(0.836)
Negative$_t$ (binary)	No	No	Yes	Yes	Yes	Yes
Low$_t$ (binary)	No	No	No	Yes	No	Yes
Macro controls	Yes	Yes	Yes	Yes	No	No
Macro controls (with $r^*_{m,t}$ & $r^*_{v,t}$)	No	No	No	No	Yes	Yes
Insurer controls	Yes	Yes	Yes	Yes	Yes	Yes
Insurer fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
No. of obs.	189,707	102,690	102,690	102,690	102,690	102,690
No. of insurers	60	37	37	37	37	37
R^2	0.2367	0.2931	0.2935	0.2938	0.2935	0.2938
Adj. R^2	0.2364	0.2927	0.2932	0.2934	0.2932	0.2934

Note: Fixed effect regressions of insurer stock returns on yield curve factors from January 2006 to March 2022. Sources: Refinitiv (insurer-level daily stock returns measured using TRI, country-level stock and volatility indices), ECB (daily interest rates), BIS (country-level monthly inflation), OECD (country-level quarterly GDP and investment growth), and SNL (insurer-level yearly life share, unit-linked share, leverage, size, and market-to-book ratio). Standard errors are clustered at the insurer and day level. ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively. P-values are in parentheses.

Table A7: Robustness: Regression results for Equations (2)–(5) with alternative empirical proxies (30-year interest rate as level) for yield curve factors

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable:	$r_{i,t}$ (stock return)					
Yield curve estimation:	Svensson					
Sample:	Full	Life				
ΔLevel$_t$	3.280***	4.010***	3.368***	3.169***	5.056***	4.846***
	(0.000)	(0.000)	(0.001)	(0.003)	(0.000)	(0.000)
ΔSlope$_t$	-1.966***	-2.255***	-1.878**	-1.908**		
	(0.000)	(0.002)	(0.016)	(0.016)		
ΔCurvature$_t$	0.591***	0.698***	0.677***	0.668***		
	(0.000)	(0.000)	(0.000)	(0.000)		
ΔCurvature2$_t$	0.312**	0.368*	0.275	0.276		
	(0.037)	(0.074)	(0.225)	(0.233)		
ΔLevel$_t$ × Negative$_t$			7.067**	7.274**	2.087***	2.296***
			(0.030)	(0.027)	(0.004)	(0.002)
ΔSlope$_t$ × Negative$_t$			-5.359*	-5.335*		
			(0.069)	(0.070)		
ΔCurvature$_t$ × Negative$_t$			0.436	0.445		
			(0.360)	(0.350)		
ΔCurvature2$_t$ × Negative$_t$			0.973	0.974		
			(0.148)	(0.149)		
ΔLevel$_t$ × Low$_t$				1.161**		1.161**
				(0.042)		(0.042)
ΔSlope$^*_t$					-1.357***	-1.395***
					(0.000)	(0.000)
ΔSlope$^*_t$ × Negative$_t$					-1.800*	-1.764*
					(0.059)	(0.064)
ΔCurvature$^*_t$					2.360***	2.350***
					(0.000)	(0.000)
ΔCurvature$^*_t$ × Negative$_t$					0.334	0.344
					(0.461)	(0.449)
ΔCurvature2$^*_t$					0.889***	0.889***
					(0.001)	(0.001)
ΔCurvature2$^*_t$ × Negative$_t$					0.971	0.972
					(0.149)	(0.150)
Negative$_t$ (binary)	No	No	Yes	Yes	Yes	Yes
Low$_t$ (binary)	No	No	No	Yes	No	Yes
Macro controls	Yes	Yes	Yes	Yes	No	No
Macro controls (with $r^*_{m,t}$ & $r^*_{v,t}$)	No	No	No	No	Yes	Yes
Insurer controls	Yes	Yes	Yes	Yes	Yes	Yes
Insurer fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
No. of obs.	189,707	102,690	102,690	102,690	102,690	102,690
No. of insurers	60	37	37	37	37	37
R^2	0.2366	0.2930	0.2938	0.2939	0.2938	0.2939
Adj. R^2	0.2364	0.2927	0.2934	0.2935	0.2934	0.2935

Note: Fixed effect regressions of insurer stock returns on yield curve factors from January 2006 to March 2022. Sources: Refinitiv (insurer-level daily stock returns measured using TRI, country-level stock and volatility indices), ECB (daily interest rates), BIS (country-level monthly inflation), OECD (country-level quarterly GDP and investment growth), and SNL (insurer-level yearly life share, unit-linked share, leverage, size, and market-to-book ratio). Standard errors are clustered at the insurer and day level. ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively. P-values are in parentheses.

Table A8: Robustness: Regression results for Equations (2)–(5) with Svensson model for estimating yield curve factors

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