Lethal lapses – how a positive interest rate shock might stress life insurers

Abstract

This paper presents a fire sale-mechanism through which the life insurance sector can amplify macroeconomic shocks. Life insurers have a common risk exposure due to their business model. They offer their customers a protection against market risk which is only credible as long as macroeconomic fluctuations remain moderate. If shocks exceed a certain threshold, customers have a common incentive to surrender their contracts. In the event of a customer run, life insurers would be forced to liquidate their assets. Using the German case as a laboratory, it is demonstrated that such fire sales could amplify interest rate shocks by up to 15%.

Keywords: Financial stability, systemic risk, customer run, fire sales, life insurance.

JEL classification: G22, G33, C72, C13.

1 Introduction

Life insurers are exposed to the risk of runs. As Draghi (2018) puts it, "there might be times when policyholders want to terminate their insurance policies in large numbers, thereby putting liquidity strain on insurers. Authorities should be able to protect financial markets [...] from the adverse impact of such an exceptional run on insurers." The risk of runs has a systemic dimension, because many life insurers have a common business model of protecting their customers against macro-wide events (cf. Acharya and Richardson (2014)). They are thus *collectively* exposed to similar risk factors and can simply be "too-many-to-fail" (cf. Acharya and Yorulmazer (2007)). This paper carves out the mechanism of fundamental-based runs on life insurers. It explores under which economic conditions customers have a common incentive to surrender their life insurance contracts.[1] Furthermore, it demonstrates that life insurers can amplify a macroeconomic shock significantly, if a run forces them to liquidate their assets.

The vulnerability of the life insurance sector is inherent in its business model. Life insurers address the widespread demand for a protection against financial risk, e.g. in order to stabilize the old-age provision of their customers. For this purpose, life insurers offer savings products which include investment guarantees.[2] Products with investment guarantees imply that life insurers do not fully and immediately pass through their own investment risk to their customers. The investment risk which remains with them is largely systematic, not idiosyncratic. Therefore, it accumulates in the life insurance sector.

[1] Throughout the paper, the terms 'surrender' and 'lapse' are used interchangeably to cover all premature extractions of cash and premature terminations of life insurance contracts.

[2] Investment guarantees are backed by the General Account (GA) of life insurers which contains pooled assets for different contracts.

The life insurance sector becomes even more exposed to market risk, if contracts feature predetermined cash values, i.e. if they combine short-term investment guarantees with liquidity guarantees. Such cash values (or surrender values) are widespread features of life insurance contracts. The universe of concerned life insurance products ranges from variable annuities with guarantees, which have recently gained popularity in the U.S.A. and have been studied by Koijen and Yogo (2015), Koijen and Yogo (2018) and Ellul et al. (2018), to contracts which are exclusively backed by the life insurers' General Accounts such as Whole Life and Universal Life policies. Such contracts still account for the vast majority of life contracts in the U.S.A., Europe and Asia. Cash values relate to put-options which allow customers to extract the guaranteed amount prematurely. They are meant to protect customers against unforeseen liquidity needs, for example in the event of unemployment or divorce. Therefore, life insurers regard (and potentially price) them as an insurance against customer-specific, largely idiosyncratic liquidity needs. Customers might, however, exercise these put-options strategically in order to take advantage of outside investment opportunities. As a consequence, life insurers are systematically at risk of losing their funding base if macroeconomic shocks exceed a certain threshold and their guarantees lose credibility.

The fundamental mechanism of a customer run explored in this paper involves a decline in the market value of a financial institution's assets in the event of a severe macroeconomic shock. If the asset value falls short of the aggregated cash values promised to customers, all customers have a common incentive to 'cash in' their policies, thereby forcing the financial institution to sell off its assets. Given the importance of life insurers as long-term investors[3], these fire sales would put further pressure on asset prices and amplify the initial shock. If asset prices spiral downward in this way, it could impact the long-term funding of the financial system and ultimately of the real economy as well. Therefore, guaranteed cash values expose life insurers to macroeconomic tail risks which can, then, be passed on to the wider financial system.

The fundamental mechanism proposed in this paper is supported by several mass lapses in the last decades. In 1991, three out of six overindebted U.S. life insurers experienced a mass lapse. In 1997, during the Asian currency crisis, some South Korean life insurance products had a *monthly* surrender rate of as high as 19% when market rates increased sharply from 12% to 30%. In 1999, there was a run on the General American Life Insurance Company (GA Life) when institutional investors withdrew their investments after a rating downgrade. In 2008, during the financial crisis, the third-largest Belgian insurer, Ethias, experienced massive redemptions until national authorities declared a €100,000 state guarantee on individual deposits.[4] The common pattern of these mass lapses is a capital shortfall on the part of life insurance companies with short-term liquidity guarantees. However, all these mass lapses had a limited effect on the financial system, either because they concerned insurance companies which were relatively small on a global scale or because they were stopped by means of a public bail-out.

