Interest Rate Risk of Life Insurers - Evidence from Accounting Data

Abstract

Life insurers are exposed to interest rate risk as their liability side is typically more sensitive to interest rate changes than their asset side. This paper explores why insurers assume this risk using a new accounting-based method to measure interest rate sensitivity of assets and liabilities. Calculation at the insurer level yields on average a wide duration gap with pronounced heterogeneity in the cross-section. This could be explained by alternative investment strategies such as asset insulation which are at least to some extent at odds with interest rate risk management. Using a 2014-17 panel, factors associated with interest rate risk support this view.

Keywords: Life insurance, interest rate risk, insurance investment management, asset liability management, duration gap

JEL classification: E43, G11, G22

1 Introduction

Life insurers assume interest rate risk, which means that the firm value changes as interest rates fluctuate. The reason for this is that insurers offer long-term savings products with guarantees. In doing so, they have to deliver on their promise of fixed interest payments irrespective of their interest income from investments. Matching the maturities of interest-bearing assets and liabilities acts to reduce risk, and it is indeed the case that insurers invest primarily in long-term bonds to match the maturities of their long-term liabilities. However, asset-liability matching is ultimately imperfect, and insurers engage in maturity transformation. The liabilities of life insurers, unlike those of banks, typically have maturities that are longer than those of investments. Life insurers therefore tend to benefit from rises in interest rates but lose if interest rates fall.

While it is well established that life insurers bear interest rate risk, there is no consensus as to whether this is good practice. In addition, little is known about whether there are significant differences in the cross-section of insurers, and if so, why. This paper discusses the reasons why life insurers assume interest rate risk. In particular, it examines the rationale for assuming interest rate risk as a deliberate choice. In a nutshell, the theoretical idea is that risk management is at least to some extent at odds with alternative investment strategies. Insurers have specific expertise in managing financial risk, and they have the competitive advantage that they can hold securities for the long term. This is because insurers' future cash outflows are relatively stable and predictable. One typical investment strategy which harnesses this competitive advantage involves holding illiquid and long-term assets to maturity. Such a strategy saves insurers portfolio adjustment costs and enables them to earn an illiquidity premium. Chodorow-Reich et al. (2018) call this asset insulation. By contrast, interest rate risk management involves the holding of liquid assets and regular asset sales and reinvestment, and therefore high portfolio adjustment costs and the realization of short-term value fluctuations. This implies that insurers' asset managers might face a trade-off between interest rate risk reduction and asset insulation.

To reconcile the trade-off with data, this paper develops a new accounting-based method to estimate interest rate risk at an insurer level. The method uses a reverse engineering approach which extracts inputs from financial statements, that is, it compares fair value and historical cost accounting data. The basic idea is to use two valuations that mainly differ in the underlying discount rates. To estimate sensitivity, it relates the difference between the two observed valuations to the change in the discount rate. This results in estimates of (modified) duration of assets and liabilities. In portfolio management, duration is a simple and generally known measure of first-order sensitivity to interest rate fluctuations. In insurance, risk managers make similar use of duration to estimate the interest rate sensitivity of asset portfolios and insurance liabilities. My top-down approach allows me to quantify interest rate sensitivity on both sides of the balance sheet at the insurer level for the entire industry within a country. This was not possible with the previous approaches, which only work with limited samples or are limited to the asset side.

As an empirical application, I calculate the interest rate risk of German life insurers. The German market provides a rich environment to study interest rate risk. First of all, it is one of the largest insurance markets in the world. Second, owing to their focus on long-term policies (average contract length of life policies is 31 years)[1] with minimum return guarantees, German life insurers have liabilities which are highly sensitive to interest rates (Kablau and Weiß, 2014 and Berdin and Gründl, 2015). This has brought them a great deal of attention, e.g. regarding potential risks to financial stability (IMF, 2016). The association between the wide duration gap - the difference in interest rate sensitivity between liabilities and assets - and capital investment behavior has been discussed at length, e.g. by Domanski et al. (2017), who show that the objective of German life insurers of narrowing an existing duration gap puts downward pressure on long-term interest rates.[2] In addition to the interesting market characteristics, it is also worth investigating the German case because I have special, unique data at hand. I exploit data from a recently enacted piece of legislation, which makes it possible to observe detailed information on liability valuations with different underlying discount rates. In some other countries, the market value and historical cost value are also observed, but not the underlying discount rates.

I obtain on aggregate a modified duration gap for German life insurers of around six. This means that, for the sector, a one percentage point drop in interest rates leads to an increase in the market value of liabilities that is approximately six percentage points greater than the relative increase in the market value of assets. I observe pronounced heterogeneity in the cross-section, on the asset side and, to an even greater extent on the liability side. This indicates that insurers are exposed to quite different degrees of interest rate risk. A wide dispersion implies differences in terms of the management of interest rate risk. The heterogeneity of interest rate risk might affect the alignment in behavior, which could have repercussions for other markets.

Using a 2014-17 panel, I study factors associated with interest rate risk. The goal is to provide evidence of a trade-off between interest rate risk reduction and an asset insulation

[1]Number from the German insurance association's statistical report 2005, the last year which reported this information.

[2]Note that this analysis uses aggregated bond portfolios of the sector; it does not allow the researcher to investigate differences between insurers.

investment strategy. The challenge is that interest rate risk reduction and asset insulation may, at least to some extent, be at odds with each other, but they are not fully exclusive. More generally, there is the empirical challenge to identify a preference where one only observes a choice - and this choice might be influenced by other factors, for example dealer relationships (Hendershott et al., 2017) or search for yield (Becker and Ivashina, 2015). I tackle the challenge by approximating asset insulation preferences with specific characteristics of insurers' investment behavior. I take advantage of the fact that certain asset classes and a particular trading behavior clearly make sense for asset insulation, while being counterproductive for duration matching. Then, I demonstrate that asset insulation approximated in this way has a strong negative correlation with investment duration. After that, I show in an empirical horse race that the proxy for the asset insulation strategy is a better predictor of investment duration than a duration-matching strategy. This difference in predictability runs counter to the view that the duration of liabilities is the main driver of asset duration. Investment characteristics which are typical for an asset insulation strategy go some way towards explaining why insurers have not changed their asset duration in order to reduce their interest rate risk. Hence, the result suggests that high levels of interest rate risk are at least to a certain extent explained by a deliberate choice.

The remainder of the paper is organized as follows. Section 2 develops the theory of why life insurers bear interest rate risk. Section 3 elaborates how different accounting valuations can be used to calculate a measure of interest rate risk. Section 4 presents the data, and explains the institutional context and the relevant accounting rules. Section 5 calculates the duration gap using company-level data and explains the results of the empirical analysis. Section 6 concludes the paper.

2 Why do life insurers bear interest rate risk

2.1 Initial thoughts

This section deals with possible explanations for the interest rate risk exposure. Households demand life insurance policies with guarantees as long-term savings schemes for various reasons, including the benefits of compulsory saving, tax advantages, and because of insurers' expertise in managing long-term capital market risks. Because customers seek such policies, the long-term horizon on the liability side of insurers' balance sheets is a business feature. It is determined by existing contractual relationships and cannot be influenced in the short term.[3] Therefore, I take the long duration on the liability side as

[3]Even though the liability duration is fixed in the short term, it can of course be reduced in the long term. To reduce the liability duration, the main candidate is new business. Koijen and Yogo (2015)

a given.

It is the duration on the asset side, then, which determines the interest rate risk exposure. The question is, given the long duration on the liability side, why do managers decide not to invest in matching long-dated assets? There is no easy answer to this question, and to my knowledge there has been no research which studies the optimal amount of interest rate risk that insurers should bear.

I see three possible kinds of explanations. First of all, interest rate risk could be a deliberate choice, i.e. there are more benefits for the firm associated with interest rate risk than costs. Besides that, it could also be the result of inaccurate measurement of interest rate risk, i.e. actual interest rate risk might be lower than initially thought. Finally, interest rate risk could be accidental, in the sense that insurers have a liability side that they cannot purchase in capital markets. In the following, I focus on the explanation that interest rate risk is a deliberate choice, and after that I comment on the other two possible explanations.

2.2 Interest rate risk exposure as a deliberate choice

Firm perspective: Interest rate risk comes with costs and benefits. Regarding costs, a duration mismatch gives rise to reinvestment risk because future interest income is uncertain and, as a consequence of falling interest rates, it may fall short of interest expenses (French et al. 2015). A prolonged low interest rate environment could lead to a situation where sufficient returns can no longer be earned. As IMF (2016) highlights, sector-wide interest rate risk also contributes to macro-prudential risk, because it increases the common exposure to market risk within the insurance sector. Finally, with a short asset duration one may miss out on additional yield potential because the yield curve is upward sloping.

There are benefits associated with investment strategies which have the side effect of increased interest rate risk. Insurers have specific expertise in managing interest rate risk, and compared to other intermediaries they can expect to hold investments for the long term. Chodorow-Reich et al. (2018) argue and provide empirical evidence that life insurers are asset insulators, i.e. they create value by buying illiquid and high-transaction-cost securities and holding them to maturity. The reason for this value creation is that insurers can pursue an investment strategy that is complementary to their involatile and illiquid liabilities. This strategy saves insurers portfolio adjustment costs and enables them to earn an illiquidity premium. Asset insulation is not feasible for other investor types

show that insurers changed their offering of policies in the financial crisis with the aim of adjusting the structure of their liability side. Besides the slow-acting effect of new business, insurers could sell existing contracts to other companies, purchase reinsurance solutions (Koijen and Yogo, 2016), or try to nudge their policyholders to surrender their contracts.

because their financing is less long-term. Such a strategy is to a certain extent contrary to a duration-matching strategy, because the two strategies require different investment choices. Duration matching involves the holding of liquid assets and regular asset sales and reinvestment, and therefore significant portfolio adjustment costs and the realization of short-term value fluctuations. It is sufficient for insurers' investment managers to believe in asset insulation benefits; it does not matter whether such a strategy really generates higher returns or not.

Policyholder perspective: Firm and policyholder interests regarding duration matching are not aligned if policies offer a high minimum return that is irrespective of investment returns. In an unregulated insurance industry, policyholders recognize the incentive problem and they could use contracts to limit risk taking (Mayers and Smith Jr, 1981). However, this is usually not possible as advocated by Plantin and Rochet (2009) with incomplete contracts. Policyholders are not sophisticated investors, and a prudential authority is needed to introduce regulatory constraints.

It is difficult to gauge the extent to which regulatory constraints are binding, such that companies reduce their interest rate risk as a result. Empirical evidence generally underlines an association between regulation and interest rate risk. The risk is higher in countries in which it is penalized less by a way of specific reserve requirements or less transparent due to historical cost valuation on the balance sheet (Moody's, 2015). Fleuriet and Lubochinsky (2005) demonstrate the effect of accounting methods using the example of a reform in Denmark: following a stipulated change in the discount rates used for premium reserves, Danish life insurers substantially increased the duration of their investments. Koijen and Yogo (2015) and Ellul et al. (2014) highlight that non-economic valuation in external accounting can distort managerial decisions. Andonov et al. (2017) find that pension funds increased risk taking in response to a regulatory link between the liability discount rate and the expected rate of return on assets.