This paper focuses on common exposures of many life insurers to a single risk factor as a source of systemic risk ("too-many-to-fail"). One specialty of life insurers is the

[3]The life insurance sector in the U.S.A. (in the euro area) held assets worth $6.8 trillion (€3.3 trillion) in 2016, compared to $18.0 trillion (€6.2 trillion) in the banking sector. The asset holdings of life insurers correspond to 9% (euro area: 14%) the total financial assets of private households. Cf. Board of Governors of the Federal Reserve System, Flow of Funds Accounts of the United States, Z.1 Statistical Release Q1 2018 and ECB Statistical Data Warehouse, 2018 Q1.

[4]More detailed information on these events is provided by Geneva Association (2012) and Moody's Investors Service (1999).

long horizon of their business model and the predominance of long-term fixed-income investments among their assets. These investments make life insurers especially vulnerable to an interest rate shock. Therefore, this paper concentrates on the connection between life insurers' lapse risk and a hike in interest rates, as in the aforementioned episode in South Korea.

In the event of a hike in interest rates, the value of life insurers' fixed-income assets decreases, reflecting the fact that new investments become more attractive relative to the life insurers' legacy assets.[5] For customers, the difference between their guaranteed fixed surrender values and their (expected) value of participating further in the life insurers' assets narrows. When interest rates exceed a certain threshold, it becomes rational for customers to terminate their contracts. This individual decision can be generalized to the whole universe of a life insurer's policies, and it can be related to the life insurer's balance sheet. If the market value of a life insurer's assets fall short of the aggregated surrender values, it is rational for every single customer to surrender their contract.

This paper uses the German case as a laboratory, because German life insurance products incorporate standardized investment and liquidity guarantees. The German life insurance sector, then, is uniformly exposed to the risks being analyzed in this paper. Furthermore, a body of granular and high-quality data is available. Therefore, critical thresholds can be identified above which individual companies are at risk of experiencing a customer run. The risk of such events can be reduced if insurers increase their capital buffers or decrease their asset duration. Furthermore, they can disentangle the combination of short-term investment and liquidity guarantees and adjust their customers' cash values. One key

[5] If interest rates hike, new investments in fixed-income assets become more attractive. At the same time, the fixed-income legacy assets held by life insurers, which cover the surrender values, lose value.

instrument are market value reductions (MVRs), which ensure that the sum of a life insurer's surrender values is always less than the market value of its assets. These variable surrender penalties transform short-term into long-term investment guarantees while still allowing customers to extract cash. In some jurisdictions, the supervisory authorities have the power to reduce cash values or suspend surrenders, at least temporarily.

This paper contributes to different strands of the literature on financial stability. The closest paper to this one is Ellul et al. (2018), which investigates a portfolio rebalancing channel of solvency constrained life insurers. It finds that even *moderate shocks* can force life insurers to sell off illiquid assets. For example, *lower* interest rates can stress the solvency of life insurers and force them to rebalance their portfolio toward liquid assets. By contrast, this paper presents a customer-driven deleveraging mechanism which only starts working in the event of *severe macroeconomics shocks*. Beyond a firm-specific critical level, *higher* interest rates make it profitable for all customers of affected life insurers to surrender their contracts and force the life insurers to sell their assets. Both papers relate to the literature on fire sales which is decisively influenced by Shleifer and Vishny (1992) and Shleifer and Vishny (2011). A third article by Berdin et al. (2017) simulates the effects of a simultaneous increase in interest rates and lapse rates on life insurers. From a financial stability perspective, all of this research supports the hypothesis of Chodorow-Reich et al. (2018) that life insurers lose their stabilizing role as 'asset insulators' under adverse macroeconomic conditions, suggesting that the business model shared by life insurers translates not only into an important common role as long-term investors, but also into common vulnerabilities to macroeconomic shocks which life insurers may, in turn, amplify. Thereby, all of this research helps to shed further light on sources of systemic risk in the insurance sector which have been summarized by Acharya and Richardson (2014). Systemic risk which results from common exposures of many institutions to a common risk factor has been analysed by Acharya and Yorulmazer (2007), Acharya and Yorulmazer (2008) and Wagner (2010). The contribution of financial institutions to systemic risk is measured empirically by another strand of literature. The pioneering articles by Acharya et al. (2017), Adrian and Brunnermeier (2016) and Billio et al. (2012) develop different measures of systemic risk. With regard to the insurance sector these papers find a significant contribution to systemic risk which is, however, below the contribution of the banking sector.

The limits of liquidity and investment guarantees being explored in this paper are also relevant from a microeconomic perspective. This paper contributes to the literature on lapse risk in the life insurance industry, as summarized by Eling and Kochanski (2013). Complementing a study by Foley-Fisher et al. (2015), this paper considers fundamental-based runs as the most extreme form of lapse risk. It is the first paper which analyzes on a theoretical basis why, and under which macroeconomic circumstances, a life insurer might experience a fundamental-based run by retail customers. The mechanism of a fundamental-based run on underfunded life insurers can also be applied to banks. Therefore, this paper also contributes to the literature on bank runs, which can be traced back to, among others, Bryant (1980). This paper considers financial intermediaries to be transparent institutions. Customers are assumed to have complete and symmetric information regarding macroeconomic shocks and their impact on the life insurers' financial situation. This assumption reflects the business model of life insurers who invest primarily in marketable securities. To the contrary, banks traditionally invest in rather opaque loans. Therefore, the financial situation of banks tends to be less transparent than the financial situation of life insurers. Consequently, bank run models assume that investors have incomplete and/or asymmetric information. Signals and expectations then determine whether a run may occur or not occur. The theoretical model in this paper removes this veil of ignorance. It is grounded on the theorem of Modigliani and Miller (1958) and the work done by Albizzati and Geman (1994).

The remainder of this paper is structured as follows. Section 2 illustrates the key characteristics of life insurers and their economic importance as providers of protection against market risk and as long-term fixed-income investors. Section 3 derives a theoretical model of a life insurer with a single policyholder (3.1) and heterogenous policyholders (3.2). This model shows that a run is rational for all customers if the life insurer is underfunded, for example because interest rates exceeded a critical level. Based on this result, in Section 4 a reverse stress test is constructed for life insurers which offer predetermined surrender values. The reverse stress test is conducted for the case of Germany. Following a short presentation of the data (4.1), the critical interest rates of life insurers are discussed at which a customer run would be rational (4.2). Section 5 assesses the potential market impact and second-round effects of a mass lapse being induced by an interest rate shock. Section 6 illustrates how the instrument of market value reductions (MVRs) allows life insurers to manage the pass-through of interest rate risk, thereby reducing the risk of a customer run. Section 7 concludes the paper.

2 Life insurance and market risk

Life insurers offer two broad categories of savings products which provide different levels of financial security for natural persons. *With-profit products* offer customers protection against market risk in the form of guarantees. These guarantees are backed by a collective pool of assets in the general account (GA). *Unit-linked products* are investment risk pass-through products which mirror the value of assets in the life insurers' separate account (SA).[6]

The relative importance of these two product categories can be gauged by comparing the value of assets in the GAs and the SAs. Table 1 shows that the GAs in five major markets comprise assets worth $9.4 trillion, which is more than twice the $4.1 trillion of assets in the SAs. This illustrates the prevalence of *with-profits products* in major markets such as the U.S.A., Japan, Germany and France. Only in the U.K. do *unit-linked products*, which are backed by the SA, dominate the life insurers' balance sheets.

The lower rows of Table 1 show that life insurers invest primarily in long-term fixed-income assets. Therefore, interest rate risk (including spread risk) is the single most important source of market risk. The average modified duration of fixed-income assets is about 10 in all major markets with the exception of France, where it is significantly lower. A modified duration of 10 implies that fixed-income assets will lose about 10% of their value if interest rates hike by one percentage point. This market risk of life insurers is not fully passed through to customers for example due to guaranteed cash values.

[6] If unit-linked products are sold with guarantees or options, these features are backed by the life insurer's GA, cf. Paulson et al. (2014), p. 65.

Table 1: Descriptive statistics of life insurers 2016

	U.S.A.	Japan	U.K.	Germany	France	Total
Separate Account	2,520	95	1,286	106	70	4,077
General Account	4,252	3,061	552	1,089	468	9,422
% fixed-income assets	*83%*	*82%*	*62%*	*89%*	*83%*	*82%*
Duration	*10.5*	*12.3*	*12.5*	*9.6*	*6.6*	
Total	6,772	3,156	1,838	1,194	539	13,499

Notes. The table reports key characteristics of life insurers in the U.S.A., Japan, U.K., Germany and France as of end-2016.