At the start of 2016, European insurers entered a new regulatory era with the launch of Solvency II. This regulatory framework has two key principles: the introduction of risk-based capital requirements, and the mark-to-market measurement for assets and liabilities. Under Solvency II, capital requirements take interest rate risk into account with due emphasis. Simply put, the higher an insurer's interest rate risk, the higher the capital requirements.[4] Hence, with Solvency II, interest rate risk management is a key factor in the optimization of investment portfolios (Braun et al. 2017). However, in the past and in particular in Germany, this was not quite so. The previous Solvency I regime determined capital requirements using a simplistic factor-based approach. Capital requirements were

[4]Capital requirements in Solvency II are based on a balance sheet with market-consistent valuation. It measures interest rate risk based on a stress test approach as the decrease of asset over liability value given a shift in the yield curve. Hence, the duration gap is a key indicator within the Solvency II framework.

independent of the duration of the asset portfolio and asset-liability management.[5] This suggests that regulatory constraints varied over time. Before 2016 the constraints of regulation addressing interest rate risk had a limited effect in Germany.

Taking all this into account, the degree of interest rate risk ultimately depends on the optimization of the firm and the relationship between the marginal benefit from this and marginal costs. The exact relationship is, however, difficult to estimate. Therefore, I do not attempt to estimate an optimal amount of duration matching. Instead, I examine the trade-off between a specific beneficial investment strategy, asset insulation, and risk management.

2.3 Explanations as an inaccurate measure

A single measure of interest rate risk exposure may not be sufficient, because there are different views on the interest rate sensitivity of life insurance liabilities. Some insurance experts are critical of the use of the fixed cash flows for estimating the interest rate sensitivity of insurance liabilities. Variability of future cash flows is disregarded in my setting, two sources of which are meaningful. Typical contracts in Germany pay a higher benefit to customers for investment income that significantly exceeds the contract-specific minimum guarantee (future discretionary benefits). This is allocated to customer accounts a few years later and cannot be revoked in years with low investment income. Second, typical contracts include a surrender option, which gives policyholders a choice to reduce the term of their policy.

There is no consensus on how to incorporate future discretionary benefits into measuring the interest rate sensitivity of insurance liabilities. EIOPA (2016) proposes, in addition to its Macaulay duration measure, the concept of effective duration. This measure takes into account that future profit participation moves in parallel to the future path of interest rates. The effective duration is therefore lower than the Macaulay / modified duration (Briys and De Varenne, 1997, EIOPA, 2016). One approach to approximate the effective duration is the definition of scenarios: first, the present values of future cash flows are calculated for the baseline and a stress scenario. This calculation must contain behavioral assumptions as to how future cash flows respond to market interest rates. Then, one simulates the profit statements and profit sharing for the relevant future years. After that, the change in the present value is expressed in relation to the change in interest rates. The effective duration estimate should be judged in the context of the two compared scenarios. In EIOPA (2016) these are a baseline scenario (which assumes that interest rates rise in

[5]To be precise, before Solvency II the regulatory landscape differed between countries. For instance, the United Kingdom introduced further requirements which were sensitive to duration matching (Swain and Swallow 2015).

the long run as the yield curve is upward sloping)[6] and a low-for-long scenario. Related to the assumption of a flattening of the yield curve, one predicts a significant drop in future discretionary benefits, which has a risk-dampening effect. The difference between the modified and effective duration depends on the scenarios compared. I believe that interest rate risk from fixed benefits is not materially reduced by the argument that in future, in some scenarios, there are additional variable benefits that one could reduce in other scenarios. Therefore, I see modified duration as the more intuitive and more useful measure.

Another source of variability of future cash flows is the policyholder option to surrender contracts, mostly involving additional surrender fees. Empirical studies report many reasons why policyholders lapse their contracts (Nolte and Schneider, 2017). Insurers can therefore calculate that a significant proportion of their obligations for a distant future will be incurred much earlier. From a purely financial view, the option to lapse becomes more valuable when interest rates rise. The reason for this is that variable benefits of policies are very slow to reflect the interest rate level, while alternative investments immediately provide a higher yield. Therefore, the surrender option has an influence on the interest rate sensitivity of insurance liabilities (Tsai, 2009). However, in a low interest rate environment lapses are unattractive, and this does not change with moderate increases in interest rates. Rather, in a low interest rate environment an increase in lapses is a tail risk. Lapses would rise significantly if interest rates rose sharply (Förstemann, 2018 and Berdin et al., 2018). Therefore, future cash flows are most likely not influenced much by lapse behavior, at least in the context of a persistent low interest rate environment or a moderate rise in interest rates.

To sum up, there are several concepts for estimating liability duration. One alternative is effective duration, which is lower than modified duration. However, effective duration can only be interpreted with respect to the scenarios compared. Different measures of interest rate risk have different interpretations, and these should always be kept in mind. This paper focuses on the interest rate risk which is based on fixed cash flows from guarantees and should therefore be interpreted accordingly.

2.4 Accidental explanation

The accidental explanation, in the sense that life insurers have a liability side that they cannot purchase in capital markets, is a story often told by practitioners. Indeed, some argue that there is a shortage of long-term bonds. In addition, a dearth of long-term

[6] One key element here is what is known as the ultimate forward rate. Solvency II stipulates the use of discount rates for liabilities with a maturity of over 20 years calculated on its basis, which was set at 4.2%.

bonds puts pressure on yields at the long end of the maturity spectrum (Greenwood and Vayanos, 2010). Besides, researchers observe a shortage of safe assets, such that the yield on safe assets is so low that they become unattractive as an investment class (Caballero et al., 2017). Ultra-long bonds usually belong to the safe assets category. Against this background, it seems a natural explanation that the supply of suitable long-term bonds alone is not sufficient to fully immunize insurers against interest rate risk.

Recent evidence suggests that asset cash flows denominated in euro with a maturity of 30 years are sufficiently available to cover life insurers' liability cash flows up to 30 years. In addition, markets for ultra-long euro-denominated sovereign bonds are sufficiently liquid (ESRB, 2017). Furthermore, German insurers historically held only a small share of the ultra-long bonds outstanding, and they have only recently increased their share (Shin, 2017). Finally, there is no significant cross-country association between asset durations as reported by EIOPA (2014) and the average term to maturity of government securities.[7] On the basis of these empirical observations, I believe it is not plausible that a shortage of long-term bonds alone can explain limited duration matching.

3 Measuring interest rate sensitivity

3.1 Approaches

In the literature so far, there are three approaches to estimating the interest rate risk of insurers. *First*, in a bottom-up approach, the European insurance regulator EIOPA (2014) and (2016) estimates, in the context of its stress tests, the interest rate risk at the country level. It uses detailed internal cash flow data requested from a sample of insurers for this purpose. A bottom-up approach is convenient, though owing to data constraints it is not feasible for most research purposes. *Second*, Brewer et al. (2007), Berends et al. (2013) and Hartley et al. (2016) use a top-down approach estimating the interest rate sensitivity of insurers' stock prices. However, the main constraint here is that only a few insurers are listed, and those that are typically operate several business segments. *Third*, Kirti (2017) and Domanski et al. (2017) estimate the duration of investments on an asset-by-asset basis whereas on the liability side they use simple estimates. This reflects that it is especially difficult to estimate the duration on the liability side and not so much on the asset side. To my knowledge, the present paper is the first to estimate insurers' interest rate risk using accounting data, which has the advantage of estimating interest rate risk separately for assets and liabilities at the insurer level for broad and balanced samples.

[7] Average term to maturity in years taken from IMF Fiscal Monitor 2014 p. 87.

3.2 Reverse engineering with accounting data

The approach reverse engineers inputs used by insurers when they estimate valuations of assets and liabilities for reporting purposes. The process is the following: First, insurers project cash flows. Second, the cash flows are discounted with different legally stipulated discount rates depending on the purpose of the reported present value. I take different present values estimates and together with the stipulated discount rates reverse-engineer the implicit duration used by insurers as an input in their estimations.

Modified duration (Dur) is a measure of first-order interest rate sensitivity. It is defined as the semi-elasticity, the relative change in the market value MV for an absolute change in the discount rate r.

$$Dur \equiv -\frac{\partial MV}{\partial r}\frac{1}{MV} \tag{1}$$

In principle, modified duration is defined if the market value is continuous and differentiable with respect to the discount rate. As a more strict version of the duration measure, I specify two further assumptions: first, the underlying cash flow is not contingent on the discount rate. Second, the discount rate is not contingent on the time horizon.

Consider MV as the observed market value of an insurer's assets or its liabilities, and r_0 and $r_0 + \Delta r$ as two discount rates. I relate the change between two market values MV_{r_0} and $MV_{r_0+\Delta r}$ to a change in discount rates from r_0 to $r_0 + \Delta r$. This means modified duration is determined by linear approximation:

$$Dur_{r_0} \approxeq -\frac{MV_{r_0+\Delta r} - MV_{r_0}}{\Delta r}\frac{1}{MV_{r_0}} \tag{2}$$

With discretization, the accuracy of the duration measure depends on the curvature of the relationship between the market value and discount rates. The relationship is convex – the sensitivity increases when discount rates fall. Equation (2) measures the slope of the secant line between the market values for two discount rate levels, which lies between the sensitivity at the lower market value (higher discount rate) and the sensitivity at the higher market value (lower discount rate). The further analysis rests on the concept that the measure is a sufficiently accurate measure of sensitivity. Further, the comparison implies the assumption that changes observed in the market value are predominantly attributable to a change in the level of discount rates. This is valid because life insurers invest primarily in fixed-income securities, and liabilities are calculated as the present value of guaranteed future payments.

I now consider a historical cost accounting regime. Each item has two observable valuations: the book value at historical cost BV and the market value MV. $MV_{r_0+\Delta r}$ and

$BV_{r_0+\Delta r}$ are observable, but MV_{r_0} and BV_{r_0} are not. I approximate MV_{r_0} with $BV_{r_0+\Delta r}$, which is sensible if some conditions are met. First, the book value and market value were identical when rates are r_0. And second, the book value does not change when rates change ($BV_{r_0+\Delta r} = BV_{r_0} \forall \Delta r$). These conditions are typically met in a strict historical cost accounting regime. Third, the use of accounting data implies the assumption that balance sheet items provide a meaningful picture of interest rate risk. This is reasonable, because the balance sheets of insurers change very little over time, and short-term holdings of derivatives play only a minor role.[8]

I transform Equation (2) with a view to deriving an equation that can be calculated with the available information. I set r_0 such that assets and liabilities were recognized on the balance sheet with this discount rate. Therefore, at level r_0, the book value equals the market value. That way, the modified duration can be approximated by the standardized amount by which the market value differs from the book value relative to the underlying change in discount rates.

$$Dur_{r_0} \approxeq -\frac{MV_{r_0+\Delta r} - BV_{r_0}}{\Delta r} \frac{1}{BV_{r_0}} \tag{3}$$

Equation (3) only considers the value effect of a change in discount rates. I set the current year as $v_0 + \Delta v$ and the time of discount rate change in the past as v_0 with $\Delta v > 0$. Δv represents the number of years that have passed. The following holds:

$$Dur_{r_0,v_0} \approxeq -\frac{MV_{r_0+\Delta r,v_0} - BV_{r_0,v_0}}{\Delta r} \frac{1}{BV_{r_0,v_0}} + Inc_{v_0+\Delta v} \tag{4}$$

Equation (4) is similar to Equation (3), apart from the stipulation that the discount change takes place without any passage of time. Furthermore, accounting for time differences requires an adjustment, because some items with a difference between market and book value disappear from the balance sheet. First, there is gains trading - insurers sell their winners, assets with a significant difference between their market value and book value, and hold on to other assets, and in doing so they generate profits by realizing capital gains (Ellul et al., 2015). The corresponding effect on liabilities is that some policyholders lapse their insurance contracts. In this case, the policyholders receive approximately the book value of the provisions. The difference between the book value and market value generates a profit for the insurer. This profit can be regarded as a lapse gain. To consider the gains trading and the lapse gain effect, I add the profit generated back to the observed book market difference. Consider the relevant profit added back $Inc_{v_0+\Delta v}$ as the sum over the years Δv of the yearly realized gains. On top of that adjustment I assume that portfolios are constant over time.