Variables: Assets in the *Separate Account* and in the *General Account* are reported in billion U.S. dollars, *% Fixed-income assets* denote the percentage of fixed-income assets in the life insurers' GA, *Duration* is the modified duration of fixed-income assets (U.K., Germany and France) or of total assets (U.S.A., Japan). The value of assets in the SA of Japanese life insurers was calculated as 3% of total investments according to BoJ Review 2017-E-2. The share of fixed-income assets for the U.S.A. was estimated as the share of bonds, mortgages and policy loans per total assets in the GA; for Japan, the U.K., Germany and France it was estimated as the share of bills, bonds and loans per total assets less the assets for unit-linked contracts and less collective investment schemes.

Sources: OECD Insurance Statistics 2009-2016, American Council of Life Insurers (ACLI) Life Insurers Fact Book 2017, Bank of Japan (BoJ) Review 2017-E-2, EIOPA Insurance Stress Test Report 2016, own calculations.

3 A model for customer runs

This section models the limits of insurance against market risk. It presents evidence that financial institutions are at risk of experiencing a customer run in the event of severe macroeconomic shocks if they offer their customers guaranteed cash values. The model presented is designed as sparsely as possible in order to illuminate the vulnerabilities of financial institutions and their economic rationale as clearly as possible. It shows that, in the strict Nash equilibrium, customers jointly lapse their contracts, if the financial institution is underfunded. These results hold for all financial institutions that guarantee their customers a fixed nominal cash value (e.g. bank deposits and life insurance contracts). Focusing on interest rate risk, the model is especially relevant for life insurers. These are vulnerable to the risk of an interest rate shock, because they operate with little equity, invest primarily in long-term fixed-income assets, and typically offer their customers a minimum cash value. Rising interest rates may drive the value of life insurers' fixed-income assets below the breaking point at which they are underfunded *at market values*. In such an event of underfunding *at market values*, regulators typically have no legal obligation to intervene.[7] Therefore, it has to be distinguished from the case of an insolvency. The presented market forces which act in the event of underfunding *at market values* are relevant for life insurers, because regulators are not obliged to stop them.

The model builds on the work done by Albizzati and Geman (1994). It considers a life insurer which has guaranteed its customers a minimum return on a 'with-profit'-product. Such guarantees are widespread in major markets such as the U.S.A., Germany and Japan. Life insurers looking to hedge these guarantees are incentivized to invest in long-term assets.[8] This investment strategy might then turn out to be a trap if interest rates hike.

3.1 Model of a life insurer with a single customer

A life insurer is founded at time $t = 0$. It receives an initial capital contribution of E_0 from its shareholders, and it sells a fairly priced life insurance policy with maturity T to

[7] Regulation is based either on *book values* or on stylized market values. Book values do not reflect temporary losses by fixed-income assets due to interest rate fluctuations, and stylized market values disregard the market risk component of surrender options. Therefore, both types of regulation typically do not consider an underfunding event equivalent to an insolvency.

[8] Please note that French life insurers pursue a similar investment strategy, although they do not offer guaranteed nominal returns but only a guaranteed profit participation (Hombert and Lyonnet (2018)). They are thus exposed to the same source of risk as life insurers in other jurisdictions which offer guaranteed mimimum nominal returns.

customer A for a net single payment of $K^*_{A,0}$. The initial total assets A_0 of the life insurer are thus made up of the cash payments E_0 of the equity holder and $K^*_{A,0}$ of the customer

$$A_0 = E_0 + K^*_{A,0}.$$

The life insurance contract bundles an investment guarantee with an option to surrender the contract and extract cash at time $t \in \{1, 2, \ldots, T-1\}$. Until termination of the policy, the customer is periodically credited a guaranteed share $\lambda_A \in (0,1)$ of the market yield at inception of the contract $y_{0,T}$.[9] The predetermined surrender value promised to customer A in $t < T$ gives

$$S_{A,t} = K^*_{A,0} \cdot (1 + \lambda_A \cdot y_{0,T})^t, \quad \forall t \in \{1, 2, \ldots, T-1\}. \tag{1}$$

It is important to note that the customer's future guaranteed yield $\lambda_A \cdot y_{0,T}$ is fixed at time $t = 0$. Therefore, the promised surrender values are independent of later market rates. Holding the contract until maturity equals termination at time T

$$S_{A,T} = K^*_{A,0} \cdot (1 + \lambda_A \cdot y_{0,T})^T.$$

[9] In line with Albizzati and Geman (1994) we abstract from fixed surrender fees. This assumption simplifies the model with little, if any, impact on the fundamental mechanism of a customer run which the model seeks to illustrate. What is more, this assumption seems plausible for many markets in light of the results of the European Systemic Risk Board (2015) survey. In the case of Germany, the Federal Court of Justice has declared common clauses on cancellation fees invalid.

We assume that the life insurer decides to be fully hedged against market risk at maturity of the contract. Therefore, it invests its initial total assets A_0 entirely in a risk-free zero-coupon bond X with the same maturity as the policy

$$A_0 = X_0.$$

The bond yields the market rate of return $y_{0,T}$, and at maturity in T it pays

$$X_T = X_0 \cdot (1 + y_{0,T})^T .$$

While the life insurer is hedged at maturity of the contract, it bears investment risk if the customer terminates their contract prematurely in order to invest in the market at a higher interest rate and thereby gain higher profits. In this case, the life insurer has to sell its investment at least partially in order to pay out the surrender value promised to the customer. The market value of the zero-coupon bond at time t equals the payment at maturity X_T discounted at the market rate $\tilde{y}_{t,T}$ prevailing at time t

$$\tilde{X}_t := X_t(\mathcal{F}_t) = X_T \cdot (1 + \tilde{y}_{t,T})^{-(T-t)} = X_0 \cdot (1 + y_{0,T})^T \cdot (1 + \tilde{y}_{t,T})^{-(T-t)}, \qquad (2)$$

being inversely related to the market rate $\tilde{y}_{t,T}$. If the market rate is high, the proceeds from selling the bond may not be sufficient to cover the predetermined surrender value, i.e. the life insurer may be underfunded.

The life insurer has limited liability. Shareholders in the life insurer receive the residual of the assets after all customer claims have been satisfied, but their liability is limited to their initial capital contribution.[10] Consequently, the value of their equity investment cannot fall below its floor of zero. On the flip side, customer A will never receive more than the market value of the insurer's total assets $\tilde{A}_t = \tilde{X}_t$, even if they had been promised a higher surrender value $S_{A,t}$. Under the assumption that there are no additional costs in the event of an insolvency, the life insurer pays its customers an effective surrender value $\tilde{V}^L_{A,t} := V^S_{A,t}(\mathcal{F}_t)$ and its shareholders $\tilde{E}^S_t := E^S_t(\mathcal{F}_t)$ in the event of termination at time t, with

$$\begin{aligned}
\tilde{V}^L_{A,t} &= \min[S_{A,t}; \tilde{A}_t] &&= \min\left[K^*_{A,0} \cdot (1+\lambda_A \cdot y_{0,T})^t \quad ; \quad \frac{X_0 \cdot (1+y_{0,T})^T}{(1+\tilde{y}_{t,T})^{T-t}}\right], \\
\tilde{E}^S_t &= \max[\tilde{A}_t - S_{A,t}; 0] &&= \max\left[\frac{X_0 \cdot (1+y_{0,T})^T}{(1+\tilde{y}_{t,T})^{T-t}} - K^*_{A,0} \cdot (1+\lambda_A \cdot y_{0,T})^t \quad ; \quad 0\right],
\end{aligned}$$

which clearly shows that the evolution of market rates $\tilde{y}_{t,T}$ is the only source of uncertainty in the model.

The customer has an incentive to use their put option strategically. At each future point in time and in any possible state of the world, they compare the surrender payment when lapsing the contract $\tilde{V}^L_{A,t}$ with the continuation value

$$\tilde{V}^C_{A,t} := V^C_{A,t}(\mathcal{F}_t) = \frac{E_Q\left[\tilde{V}_{A,t+1} | \mathcal{F}_t\right]}{1+\tilde{y}_{t,t+1}}$$

[10] The model assumes that the maturity of equity equals the maturity of the contracts, i.e. equity holders cannot withdraw their capital (e.g. in the form of dividend payments) before the contract matures.

which is the conditional expected discounted value of the market value $\tilde{V}_{A,t+1}$ in the next period under a risk-neutral pricing measure Q, where the short-term interest rate $\tilde{y}_{t,t+1}$ is used as the discounting rate:

$$\begin{aligned}\tilde{V}_{A,t} &= \max\left(\tilde{V}^{L}_{A,t}, \tilde{V}^{C}_{A,t}\right)\\ &= \max\left(\min\left(S_{A,t}, \tilde{A}_t\right), \frac{E_Q\left[\tilde{V}_{A,t+1}|\mathcal{F}_t\right]}{1+\tilde{y}_{t,t+1}}\right), \quad t \in \{1, 2, \ldots, T-1\}.\end{aligned}$$

Evidently, the market value of the contract is dependent on the current and future interest rate evolution and the resulting incentives for the customer to surrender their contract.