[8] German insurers hold derivatives only to a very small extent, see EIOPA (2018) p. 45.

Because I observe neither $MV_{r_0+\Delta r,v_0}$ nor $BV_{r_0+\Delta r,v_0}$, I need an approximation based on $MV_{r_0+\Delta r,v_0+\Delta v}$ and $BV_{r_0+\Delta r,v_0+\Delta v}$, which I observe. I approximate the change in book and market values for a change in observation time. Any present value is sensitive to the passing of time, and the sensitivity to the passing of time increases in the discount rate.[9] Therefore, the interest-rate-induced difference between the market and book value decreases over time.

For a simple presentation I use a valuation at different years z of a future payment a at time to maturity T. I start with a time structure that discount rates changed from r_0 to $r_0 + \Delta r$ just after the item was recognized on the balance sheet and then, from time v_0, a time Δv passed while rates remained constant. The market value is calculated with the current interest rate $r_0 + \Delta r$ as the discount rate. For the book value, the pre-change rate r_0 is the discount rate. Note that it is necessary to also consider the time passing effect of the book value even in a historical cost accounting regime. In such a regime, the book value changes when the time value changes because of a later observation time. Book and market values conditional on observation year $z \in \mathbb{N}$ can be written as:

$$MV_{r_0+\Delta r}(z) = \frac{a}{(1 + r_0 + \Delta r)^{T-z}} \tag{5a}$$

$$BV_{r_0}(z) = \frac{a}{(1 + r_0)^{T-z}} \tag{5b}$$

This means that the face value is discounted back to an earlier date with a later year z. The sensitivity to a change in z is:

$$\frac{\partial MV_{r_0+\Delta r}}{\partial z}\frac{1}{MV_{r_0+\Delta r}} = \frac{ln(1 + r_0 + \Delta r)a}{(1 + r_0 + \Delta r)^{T-z}}\frac{1}{MV_{r_0+\Delta r}} = ln(1 + r_0 + \Delta r) \tag{6a}$$

$$\frac{\partial BV_{r_0}}{\partial z}\frac{1}{BV_{r_0}} = \frac{ln(1 + r_0)a}{(1 + r_0)^{T-z}}\frac{1}{BV_{r_0}} = ln(1 + r_0) \tag{6b}$$

In the following, I approximate the value change at interest level $r_0+\Delta r$ for an absolute time change. A multi-period value change is derived from multiple stages of one-period difference equations. Consider a change of Δv years. This gives the following relationship between the market and book values at year $v_0 + \Delta v$ and year v_0:

$$MV_{r_0+\Delta r,v_0+\Delta v} \approxeq (1 + ln(1 + r_0 + \Delta r))^{\Delta v}\, MV_{r_0+\Delta r,v_0} \tag{7a}$$

$$BV_{r_0,v_0+\Delta v} \approxeq (1 + ln(1 + r_0))^{\Delta v}\, BV_{r_0,v_0} \tag{7b}$$

The later the discount rate changed, the less the present value increased with the passage of time. I relax the full consideration of the time passage effect which is attributable

[9] See Chance and Jordan (1996) for background on the effect of time on the price of financial securities.

to the basic case of an abrupt change in discount rates first and time passage afterwards. Instead, I take half of the time period of Δv in the exponent. This roughly approximates that interest rate uniformly decreased over time. It gives the following approximate relationship:

$$MV_{r_0+\Delta r, v_0+\Delta v} \approxeq (1 + ln(1 + r_0 + \Delta r))^{0.5\Delta v} \, MV_{r_0+\Delta r, v_0} \tag{8a}$$

$$BV_{r_0, v_0+\Delta v} \approxeq (1 + ln(1 + r_0))^{0.5\Delta v} \, BV_{r_0, v_0} \tag{8b}$$

Then, I derive the following estimate of the book market difference which considers the time passing effect.

$$MV_{r_0+\Delta r, v_0} - BV_{r_0, v_0} \approxeq \frac{MV_{r_0+\Delta r, v_0+\Delta v}}{(1 + ln(1 + r_0 + \Delta r))^{0.5\Delta v}} - \frac{BV_{r_0, v_0+\Delta v}}{(1 + ln(1 + r_0))^{\,0.5\Delta v}} + Inc_{v_0+\Delta v} \tag{9}$$

This gives the following approximation of the duration prior to the change in discount rate and the related time change:

$$Dur_{r_0, v_0} \approxeq - \frac{\frac{MV_{r_0+\Delta r, v_0+\Delta v}}{(1+ln(1+r_0+\Delta r))^{0.5\Delta v}} - \frac{BV_{r_0, v_0+\Delta v}}{(1+ln(1+r_0))^{0.5\Delta v}} + Inc_{v_0+\Delta v}}{\Delta r} \frac{1}{\frac{BV_{r_0, v_0+\Delta v}}{(1+ln(1+r_0))^{0.5\Delta v}}} \tag{10}$$

The duration estimate is therefore the relative change in the valuation of market over book value divided by the discount rate change, where the book and market values are the currently observed valuations discounted back to the time of recognition on the balance sheet. Because the book value is discounted at a different rate than the market value, the difference in valuation between the market and book values changes through discounting relative to the undiscounted difference. This reflects that the currently observed difference in valuation differs from the original valuation difference. In addition, an adjustment is made for gains on the sale of securities and for lapses to cover portfolio changes.

Using Equation (10) one can, in principle, separately calculate the duration of liabilities $Dur_{r_0, v_0}^{Liabilities}$ and the duration of assets Dur_{r_0, v_0}^{Assets}. The duration gap is defined as the difference between the two.

$$Durationgap = Dur_{r_0, v_0}^{Liabilities} - Dur_{r_0, v_0}^{Assets} \tag{11}$$

This difference should be interpreted as a comparison of sensitivities, and not as a difference in value changes, because the asset value usually exceeds the liability value. The sensitivity of own funds is approximated by:

$$SensitivityOwnFunds = \frac{BV_{r_0, v_0+\Delta v}^{Assets} \frac{Dur_{r_0, v_0}^{Assets}}{100} - BV_{r_0, v_0+\Delta v}^{Liabilities} \frac{Dur_{r_0, v_0}^{Liabilities}}{100}}{OwnFunds} \tag{12}$$

with $OwnFunds$ being the national GAAP own funds.

4 Application to German life insurers

4.1 German life insurance sector

As an empirical application, I estimate the interest rate risk of German life insurers. This subsection introduces important characteristics of the German insurance sector.

Life insurance within Germany is always regulated as a standalone entity and it is consequently organized and managed as a separate subsidiary. In 2014, there are 86 German life insurers, which are subsidiaries of 54 insurance groups. Among the groups, 15 are listed on the stock exchange, 4 are non-listed private corporations, 28 are mutual insurance companies, 6 are public sector firms, and one is the policyholder protection scheme, a corporation with German life insurers being the shareholders. The listed groups include insurance companies headquartered in Germany (e.g. Allianz and Munich Re) as well as companies with headquarters abroad (e.g. Axa, Generali and Zurich). Most of the groups operate only in insurance, but a few are large diversified groups with additional activities in asset management and banking.

Germany has a large life insurance industry with life insurance policies being important long-term saving vehicles. Typical products are endowment and annuity policies.[10] Total financial assets of the life insurance sector are 818 billion euro (year 2014), which corresponds to about 28% of GDP. Approximately 90% of financial assets are fixed-income investments. The vast majority of customers' claims and the corresponding liabilities of insurers have fixed interest rates. The premium reserve is the most important liability at 750 billion euros. Life insurers create this provision to provide for future net benefit obligations that are guaranteed and attributed to individual policies. If in the following the term liabilities is used, then this refers to the premium reserves.

The fixed interest liabilities arose from minimum return guarantees, which are applied on a year-by-year basis to the policyholders' savings (for more details see Eling and Holder, 2013). The minimum return is set at the inception of the contract and cannot be changed afterwards. All insurance contracts entered into within the same period have the same minimum return. For example, all insurance contracts entered into between July 1986 and June 1994 provide 4%. Over time, the minimum return guarantee was reduced for new contracts. For this reason, the average is essentially determined by the years in which

[10] Simply put, an endowment policy is a savings vehicle for which policyholders pay monthly premiums and the full benefit becomes due at an expiry date (or before, if the policyholder dies). Annuity policies provides life-long annuity payments after either a large one-time payment or as a savings vehicle following the payment of regular monthly premiums.

policies were sold. The industry average in 2014 is 3.1%, which is higher than current market yields. This implies that the expense for the minimum return makes up the lion's share of expenses. This contrasts with, for example, France, where the average minimum return is much lower and usually not binding (Hombert and Lyonnet, 2017).

German life insurers' liabilities are highly sensitive to interest rates. This is documented by EIOPA (2014), whose estimate for the duration gap of Germany's life insurance sector is one of the widest of all the countries included in its analysis. Typical characteristics of long-duration insurance policies are long-term contracts with a long-term accumulation phase which provide fixed minimum returns that are independent of the underlying investment returns. Alternative popular life insurance products with lower or no fixed interest rate guarantees such as unit-linked policies have been rarely sold in Germany. Single premium annuities have just recently become more popular. The tax system has also contributed to long-duration policies, because very long-term annuity policies with an accumulation phase offer tax advantages compared to other saving options. In contrast to Germany, life insurers in the United States have a narrower duration gap and those in the United Kingdom have none at all.[11]

4.2 Basics of German insurance accounting

This paper uses insurance data taken from single-entity balance sheets. Life insurers prepare their single-entity financial statements in accordance with German national GAAP, the German Commercial Code (*HGB*) and regulatory provisions.

On the asset side, investments are, in principle, valued at the lower of current market value or historical cost. In the low interest rate environment, this implies that most investments - the vast majority of which are fixed-income securities - are carried at par value. Insurers also report their valuation reserves, the difference between market and book values. For this reason, the financial statements disclose two valuations for investments that differ mainly in terms of the discount rate.

On the liability side, the premium reserve is valued at the present value of expected cash flows. It consists of two parts, an interest-rate-insensitive reserve (denoted here as the book value) and an interest-rate-sensitive surcharge, the additional interest provision. The surcharge has the effect, in principle, of adjusting the level of reserves towards the market

[11] EIOPA (2014) and Moody's (2015) provide overviews of duration gaps by country. There is no comprehensive estimate of the duration of U.S. life insurers. Estimates are available from the IMF, which assumes a duration gap of two based on expert judgment and discussion with market participants (IMF, 2015, p. 60) and from Moody's, which estimates a duration gap of less than one based on data reported by large insurance companies (Moody's, 2015). By contrast, empirical studies such as Berends et al. (2013) show considerable interest rate risk for U.S. insurers. An estimate for the U.K. is included in EIOPA (2014).

value. The reasoning is to increase provisions for under-provisioned policies. However, the adjustment is only partial, and there remains a significant portion of hidden losses. It recently became possible to observe the hidden losses on the balance sheet and therefore the market value of insurer liabilities. In 2014 there was a major reform in Germany, the Life Insurance Reform Act, which included a block on dividend payouts. Insurers are only allowed to distribute dividends depending on the hidden losses carried on the liability side. Therefore, I effectively have two valuations of the premium reserve which differ mainly in terms of their discount rate. The difference between the two valuations, the book value and the market value, is the sum of the hidden losses and the additional interest provision.