The properties of the model are shown graphically in Section 6. They also become clear in two cases:

Without premature termination of the policy, the life insurer will always profit from the contract due to the deterministic positive value of equity at $t = T$ and the guaranteed yield of $\lambda_A \in (0, 1)$

$$\begin{aligned}E_T(nolapse) &= A_T - S_{A,T}\\ &= \left(E_0 + K^*_{A,0}\right)\left(1 + y_{0,T}\right)^T - K^*_{A,0} \cdot \left(1 + \lambda_A \cdot y_{0,T}\right)^T\\ &= E_0 \cdot \left(1 + y_{0,T}\right)^T + \underbrace{K^*_{A,0}\underbrace{\left[\left(1 + y_{0,T}\right)^T - \left(1 + \lambda_A \cdot y_{0,T}\right)^T\right]}_{\geq 0}}_{\text{Profit from the policy}}.\end{aligned}$$

This result holds regardless of the evolution of market rates, because the maturities of the life insurance contract and of the investment match. It is obvious that, in the model, the life insurer does not bear any reinvestment risk at all; it is perfectly hedged at the maturity of the contract.

If the customer decides to extract cash from the contract in $t^* < T$ before the contract matures, the life insurer is exposed to combined liquidity and interest rate risk. In this case, the life insurer has to sell off its investments prematurely, when the market price may be relatively low. That might occur if market rates have hiked significantly in the meantime, thereby decreasing the present value of the bond's deterministic payment at maturity X_T. The life insurer is underfunded if the surrender value promised to the customer exceeds the market value of the life insurer's assets ($S_{A,t} > \tilde{A}_t$). That is the case if the market rate $\tilde{y}_{t,T}$ exceeds the predetermined critical market rate $y^*_{t,T}$ for which $S_{A,t} = \tilde{A}_t$ holds

$$K^*_{A,0}\left(1 + \lambda_A \cdot y_{0,T}\right)^{t^*} = \frac{\left(E_0 + K^*_{A,0}\right)\left(1 + y_{0,T}\right)^T}{\left(1 + y^*_{t,T}\right)^{T-t^*}}$$

$$y^*_{t,T} = \sqrt[(T-t^*)]{\frac{\left(E_0 + K^*_{A,0}\right)\left(1 + y_{0,T}\right)^T}{K^*_{A,0}\left(1 + \lambda_A \cdot y_{0,T}\right)^{t^*}}} - 1$$

If the customer terminates their contract while the market rate is above the critical interest rate $\tilde{y}_{t,T} > y^*_{t,T}$ the life insurer will be insolvent.

3.2 Model with heterogeneous customers

Staying with the same model, we assume that a second contract is opened at $t_B > 0$ with a savings portion K^*_{B,t_B}, a guaranteed yield λ_B and a maturity T. The promised surrender value of the contract at time $t > t_B$ equals

$$S_{B,t} = K^*_{B,t_B} \cdot (1 + \lambda_B \cdot y_{t_B,T})^{(t-t_B)}$$

Both contracts are backed by the life insurer's general account (GA). The life insurer invests the proceeds from selling the second contract in a riskless bond with maturity T. Absent any premature surrenders, the life insurer's GA contains assets $\tilde{A}_t = \tilde{X}_t$ at time $t > t_B$ which have a market value of

$$\tilde{X}_t = \frac{X_T}{(1 + \tilde{y}_{t,T})^{T-t}} = \frac{(E_0 + K^*_{A,0})(1 + y_{0,T})^T + K^*_{B,t_B} \cdot (1 + y_{t_B,T})^{T-t_B}}{(1 + \tilde{y}_{t,T})^{T-t}}.$$

In each period $t > t_B$, both customers decide simultaneously whether or not to lapse their contract.[11] This situation can be interpreted as a 'surrender game' in which each player has two possible strategies: lapse ('L') and no lapse ('NL'). The strategy set of customer $j = A, B$ at time t is denoted $\alpha_{j,t}$. Both customers maximize the value of their contracts $\tilde{V}_{i,t}$, which may depend on the chosen strategy:

[11]This assumption is based on the fact that life insurers publish information on lapse rates only periodically (mostly annually). Within each period, customers have no information about the decisions made by other customers. Furthermore, surrenders are mostly executed jointly with a certain time lag; within the period no strict 'first come, first served' principle is in force. Therefore, the decision may hypothetically be considered a simultaneous decision.

		B				
		NL			L	
A	NL	$\tilde{V}_{A,t}$(NL,NL) ,	$\tilde{V}_{B,t}$(NL,NL)	$\tilde{V}_{A,t}$(NL,L) ,	$\tilde{V}_{B,t}$(NL,L)
	L	$\tilde{V}_{A,t}$(L,NL) ,	$\tilde{V}_{B,t}$(L,NL)	$\tilde{V}_{A,t}$(L,L) ,	$\tilde{V}_{B,t}$(L,L)

A strategy set $(\alpha^*_{A,t}, \alpha^*_{B,t})$ is a strict Nash equilibrium (NE) if no unilateral deviation in strategy $\alpha^*_{j,t}$ by any single player $j = A, B$ is profitable for the player. In a strict NE, it thus holds that:

$$\tilde{V}_{A,t}(\alpha^*_{A,t}, \alpha^*_{B,t}) \geq \tilde{V}_{A,t}(\alpha_{A,t}, \alpha^*_{B,t})$$

$$\tilde{V}_{B,t}(\alpha^*_{A,t}, \alpha^*_{B,t}) \geq \tilde{V}_{B,t}(\alpha^*_{A,t}, \alpha_{B,t})$$

The contract value $\tilde{V}_{i,t}$ of each customer $i = A, B$ can be decomposed further into a continuation value $\tilde{V}^C_{i,t}$ and a surrender value $\tilde{V}^L_{i,t}$

$$\tilde{V}_{i,t} = \max\left(\tilde{V}^C_{i,t}, \tilde{V}^L_{i,t}\right)$$

The *factual* surrender value $\tilde{V}_{i,t}$ may deviate from the *promised* surrender value $S_{i,t}$. The promised surrender values are jointly backed by a pool of assets worth A_t. If at least one customer surrenders their contract, the life insurer sells off parts of the assets ΔA_t in order to pay out the promised surrender value:

$$\Delta\tilde{A}_t = \tilde{A}_t - \tilde{A}'_t = \begin{cases} 0 & \text{if } \alpha_{j,t} = \alpha_{j,t} = NL \\ \min[\tilde{A}_t; S_{i,t}] & \text{if } (\alpha_{i,t} = L) \wedge (\alpha_{j,t} = NL) \\ \min[\tilde{A}_t; S_{i,t} + S_{j,t}] & \text{if } \alpha_{j,t} = \alpha_{j,t} = L. \end{cases}$$

The proceeds from these asset sales are distributed to the customers who surrender their contract. If the proceeds are insufficient to pay out the *promised* surrender values in full, all customers that have surrendered their contracts receive a fair share of the liquidated assets. Consequently, each *factual* surrender value $\tilde{V}^L_{i,t}(\alpha_{A,t}, \alpha_{B,t})$ depends on the strategy sets of both players $(\alpha_{A,t}, \alpha_{B,t})$. For customer $i \neq j$ the *factual* surrender value gives

$$\tilde{V}^L_{i,t}(\alpha_{j,t}) = \begin{cases} \min[S_{i,t}; \tilde{A}_t] & \text{if } \alpha_{j,t} = NL \\ \min[S_{i,t}; \frac{S_{i,t}}{S_{i,t}+S_{j,t}} \tilde{A}_t] & \text{if } \alpha_{j,t} = L \end{cases},$$

where the term $\frac{S_{i,t}}{S_{i,t}+S_{j,t}} \tilde{A}_t$ in the lower case refers to the situation that both customers surrender their contracts while the life insurer is underfunded. That is the case if interest rates hike above the critical interest rate in

$$y^*_{t,T} = \sqrt[(T-t^*)]{\frac{(E_0 + K^*_{A,0})\,(1+y_{0,T})^T + K^*_{B,t_B} \cdot (1+y_{t_B,T})^{T-t_B}}{K^*_{A,0}\,(1+\lambda_A \cdot y_{0,T})^{t^*} + K^*_{B,t_B} \cdot (1+\lambda_B \cdot y_{t_B,T})^{(t^*-t_B)}}} - 1.$$

The case of underfunding $\left(\tilde{A}_t < S_{A,t} + S_{B,t}\right)$, which can occur after a macroeconomic shock, is considered in the following.[12]

Proposition: All customers A, B of a life insurer jointly extract cash from their contracts at time t in the unique Nash equilibrium if the life insurer's assets at market values do not fully cover the potential aggregated cash extractions $(A_t < S_{A,t} + S_{B,t})$.