4.3 Data set

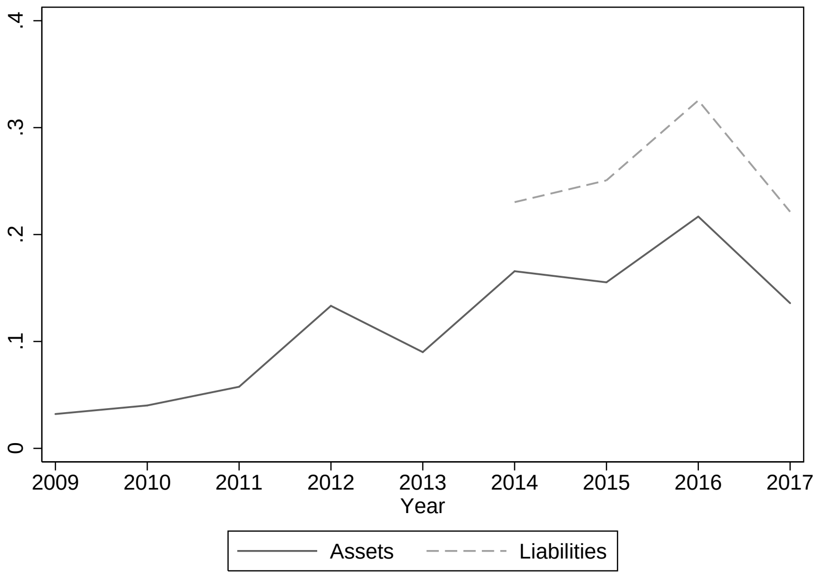
The data set I use is the extended forecast collected by the Federal Financial Supervisory Authority (*BaFin*). The publicly unavailable cross-sectional data set includes detailed reports from the financial reporting systems of all German life insurers. The data are based on company business plans as at 30 September for the full year, assuming stable capital market conditions for the fourth quarter. The detailed accounting and business plan data are collected in the process of preparing financial statements but do not end up being published.

For the year 2014 the data contain 86 life insurers, of which I exclude three insurers with missing observations. These three are very small insurers - in 2014 all three combined have a premium reserve of around 0.25 billion euro compared to an average premium reserve of 9 billion euro. This leaves me with a sample of 83 insurers.

The data set is available yearly. The 2014 edition is the first one that includes data on the market value on the liability side. So far, three more recent versions have been available which include this information, the 2015-17 editions. The annual cross-sections are merged on the basis of a unique identification number for the insurers. Adding the 2015-17 data sets reduces the sample to 76 insurers. This is due to seven insurers either going out of business, being converted to a pension fund, or reporting missing data. These insurers are relatively small, with an average premium reserve of 0.6 billion euro.

The data set includes information on the book and the market value of liabilities. Regarding financial assets, the data set includes information on the book value of investments as well as on the valuation reserves, which are the difference between market and book values. Figure 1 compares the development of book-market differences between the asset and liability side. It is evident that the difference on the liabilities side exceeds the difference on the assets side. This is a first indication of a higher interest rate sensitivity on the liabilities side.

Figure 1: Book-market difference of German life insurers, asset vs. liability side



The graph displays the aggregate book-market difference relative to the book value of 76 German life insurers over time. The sample includes all German life insurers which reported data throughout 2014-17. The solid line displays investments and the dashed line displays liabilities. Based on German national GAAP. The book value of liabilities displayed here is the premium reserve and excludes the additional interest provision. The book-market difference is approximated by the additional interest provision and the hidden losses approximated with what is known in the German legislation as the safeguarding amount. 2014 is the first year that includes data on the market value on the liability side.

The market value of liabilities is based on an industry-wide discount rate prescribed by regulators. For the book value of liabilities I observe an insurer-specific underlying discount rate. In many jurisdictions life insurers are required to report estimated market/fair values and historical costs; however, it is the underlying discount rates which are mostly not observed. The data set has the main advantage that I observe both. On the asset side, both discount rates need to be estimated. I estimate the discount rate for the book value at an insurer level based on average yearly coupon payments. The idea is that coupon payments roughly correspond to the yield at the issue date. Regarding the discount rate for the market value, I estimate the current yield of the fixed-income portfolio. I consider the insurer-specific portfolio split between investment grade bonds and high yield bonds.[12] For the share of investment-grade bonds I use the average current yield of debt securities in Germany.[13] For the high yield bonds I use the sum of the average current yield of debt securities in Germany and the spread of euro-denominated high yield corporate bonds.

To give an overview of the data, Table 1 presents the key balance sheet items and the underlying discount rates for the year 2014. The total market value of investments is

[12]Bonds with a rating of BB or lower and unrated bonds.

[13]Yields on debt securities outstanding issued by German residents, Bundesbank time series BBK01.WU0017.

Table 1: Descriptive statistics of key balance sheet items for the year 2014 [bn euro]

Balance sheet item	Mean	SD	Median	Total
Book value investments	10.7	21.6	3.6	814
Underlying discount rate	*3.7%*	*0.5%*	*3.6%*	
Market value investments	12.5	26.4	4.0	949
Underlying discount rate	*1.0%*	*0.2%*	*1.0%*	
Book value premium reserve	10.1	19.8	3.5	767
Underlying discount rate	*3.1%*	*0.3%*	*3.1%*	
Market value premium reserve	12.1	23.7	4.1	918
Underlying discount rate	*1.2%*	*0.0%*	*1.2%*	

The table shows descriptive statistics of key balance sheet items for 76 German life insurers in the year 2014 based on German national GAAP. The sample is all German life insurers which reported data throughout 2014-17. The book value of the premium reserve displayed here excludes the additional interest provision. The market value of the premium reserve is approximated by adding the additional interest provision and the hidden losses approximated with what is known in the German legislation as the safeguarding amount. The underlying discount rate for the book value of investments is based on average yearly coupon payments. Regarding the discount rate for the market value, an estimate based on the portfolio composition is used. The underlying discount rate for the book value of the premium reserve is the average discount rate reported by insurers. The underlying discount rate for the market value of the premium reserve is the market rate used for calculating the safeguard amount, which is the same for all insurers.

17% higher than the book value. This difference in valuation corresponds to a decrease in discount rates of 2.7 percentage points. The total market value of the premium reserve is 23% higher than the book value. This difference in value corresponds to a decrease in the average underlying discount rate of 1.9 percentage points. Already, this descriptive statistics suggest that liabilities are more sensitive to interest rate changes than assets.

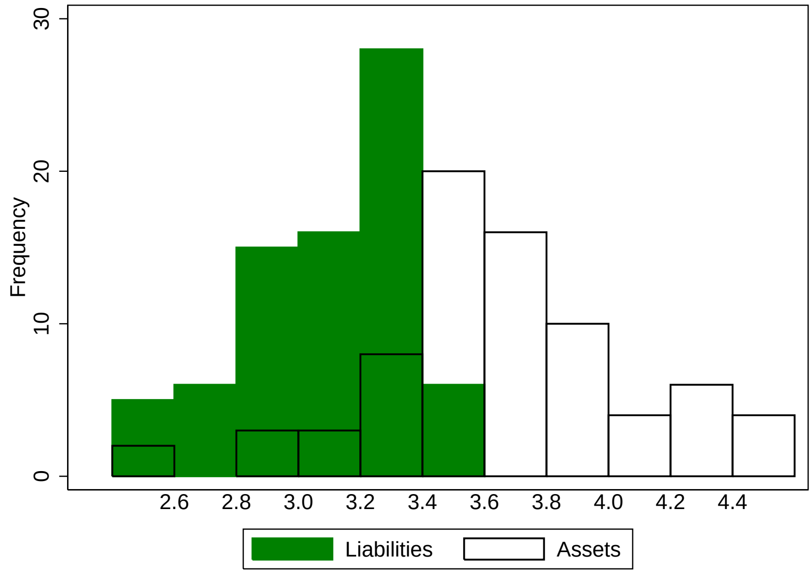
Measured in terms of book value, the discount rates of investments are higher than the discount rates of liabilities. Due to a different age structure of contracts and investments, the average discount rate of the book value differs widely between insurers. Simply put, older contract and investment portfolios have a higher discount rate than younger ones. The discount rate on the asset side differs even more widely between insurers than it does on the liability side (Figure 2).

4.4 Estimate of time passed since recognition on the balance sheet

I derive an estimate of Δv, which is the time period between today and the point of time when the average investment was purchased or the average contract was concluded.

For the liability side, I estimate Δv at an insurer level by using the policy structure set out in the yearly industry report from the rating agency Assekurata. This includes a contract breakdown by guaranteed interest rate for 64 life insurers (89% market share). This breakdown can be used to derive a contract breakdown by starting year, because each observed guarantee rate was only valid for a few years. For the few insurers with no contract split I estimate Δv based on the average guaranteed rate. For the year 2014 this

Figure 2: Histogram of the underlying discount rates for the book value of assets and liabilities for the year 2014 [%]



The histogram shows the distribution of the discount rates r_0 in Equation (10) used to estimate the asset and liability durations. For assets, the discount rate corresponds to the average yearly coupon payments for the year 2014. For liabilities, insurers report this discount rate. The sample is 76 insurers, all German life insurers which reported data throughout 2014-17. Each bin illustrates the number of insurers with a discount rate within the interval.

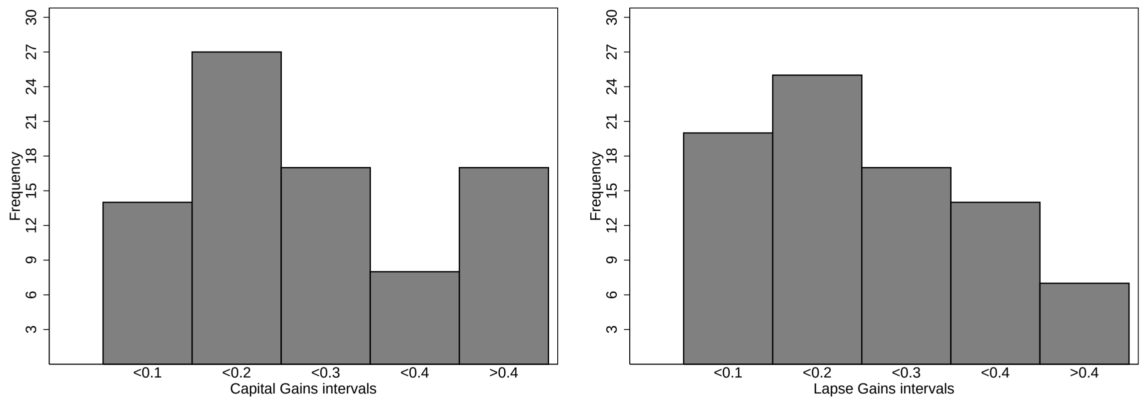
approach gives me an average contract age estimate of 13 years with a standard deviation of 2.3.

For the investment side, I base my estimate on the current return on investments, which excludes valuation effects and is a good proxy for the average yield at the time of investment. I adjust the observed return for portfolio risk, because more investment risk would generally translate into higher coupon payments which maps into this measure. I match, at an insurer level, the current return on investment and the investment yield of a typical investment by year in the past.[14] For the year 2014 this approach results in an average asset age of 6.1 years with a standard deviation of 0.8.

The time passing effect of the market value of the premium reserve cannot be estimated with the general approach outlined above because of measurement specifics: the safeguard amount, which is used to approximate the book-market difference, covers exactly the next 15 years. If the observation year were to move forward, the time period of 15 years would remain constant, but the years included would change. For example, if one measures the hidden losses in year $n + 1$ rather than in year n, one then observes hidden losses from year $n + 1$ until $n + 15$, rather than from year n to $n + 14$. Therefore, the hidden losses

[14]For this purpose, I use yields on German mortgage covered bonds outstanding with ten years maturity (Bundesbank time series BBK01.WX4260). Mostly, interest rates decreased over time. If they did not for a certain year, I would interpolate.

Figure 3: Share of book-market differences that disappeared due to the realization of capital gains (left-hand side) and lapses (right-hand side)



The histograms show the distribution of book-market difference that disappeared from the balance sheet during the time passed Δv, which is used in Equation (9), standardized by division with the book-market difference of the year 2014. The left-hand side displays capital gains realized through the sale of assets with a market value that exceeds the book value. The right-hand side displays the gains realized through lapses, as policyholders who lapse their contracts receive the book value. The sample is 76 insurers, all German life insurers which reported data throughout 2014-17. Each bin illustrates the number of insurers with a yearly income from realized capital gains within the interval.

measure keeps itself up to date. For this reason, in the specific case of German insurance accounting, one needs not account for the time passing effect of the difference between market and book value.

4.5 Estimate of the effect of gains trading and lapses

Insurers generate accounting profits from the sale of assets (realization of capital gains) and from lapses (realization of book-market differences on the liability side). I calculate the relevant profit $Inc_{v_0+\Delta v}$ for the period between v_0 and $v_0 + \Delta v$.

Each insurer reports the investment income from gains trading each year in their profit and loss statement. This information permits me to calculate the relevant profit. On aggregate, the valuation reserves that disappeared due to the realization of capital gains are 28 billion euro, or 21% of the book-market difference. On the liability side, I use the yearly lapse rate of insurers and multiply it for each year by the observed book-market difference. On aggregate, the hidden losses that disappeared due to lapses are 27 billion euro, or 18% of the book-market difference.

Figure 3 displays the distribution between insurers for the year 2014, with both the asset and liability side standardized by the observed book-market difference. It illustrates that most insurers have made only moderate use of profit generation from realized capitals gains; however, the effect on the book-market difference is considerable larger on the asset side than on the liability side. One observes long tails on the asset side as some insurers generated considerably more profit than the median insurer.

5 Results

5.1 Estimation of the duration gap

On the basis of the data discussed in the previous section I calculate for German life insurers the duration of assets and liabilities as well as the difference between the two, the duration gap. In the aggregate, the sector has an estimated asset duration of 11 and a liability duration of 17 in 2014 (Table 2). The resulting duration gap amounts to 6. This means that a one percentage point decrease in interest rates leads to an increase in the market value of liabilities that is approximately six percentage points greater than the relative increase in the market value of assets. The aggregate view weighs larger insurers more heavily than smaller ones. The median duration gap is larger than the aggregate estimate, which implies that smaller insurers tend to have a wider duration gap than larger insurers. In fact, the insurers with particularly large duration gaps tend to be small. Looking at the time series, both asset and liability duration grow over time until 2016. The asset duration grows more strongly and the duration gap narrows. Insurers adjust their portfolio, but the adjustment takes place slowly, so that the duration gap slowly narrows over time. This result is largely in line with the development described by Domanski et al. (2017). It is also consistent with the result of Koijen et al. (2017) that insurers were net buyers of government bonds in the environment of quantitative easing and falling interest rates.

The estimated duration gap can be compared with estimates of other studies on German life insurers. The results are in a similar range. EIOPA (2014) derives a (Macaulay) duration for assets of 10 and for liabilities of 21. The rating agency Assekurata estimates the modified duration for fixed-income investments at 8 for 2011, with an upward trend since that time. The German insurance association estimates in an unpublished analysis the modified duration for fixed-income investments at 7 for 2009, again with an upward trend since then, and the duration for liabilities at 15 (no estimate for different years). Domanski et al. (2017) estimate the asset duration at about 10 for 2010 with an upward trend since.

I use the duration result to calculate the sensitivity of the residual claim, the own funds. In analogy to the previous definition of the book value, I use the reported own funds to which the additional interest reserve has been added. Because German life insurers operate with little own funds relative to the balance sheet size, their sensitivity to interest rate changes is high. The estimate for the year 2014 implies that, on aggregate, a one percentage point decrease in interest rates results in a 45 percent decrease in own funds (Table 2). The sensitivity of balance sheet own funds is higher than stock market value sensitivity. Hartley et al. (2016) observe, based on stock market data, that a one

Table 2: Interest rate sensitivity estimate of German life insurers (2014-17)

		Total	Mean	SD	p25	p50	p75
2014	Asset duration	11.4	10.1	1.9	8.8	10.0	11.1
	Liability duration	17.1	17.6	4.3	14.2	16.9	20.3
	Duration gap	5.7	4.3	4.3	4.2	6.9	10.4
	Sensitivity own funds	.45	.56	.39	.29	.52	.77
2015	Asset duration	12.0	11.0	3.0	9.1	10.6	12.1
	Liability duration	17.4	18.5	5.0	14.9	17.8	20.6
	Duration gap	5.4	7.5	5.0	4.2	6.6	10.0
	Sensitivity own funds	.33	.44	.36	.20	.40	.66
2016	Asset duration	14.0	12.3	2.3	10.5	12.1	13.8
	Liability duration	17.5	19.1	6.7	15.8	17.8	20.8
	Duration gap	3.4	6.8	6.9	2.8	5.5	8.6
	Sensitivity own funds	.09	.27	.30	.08	.24	.44
2017	Asset duration	14.2	11.7	2.3	10.3	11.5	13.0
	Liability duration	16.1	17.2	4.4	14.5	16.4	19.1
	Duration gap	1.9	5.5	4.5	2.8	4.7	7.3
	Sensitivity own funds	.00	.22	.28	.03	.21	.37

The table shows descriptive statistics of the modified durations estimated in Equation (10), the duration gap estimated in Equation (11) and the sensitivity of own funds estimated in Equation (12) for 76 insurers, all German life insurers which reported data throughout 2014-17. The wider the duration, the more sensitive is the value of the balance sheet side to a change in interest rates. The wider the duration gap, the more an insurer is exposed to interest rate risk.

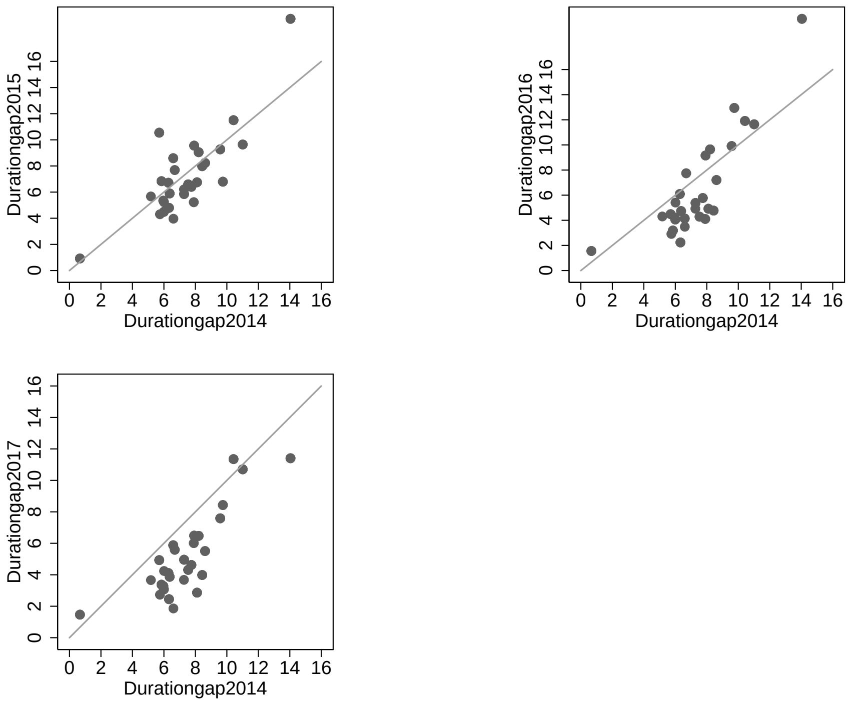
percentage point decrease in yield in mid-2015 is associated with an nine percent drop in the stock market value of U.S. life insurers. Sensitivity was lower before that date. For U.K. life insurers the effect is not significantly different from zero. Domanski et al. (2017) replicate the analysis using a German life insurance stock market index. They find that a one percentage point decrease in yield is associated with a seven percent drop in the stock market value. That the book value of own funds is more sensitive than the stock market value is in line with the asset insulator view of Chodorow-Reich et al. (2018). It is also in line with the fact that listed insurance companies are diversified companies and therefore less sensitive to interest rate risk than pure life insurance companies.

To get an overview of the association between the duration gaps across different years, I graphically compare the duration gap of the year 2014 with the duration gaps of the years 2015, 2016 and 2017, respectively (Figure 4). The correlation between the individual years is high.

5.2 Variation in interest rate risk between insurers

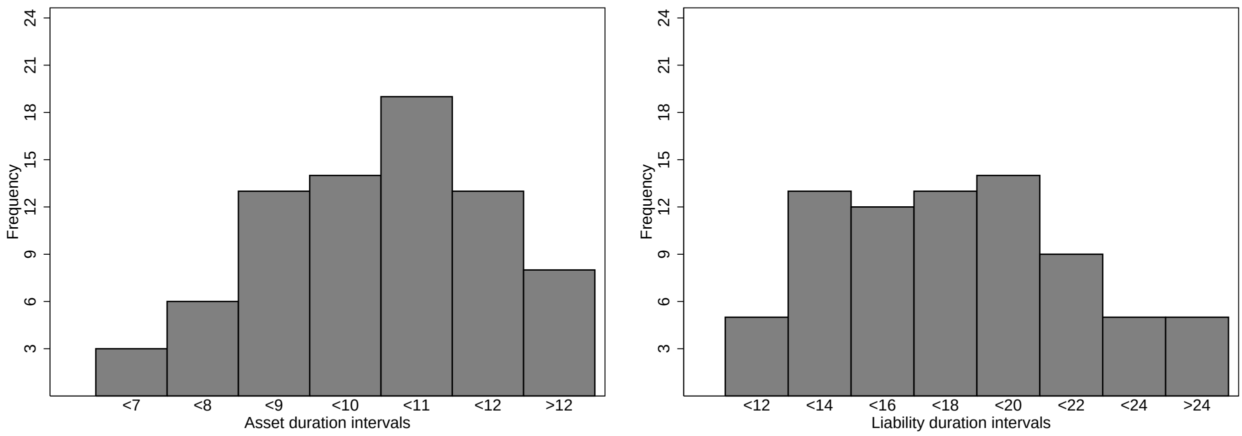
Figure 5 illustrates the distribution of the estimated duration between insurers, both for the asset and the liability side. The variation in duration on the liability side is wider than on the asset side. While the asset duration is approaching a normal distribution,

Figure 4: Comparison of duration gap estimates between years



The scatterplots show the association between the duration gaps estimated in Equation (11) across different years. The dots displayed are averages between three insurers selected at random to comply with data confidentiality. The top-left scatterplot compares the years 2014 and 2015, while the top-right scatterplot compares the years 2014 and 2016 and the bottom-left scatterplot compares the years 2014 and 2017. The mid-lines indicate combinations for which the duration gap is identical in both years.

Figure 5: Distribution of asset and liability duration (2014)



The histograms show the distribution of the modified durations estimated in Equation (10) for 76 German life insurers for the year 2014. The left-hand side shows the distribution of asset durations, while the right-hand side shows the distribution of liability durations. Each bin illustrates the number of insurers with a duration within the interval. The wider the duration, the more sensitive is the value of the balance sheet side to a change in interest rates.

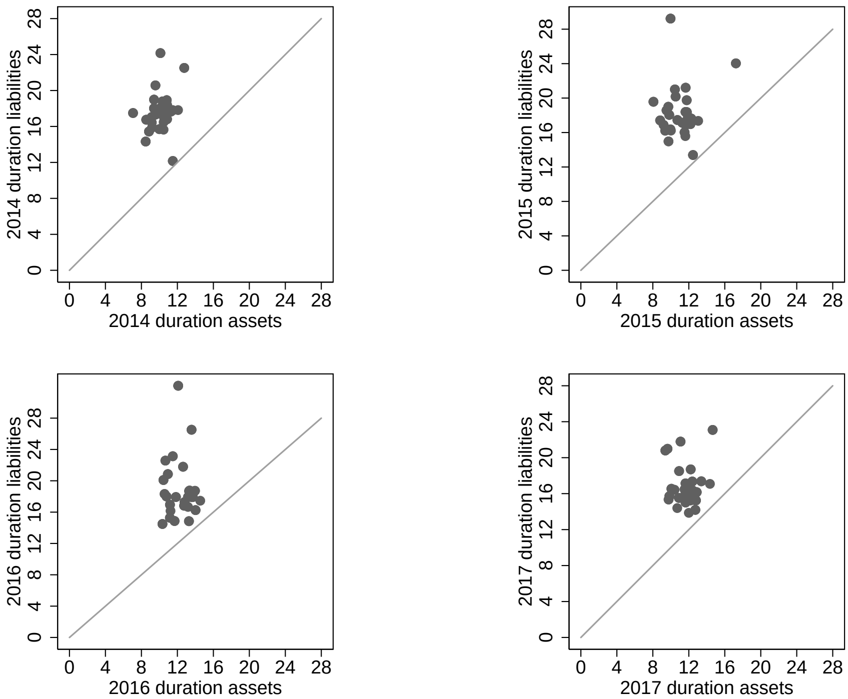
the distribution of the liability duration is relatively broad with a long tail. The wide distribution of liability durations illustrates that it is advisable to take into account large differences when making statements about interest rate risk of life insurers. The cross-insurer standard deviation of the gap is 4.3 for the year 2014, which is higher than the cross-country standard deviation of 3.6 reported by EIOPA (2014). A comparison of distributions on the asset and liability sides indicates that the variation of both contributes to the cross-sectional differences in the duration gap.

5.3 Relationship between asset duration and liability duration

Asset-liability management implies that insurers with a higher liability duration should have a higher asset duration. The idea is that the investment process is liability-driven. An insurer should adjust the duration of its investment portfolio as the duration of its liabilities changes. This implies that, in theory, liability duration causes asset duration. Figure 6 compares asset and liability durations in the cross-section of insurers for the years 2014-17. Given complete matching, all the dots would be on the mid-line. However, this requires only low degrees of freedom for investment management and only limited opportunities to follow alternative investment strategies. The relationship between asset and liability durations is weak. The scatterplots suggest that the two sides of the balance sheet are barely related. This implies limited liability-driven investment and insurers giving low priority to duration matching compared with other investment objectives.

To investigate the asset-liability correlation of investment duration with liability duration, I estimate

Figure 6: Comparison of the distribution of asset and liability duration of German life insurers (2014-17)



The scatterplots show the relationship between the asset duration on the x-axis and the liability duration on the y-axis for the years 2014-17, both estimated in Equation (10), for 76 German life insurers. The dots displayed are averages between three insurers selected at random to comply with data confidentiality. The greater the duration, the more sensitive is the value of the balance sheet side to a change in interest rates. The mid-line indicates combinations for which the asset duration equals the liability duration. The distance to the mid-line indicates the duration gap.

$$\left(Dur^{Assets}_{r_0,v_0}\right)_{i,t} = \beta_0 + \beta_1 \left(Dur^{Liabilities}_{r_0,v_0}\right)_{i,t} + \beta_2 X_{i,t} + \epsilon_{i,t} \tag{13}$$

Standard errors are clustered by group to address the potential correlation of insurers' durations across the firms in a group. Extreme values of the duration measures were set to the mean plus/minus the 2.5 standard deviations if they exceeded this value. I use both fixed-effects and random-effects models. The liability duration cannot be influenced by the insurer, while the asset duration is the result of decisions by the insurers' investment managers. Nevertheless, the regression results should in principle only be interpreted as the correlation between the asset-side and liability-side duration. If insurers seek to exactly match the durations of assets and liabilities, one would expect $\beta_1 = 1$. Where asset-liability management takes place, but duration matching is done only partly, one would expect β_1 to be substantially larger than zero, but below one.

Some specifications include firm characteristics $X_{i,t}$. The first one is size, measured by the natural logarithm of the book value of the premium reserve. A dummy variable is used to control for insurers in run-off. These are insurers that have stopped selling new policies. I also control for growth perspectives, measured by the planned annual premium growth in percent during the next three years. I take this information from the respective company forecasts in the extended forecasts data sets for the years 2014-17. Further dummy variables are used to control for the following aspects: whether the final shareholder of the life insurer is an exchange-listed group, a mutual insurance company or a public sector firm. The remaining insurers' final shareholders are private corporations or it is the policyholder protection scheme. Further, I control for direct insurers. These are insurers that do not work with brokers or insurance agents. Instead, they sell policies mostly through their websites. This is also a proxy for age because these companies have been established more recently. Finally, I control for whether an insurer used interest rate derivatives as a hedging instrument during the years 2010-2013. The derivatives data are taken from regulatory reporting. Table 3 displays detailed descriptive statistics of these firm characteristics. I expect asset and liability duration to differ between insurers with different attributes, though, I do not have directional hypotheses.

Table 4 displays the results. The relationship between asset and liability duration is not significantly different from zero. In addition, the coefficient is far from 1. This is contrary to liability-driven investment; it suggests that insurers do not attach much priority to duration matching.

5.4 Role of asset insulation

This subsection studies the trade-off between interest rate risk reduction and asset insulation. Asset insulation preferences are approximated with specific traits of insurers'

Table 3: Descriptive statistics of life insurer attributes

Variable:	Mean.	SD	p25	Median	p75
Planned premium growth	-.08	5.25	-1.80	.19	1.98
Run-off	.08	.27	0	0	0
Size (log premium reserve)	15.0	1.67	14.0	15.1	16.4
Final shareholder listed group	.37	.48	0	0	1
Final shareholder mutual insurer	.45	.50	0	0	1
Final shareholder public	.11	.31	0	0	0
Direct insurer	.08	.27	0	0	0
Interest rate derivatives	.43	.50	0	0	1

The table shows descriptive statistics of company attributes used as variables in regressions 13 and (14a). There are two continuous variables: projected premium growth for the next three years, measured in percent, and size, measured as the natural logarithm of the book value of the premium reserve. Further, it includes the following dummies: being in run-off, being a direct insurer and being a subsidiary where the final shareholder is a listed group, a mutual insurance company or in public ownership. The remaining insurance companies are subsidiaries of a private corporation which is not listed or the policyholder protection scheme. Finally, it includes as a dummy variable the use of derivatives as a hedging instrument in the years 2010-2013.

Table 4: Association between investment and liability duration

	(1)	(2)	(3)	(4)	(5)	(6)
	Fixed-effects		Random-effects		Pooled	
Variable	Coeff	Coeff	Coeff	Coeff	Coeff	Coeff
	(SE)	(SE)	(SE)	(SE)	(SE)	(SE)
Liability duration	.026	.020	.032	.029	.059	.028
	(.049)	(.047)	(.038)	(.037)	(.049)	(.037)
Firm characteristics	No	Yes	No	Yes	No	Yes
Year fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes
Adj. R-squared	.56	.57	.14	.37	.14	.37

The table shows results from panel regression (13). The sample consists of 76 life insurers for the three years 2014-17. The dependent variable is the investment duration and the variable is the liability duration, both estimated in Equation (10). Extreme values are set to the mean plus/minus the 2.5 standard deviations if they exceed this value. Column (1) and (2) display results of a fixed-effects regression, column (3) and (4) of a random-effects regression and column (5) and (6) of a pooled-model. Standard errors are clustered by group and displayed in brackets. *, ** and *** show a significance level of 0.1, 0.05 and 0.01, respectively.

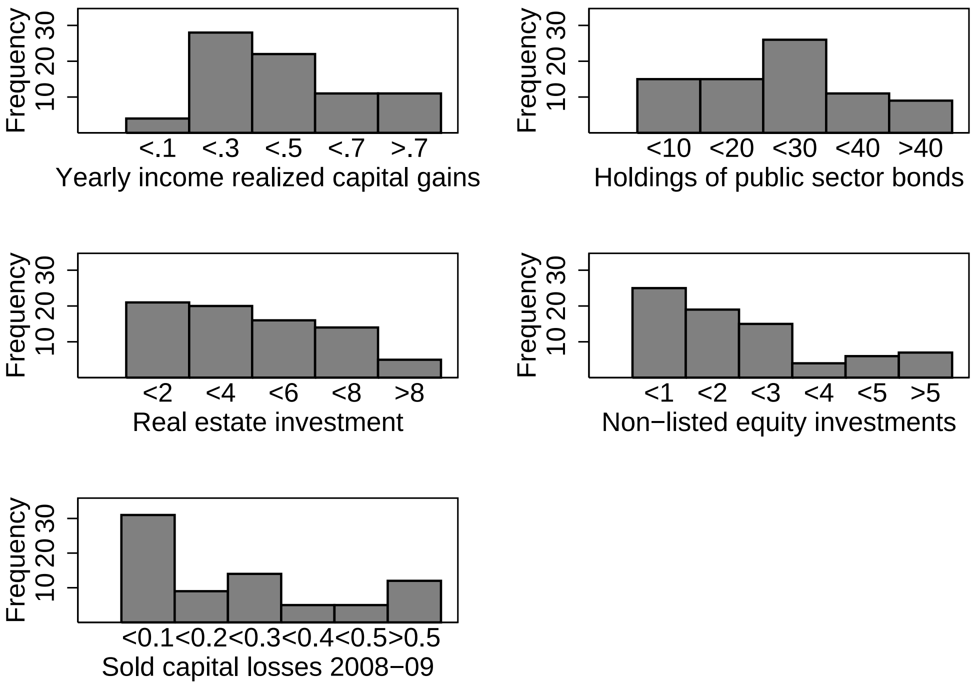
investment behavior, as certain asset classes and a particular trading behavior make sense for asset insulation, while being counterproductive for duration matching. Characteristics from the past need to be used, because the interest rate risk calculated in this paper is the result of investment strategies from the past. Detailed data on pre-defined categories of investments are available for the German market, but not on an asset-by-asset basis. On this basis, I use five variables whose values can be considered typical for asset insulation.

The first variable covers the holding period of investments. I use the average yearly income from realized capital gains between 2006 (the first available year) and 2013 (the last year before the first measure of interest rate risk) observed in accounting statements. Income is shown relative to the market value of total investments in 2014. The higher this proxy, the higher the share of securities sold at a profit before the maturity date. This approximates asset turnover and the tendency whether an insurer holds assets for the short run or the long run. For insurers with a full buy-and-hold strategy this variable is zero. The more an insurer pursues an asset insulation strategy, the lower I expect this variable to be. In contrast, it is advisable for a duration matching strategy to regularly sell assets. A typical strategy for extending the duration of asset holdings is to replace securities with a diminished duration with newer long-dated securities, because the duration of an asset typically declines over time, since the residual maturity shrinks. A histogram illustrates some heterogeneity between insurers, with the median insurer having a yearly income from gains trading of 0.3% relative to total investments (top-left side of Figure 7).

The second variable covers the type of investments. Insurers miss out on opportunities to create value if they hold a certain amount of public sector bonds. Instead, the advantage of asset insulation is greatest if illiquid and volatile securities are held. By contrast, public sector bonds are essential for duration matching because they are often the only bonds available with very long-term maturities. I use the share of public sector bonds compared to total investments in 2013, one year before the period used for the remaining analysis (2014-17). The more insurers pursue an asset insulation strategy, the lower I expect this variable to be. There is considerable heterogeneity among insurers, with the median insurer having holdings of 23% relative to total investments (top-right side of Figure 7).

The third variable covers real estate investments. Real estate is an attractive investment class for asset insulation, because real estate investments are illiquid and have high transaction costs. By contrast, real estate is of limited use for duration matching, because the duration of real estate is typically lower than the duration of long-term bonds (e.g. Constantinescu, 2010) and at the same time, high transaction costs do not permit a regular adjustment of portfolios. I use the share of real estate investments compared to total investments in 2013. The variable covers the following investments: direct investment in land and land rights, direct investment in real estate, shares of real estate companies, real

Figure 7: Distributions of typical investment features that suggest a prevalence of an asset insulation strategy [%]



The top-left histogram shows the distribution of asset turnover, measured as the average yearly income from realized capital gains between 2006 and 2013 as a percentage of total investments for the year 2014. The higher the income, the higher the asset turnover. A high level indicates a low degree of asset insulation. The top-right histogram shows the distribution of public sector bond holdings, measured as the holdings of public sector bonds as a percentage of total investments for the year 2013. A high level indicates a low level of asset insulation. The centre-left histogram shows the distribution of real estate investments, measured as the holdings of real estate investments as a percentage of total investments for the year 2013. A high level indicates a high level of asset insulation. The centre-right histogram shows the distribution of non-listed equity investments, measured as the holdings of non-listed equity as a percentage of total investments for the year 2013. A high level indicates a high level of asset insulation. The bottom-left histogram shows the distribution of realized capital losses during the years 2008 and 2009 divided by total investments during these years. A high level indicates a low level of asset insulation. The sample is 76 German life insurers for which data are available throughout. Each bin illustrates the number of insurers with a level within the interval.

estate investment trusts, shares in closed-end real estate funds and shareholder loans to real estate companies. While many insurers invest less than 2% in real estate, there are also many insurers which invest considerable shares in this investment class (centre-left side of Figure 7).

The fourth variable covers non-listed equity investments, an investment class which is also typically illiquid and has high transaction costs. The variable covers the following investments: intragroup equity investments, private equity investments and shares in private-public partnerships. I use the share of non-listed equity investments compared to total investments in 2013. Most insurers invest less than 2% of their portfolios in non-listed equity, though there are some which invest a considerable share of their portfolios in this asset class (centre-right side of Figure 7).

Finally, the fifth variable covers realized capital losses during the peak of the financial crisis in 2008-09. During this time, prices of many financial securities plummeted, in particular those of equity and other risky assets. If insurers sold assets at market prices below book prices they would have realized capital losses. However, if they held securities to maturity, potential losses would not be included in this income category. In 2008 German insurers realized on aggregate capital losses of 2.3 billion Euro, an increase of 90% compared to 2007 and of 230% compared to 2006. The realization of capital losses on this scale is at odds with the idea of asset insulation, that insurers could actually hold securities to maturity and thus endure interim losses. While it was indeed the case that many insurers did not realize any capital losses at all, there are some which realized losses amounting to more than 0.5% of assets. Overall, the distribution is right-skewed (bottom-left side of Figure 7).

I construct two indices of asset insulation with five variables all having an equal weight. The first one is a normalized index between 0 and 1. For asset turnover, public sector bonds and realized losses in 2008-09, it is 1 minus the cross-sectional quantile category divided by the number of insurers. For real estate and non-listed equity investment it is the cross-sectional quantile category divided by the number of insurers. The second one is a standardized index using the z-score of the five variables. Asset turnover, public sector bonds and realized losses enter the index with a negative algebraic sign, while real estate and non-listed equity investment enter the index with a positive algebraic sign. The higher the indices, the higher the degree of asset insulation. Figure 8 displays scatterplots between asset duration and the two indices of asset insulation. In line with a trade-off, the correlation is negative.

Table 5 displays a correlation matrix of the five variables, the indices and the asset duration estimate. All the correlations are mostly as predicted. That is, insurers with a higher asset duration invest more in public sector bonds, less in non-listed equity, they

Table 5: Correlation matrix of the asset duration estimate, asset insulation indices and the five characteristics typical for asset insulation

		Predicted correlation with asset duration	Dur	I1	I2	Var1	Var2	Var3	Var4	Var5
Dur	Mid asset duration 2014-17		1							
I1	Asset insulation index	−	-.45	1						
I2	Asset insulation index 2	−	-.40	.89	1					
Var1	Asset turnover	+	.43	-.69	-.70	1				
Var2	Public sector bonds	+	.54	-.31	-.37	.22	1			
Var3	Real estate	−	.01	.54	.58	-.15	.27	1		
Var4	Non-listed equity	−	-.02	.56	.37	-.05	.20	.46	1	
Var5	Realized losses 2008-09	+	.09	-.14	-.43	.30	.25	-.01	.36	1

The table shows a correlation matrix calculated for 76 German life insurers. Dur is the average asset duration for the years 2014-17, for each year estimated in Equation (10). Extreme values are set to the mean plus/minus the 2.5 standard deviations if they exceed this value. I1 measures the degree of asset insulation as a normalized index. I2 measures the degree of asset insulation as a standardized index. The higher the indices, the more the investment strategy of an insurer has the typical traits of an asset insulator strategy. Both indices are based on Var1 to Var5. Var1 is the average yearly realized capital gain between 2006 and 2013 relative to total investment in percent. A high level indicates a low level of asset insulation. Var2 is the average holding of public sector bonds relative to total investment in 2013 in percent. A high level indicates a low degree of asset insulation. Var3 is the investment in real estate relative to total investment in 2013 in percent. A high level indicates a high degree of asset insulation. Var4 is the natural logarithm of the investment in non-listed equity relative to total investment in 2013 in percent plus 1. A high level indicates a high degree of asset insulation. Var5 is the natural logarithm of average yearly capital losses in 2008 and 2009 relative to total investment in percent plus 1. A high level indicates a low degree of asset insulation. The framed column indicates the correlations relevant for interpreting the effect of insurers' investment traits on asset duration.

trade more often and they realized more capital losses during the financial crisis. Only the correlation with real estate investment is largely zero. The correlation of the asset insulation indices with asset duration is negative as expected.

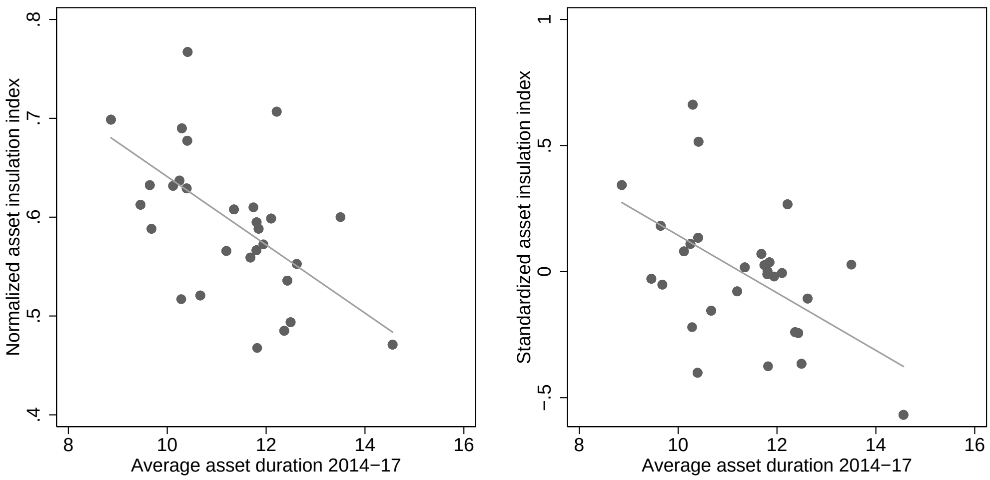
To conduct an empirical horse race between interest rate risk reduction and asset insulation, I estimate the following regressions, whose results are compared with Equation (13).

$$\left(D^{Assets}_{r_0,v_0}\right)_{i,t} = \alpha_0 + \alpha_1 Traits_i + \alpha_2 X_{i,t} + \epsilon_{i,t} \tag{14a}$$

$$\left(D^{Assets}_{r_0,v_0}\right)_{i,t} = \beta_0 + \beta_1 AssetInsulation_i + \beta_2 X_{i,t} + \epsilon_{i,t} \tag{14b}$$

where the dependent variable is the asset duration of insurers i at year t, $Traits_i$ is a vector of characteristics (Var1) to (Var5) in Table 5 and $AssetInsulation_i$ is one of two indices (I1) and (I2) in Table 5, which approximate asset insulation. The regressions include firm characteristics $X_{i,t}$ as in Equation (13) which includes time-varying variables as well as variables which do not change over time. First, I estimate a random-effects model with and without firm characteristics included (column 1 and 2). Column (3) displays a pooled model without control for company characteristics. Column (4) shows

Figure 8: Distribution of asset duration and the proxy for the degree of asset insulation



The scatterplots show the relationship between the average asset duration for the year 2014-17 on the x-axis and indices for the degree of asset insulation for 76 German life insurers. The dots displayed are averages between three insurers selected at random to comply with data confidentiality. Asset duration is estimated in Equation (10). Extreme values of asset duration are set to the mean plus/minus the 2.5 standard deviations if they exceed this value. The greater the duration, the more sensitive the value of the balance sheet side is to a change in interest rates. The index displayed on left-hand side measures the degree of asset insulation as a normalized index. The index displayed on the right-hand side measures the degree of asset insulation as a standardized index. The higher the indices, the more the investment strategy of an insurer has the typical traits of an asset insulator strategy.

the same model but with firm characteristics included.[15]

Table 6 displays the results. For multivariate regressions, any interpretation should bear in mind that the small sample and multicollinearity make it difficult to obtain significant results for each variable. I find in all specifications that the coefficient of asset turnover is highly significantly positive. The effect of public sector bond holdings on asset duration is also significantly larger than zero in all specifications. The effect of real estate investment on asset duration is, as expected, significantly negative, in specifications with control variables. The estimated effect of non-listed equity is negative as expected, though it is not significantly different from zero. The effect of realized losses in 2008-09 is not significant and does not have the expected algebraic sign (even though the bivariate correlation indicated otherwise). The indices of asset insulation have a negative significant effect in all specifications. In summary, investment features which approximate asset insulation have a significant negative effect on asset duration.

In a comparison of the regression of asset duration on liability duration (Table 4) and the regression of asset duration on the indices for asset insulation (Table 6), one sees that asset insulation is much better at explaining asset duration than the liability duration. This result suggests that asset insulation goes some way towards explaining why insurers have not changed their asset duration in order to reduce their interest rate risk.

It is important to acknowledge that the empirical analysis is based on correlations. The same effect could result from omitted variables that are related to asset duration as well as to the investment features. I explicitly control for firm characteristics to mitigate this concern. Nevertheless, there is not a conclusive identification strategy, so the result should be interpreted carefully.

5.5 Robustness

I repeat the analysis with simple estimates of interest rate sensitivity, starting with the ratio of the book-market difference to the book value. The purpose is to illustrate that the results do not depend on the details how the interest rate risk variable is calibrated. Table 7 displays the results which are similar to the ones obtained before. The effect of asset insulation is negative, being highly significant in most specifications. The effect of the interest rate sensitivity of liabilities, calculated in analogy to the asset side, is not significant in any specification.

[15] Note that, in principle, one could also calculate a yearly estimate of investment characteristics and estimate a fixed-effects model. However, I do not consider that approach to be meaningful, because the theory followed here concerning insurers' behavior is about a feature of investment management and not about a yearly change of behavior. This feature should be captured with the average that covers a series of past decisions.

Table 6: Panel regression: Relationship between asset duration and the proxy for the degree of asset insulation

		(1)		(2)		(3)		(4)	
		Random-effects				Pooled			
Variable:	Predicted	Coeff.	SE	Coeff.	SE	Coeff.	SE	Coeff.	SE
Regression (14a)		Dependent variable: Asset duration							
Asset turnover	+	3.6***	(.62)	3.8***	(.64)	3.6***	(.62)	3.9***	(.64)
Public sector	+	.056***	(.019)	.032*	(.017)	.056***	(.019)	.031*	(.017)
Real estate	−	-.041	(.075)	-.14**	(.064)	-.041	(.75)	-.15**	(.063)
Non-listed equity	−	-.13	(.48)	-.36	(.45)	-.13	(.48)	-.36	(.45)
Losses 2008-09	+	-.87	(.55)	-.41	(.60)	-.87	(.55)	-.41	(.61)
Adj. R-Squared		.45		.57		.45		.57	
Regression (14b)		Dependent variable: Asset duration							
Insulation index (normalized)	−	-7.3***	(1.7)	-8.0***	(2.0)	-7.3***	(1.7)	-7.9***	(2.0)
Adj. R-Squared		.29		.47		.29		.47	
Regression (14b)		Dependent variable: Asset duration							
Insulation index (standardized)	−	-1.7***	(.49)	-1.9***	(.48)	-1.7***	(.49)	-1.8***	(.48)
Adj. R-Squared		.25		.46		.25		.46	
Firm characteristics		No		Yes		No		Yes	
Year fixed effects		Yes		Yes		Yes		Yes	

The table shows regression results for a panel of 76 German life insurers for the years 2014-17. The dependent variable is the asset duration estimated in Equation (10). Extreme values are set to the mean plus/minus the 2.5 standard deviations if they exceed this value. The upper part of the table uses five investment features as a vector of variables as in Equation (14a). The lower part of the table uses two asset insulation indices as in Equation (14b). The first variable is the average yearly realized capital gain between 2006 and 2013 relative to total investment in percent. The second variable is the average holding of public sector bonds relative to total investment in 2013 in percent. The third variable is the investment in real estate relative to total investment in 2013 in percent. The fourth variable is the natural logarithm of the investment in non-listed equity relative to total investment in 2013 in percent plus 1. The fifth variable is the natural logarithm of average yearly capital losses in 2008 and 2009 relative to total investment in percent plus 1. Column (1) displays the results of random-effects regression with no other variables. Column (2) displays the same regression with firm variables as displayed in Table 3. Column (3) displays the results of a pooled model with no other variables. Column (4) displays the same model with the control variables displayed in Table 3 included. Standard errors are clustered by group and displayed in brackets. *, ** and *** show a significance level of 0.1, 0.05 and 0.01, respectively.

Table 7: Robustness check, regressions with simpler measures of interest rate sensitivity

	(1)	(2)		(3)		(4)	
	Correlation asset duration	Liability interest rate sensitivity		Insulation index (normalized)		Insulation index (standardized)	
Dependent variable:		Coeff.	SE	Coeff.	SE	Coeff.	SE
Valuation reserves / book value of assets	60%	.063	(.096)	-.076**	(.033)	-.015	(.010)
Valuation reserves / market value of assets	60%	.11	(.12)	-.058**	(.026)	-.012	(.008)
Valuation reserves / (book value of assets * change of interest rates)	71%	.029	(.040)	-4.7***	(1.2)	-1.1***	(.285)
Valuation reserves / (market value of assets * change of interest rates)	70%	.037	(.046)	-3.8***	(1.0)	-.89***	(.23)

The table shows pooled regression results for a panel of 76 German life insurers for the years 2014-17. The dependent variables are alternative, simpler measures of asset interest rate sensitivity based on the valuation reserves, the observed difference between book and market value of assets. Extreme values are set to the mean plus/minus the 2.5 standard deviations if they exceed this value. Column (1) displays the correlation between the dependent variables and the asset duration estimated in Equation (10). The regressions displayed in column (2) use as variables simpler measures of liability interest rate sensitivity which are calculated in analogy to the asset side based on the observed difference between book and market value of liabilities. The regressions displayed in column (3) use as variable an index which measures the degree of asset insulation as a normalized index. The regressions displayed in column (4) use as variable an index which measures the degree of asset insulation as a standardized index. All regressions include year fixed effects. Standard errors are clustered by group and displayed in brackets. *, ** and *** show a significance level of 0.1, 0.05 and 0.01, respectively.

6 Conclusion

This paper sheds light on the still-incomplete picture on the degree of insurers' interest rate risk and of why insurers assume this risk. Calculation at the insurer level for German life insurers yields on average a wide duration gap with pronounced heterogeneity in the cross-section. A panel analysis supports the view that insurers might assume interest rate risk as a deliberate choice with the goal of following an asset insulation strategy rather than pursuing a strict duration-matching strategy.

The results of this paper have important implications for the understanding and interpretation of insurers' interest rate risk. Insurance policies compete with other intermediaries' products. Insurers might be able to generate extra returns in the short term through investment strategies such as asset insulation. The creation of value is, however, limited by the trade-off that alternative investment strategies have the side effect of higher interest rate risk. A prolonged low-interest-rate environment could lead to solvency problems, and sector-wide interest rate risk increases the common exposure to market risk within the insurance sector. This implies that short-term private benefits come with long-term risks. This points towards an important role of regulators.

References

Andonov, A., R. M. Bauer, and K. M. Cremers (2017). Pension fund asset allocation and liability discount rates. *The Review of Financial Studies 30*(8), 2555–2595.

Becker, B. and V. Ivashina (2015). Reaching for yield in the bond market. *Journal of Finance 70*(5), 1863–1902.

Berdin, E. and H. Gründl (2015). The effects of a low interest rate environment on life insurers. *The Geneva Papers on Risk and Insurance 40*, 385–415.

Berdin, E., H. Gründl, and C. Kubitza (2018). Rising interest rates, lapse risk, and the stability of life insurers. *Working Paper*.

Berends, K. R., R. McMenamin, T. Plestis, and R. J. Rosen (2013). The sensitivity of life insurance firms to interest rate changes. *Economic Perspectives 37*(2).

Braun, A., H. Schmeiser, and F. Schreiber (2017). Portfolio optimization under Solvency II: implicit constraints imposed by the market risk standard formula. *Journal of Risk and Insurance 84*(1), 177–207.

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

Briys, E. and F. De Varenne (1997). On the risk of insurance liabilities: debunking some common pitfalls. *Journal of Risk and Insurance*, 673–694.

Caballero, R. J., E. Farhi, and P.-O. Gourinchas (2017). The safe assets shortage conundrum. *Journal of Economic Perspectives 31*(3), 29–46.

Chance, D. M. and J. V. Jordan (1996). Duration, convexity, and time as components of bond returns. *Journal of Fixed Income 6*(2), 88–96.

Chodorow-Reich, G., A. Ghent, and V. Haddad (2018). Asset insulators. *NBER Working Paper* (24973).

Constantinescu, M. (2010). What is the "duration" of Swiss direct real estate? *Journal of Property Investment & Finance 28*(3), 181–197.

Domanski, D., H. S. Shin, and V. Sushko (2017). The hunt for duration: not waving but drowning? *IMF Economic Review 65*(1), 113–153.

EIOPA (2014). *Insurance Stress Test*, Volume November 2014. European Insurance and Occupational Pensions Authority.

EIOPA (2016). *Insurance Stress Test*, Volume December 2016. European Insurance and Occupational Pensions Authority.

EIOPA (2018). *Systemic risk and macroprudential policy in insurance*. European Insurance and Occupational Pensions Authority.

Eling, M. and S. Holder (2013). Maximum technical interest rates in life insurance in Europe and the United States: An overview and comparison. *The Geneva Papers on Risk and Insurance-Issues and Practice 38*(2), 354–375.

Ellul, A., C. Jotikasthira, C. T. Lundblad, and Y. Wang (2014). Mark-to-market accounting and systemic risk: evidence from the insurance industry. *Economic Policy 29*(78), 297–341.

Ellul, A., C. Jotikasthira, C. T. Lundblad, and Y. Wang (2015). Is historical cost accounting a panacea? Market stress, incentive distortions, and gains trading. *Journal of Finance 70*(6), 2489–2538.

ESRB (2017). *Regulatory risk-free yield curve properties and macroprudential consequences*. European Systemic Risk Board (ESRB).

Fleuriet, V. and C. Lubochinsky (2005). Interest rate risk management by life insurance companies and pension funds. *Banque de France Financial Stability Review*.

Förstemann, T. (2018). Lethal lapses: How a positive interest rate shock might stress life insurers. *Working Paper*.

French, A., M. Vital, and D. Minot (2015). Insurance and financial stability. *Bank of England Quarterly Bulletin 3*, 242–257.

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

Hartley, D. A., A. L. Paulson, and R. J. Rosen (2016). Measuring interest rate risk in the life insurance sector: the US and the UK. *Federal Reserve Bank of Chicago Working Paper No. 2016-2*.

Hendershott, T., D. Li, D. Livdan, and N. Schürhoff (2017). Relationship trading in OTC markets. *Working Paper*.

Hombert, J. and V. Lyonnet (2017). Intergenerational risk sharing in life insurance: Evidence from France. *Working Paper*.

IMF (2015). *United States - Financial Sector Assessment Program. Stress Testing - Technical Note*. International Monetary Fund.

IMF (2016). *Global Financial Stability Report*, Volume April 2016. International Monetary Fund.

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

Kirti, D. (2017). When gambling for resurrection is too risky. *International Monetary Fund Working Paper WP/17/180*.

Koijen, R. S., F. Koulischer, B. Nguyen, and M. Yogo (2017). Euro-area quantitative easing and portfolio rebalancing. *American Economic Review 107*(5), 621–627.

Koijen, R. S. and M. Yogo (2015). The cost of financial frictions for life insurers. *American Economic Review 105*, 445–475.

Koijen, R. S. and M. Yogo (2016). Shadow insurance. *Econometrica 84*(3), 1265–1287.

Mayers, D. and C. W. Smith Jr (1981). Contractual provisions, organizational structure, and conflict control in insurance markets. *Journal of Business*, 407–434.

Moody's (2015). Low interest rates are credit negative for insurers globally, but risks vary by country. *Global Insurance Themes*.

Nolte, S. and J. C. Schneider (2017). Don't lapse into temptation: A behavioral explanation for policy surrender. *Journal of Banking & Finance 79*, 12–27.

Plantin, G. and J.-C. Rochet (2009). *When insurers go bust: an economic analysis of the role and design of prudential regulation*. Princeton University Press.

Shin, H. S. (2017). Is there a risk of snapback in long-dated yields? *Panel remarks at the Second ECB Annual Research Conference*.

Swain, R. and D. Swallow (2015). The prudential regulation of insurers under Solvency II. *Bank of England Quarterly Bulletin 2*, 139–152.

Tsai, C. (2009). The term structure of reserve durations and the duration of aggregate reserves. *Journal of Risk and Insurance 76*(2), 419–441.