[12] Underfunding in general is not a necessary condition for a customer run. This paper, however, focuses on this particular case.

Proof: In arbitrage-free markets and absent any frictions, the market value of both contracts can never exceed the market value of the life insurer's assets, regardless of the strategy pursued by both customers

$$\tilde{V}_{A,t} + \tilde{V}_{B,t} \leq \tilde{A}_t. \tag{3}$$

In the case of underfunding, the aggregate surrender values promised to customers exceed the market value of the life insurer's assets. If the life insurer is underfunded, it thus holds that

$$\tilde{A}_t < S_{A,t} + S_{B,t}. \tag{4}$$

It is obvious that the strategy $(\alpha_{A,t}, \alpha_{B,t}) = (NL, NL)$ is not a Nash equilibrium in this situation. From equation (3) it follows that there is at least one $\alpha \in [0,1]$ which limits the continuation value of both customers if they jointly keep their contracts. This continuation value cannot exceed the market value of the life insurer's assets:

$$\tilde{V}^C_{A,t}(\text{NL,NL}) \leq \alpha A_t \quad \wedge \quad \tilde{V}^C_{B,t}(\text{NL,NL}) \leq (1-\alpha) A_t.$$

Hence, at least one continuation value $\tilde{V}^C_{i,t}$ falls below the surrender value $\tilde{V}^L_{i,t}$ due to

$$\tilde{V}^C_{A,t}(\text{NL,NL}) \leq \alpha A_t \leq \underbrace{\min\left(S_{A,t}; A_t\right)}_{=\tilde{V}^L_{A,t}(\text{L,NL})} \quad \vee \quad \tilde{V}^C_{B,t}(\text{NL,NL}) \leq (1-\alpha) A_t \leq \underbrace{\min\left(S_{B,t}; A_t\right)}_{=\tilde{V}^L_{B,t}(\text{NL,L})}$$

Otherwise, it holds that

$$\alpha A_t > \min\left(S_{A,t}; A_t\right) \quad \wedge \quad (1-\alpha)A_t > \min\left(S_{B,t}; A_t\right)$$

$$\Rightarrow \underbrace{\alpha A_t + (1-\alpha)A_t}_{A_t} > \underbrace{\min\left(S_{A,t}; A_t\right) + \min\left(S_{B,t}; A_t\right)}_{=\tilde{V}^L_{A,t}+\tilde{V}^L_{B,t}}$$

and this is a contradiction to the assumption that the life insurer is underfunded in equation (4). Therefore, at least one customer has an incentive to lapse their contract, if the life insurer is underfunded.

If one customer surrenders their contract, the other customer has an incentive to surrender their contract, too. If both customers surrender their contracts, they receive

$$\tilde{V}^S_{A,t}(L, L) = \frac{S_{A,t}}{S_{A,t} + S_{B,t}}\tilde{A}_t = \tilde{A}_t - \frac{S_{B,t}}{S_{A,t} + S_{B,t}}\tilde{A}_t.$$

If one customer keeps their contract, they receive the continuation value. Without loss of generality, we assume that customer A keeps their contract. If markets are free of arbitrage, their continuation value $\tilde{V}^C_{A,t}(NL, L)$ cannot exceed the value of the remaining assets:

$$\tilde{A}_t - S_{B,t} \geq \tilde{V}^C_{A,t}(NL, L).$$

Combining both equations, it is clear that customer A is better off if they anticipate the decision of customer B to surrender their contract

$$\tilde{V}^S_{A,t}(L, L) = \tilde{A}_t - \underbrace{\frac{S_{B,t}}{S_{A,t} + S_{B,t}} \cdot \tilde{A}_t}_{<S_{B,t}} > \tilde{A}_t - S_{B,t} \geq \tilde{V}^C_{A,t}(NL, L).$$

For customer B the argument holds analogously. Neither A nor B have an incentive to deviate from (L,L). Hence, (L,L) is the unique Nash equilibrium in every state of the world in which the life insurer becomes underfunded. In this unique Nash equilibrium both customers surrender their contracts and the life insurer is forced to sell off its assets.

The following table illustrates the boundaries for the values of both contracts. These boundaries result from the conditions of arbitrage-free markets (equation (3)) and underfunding at the life insurer (equation (4)).

		B					
		NL			L		
A	NL	$\tilde{V}^C_{A,t}$(NL,NL) $\leq \alpha A_t$	,	$\tilde{V}^C_{B,t}$(NL,NL) $\leq (1-\alpha)A_t$	$\tilde{V}^C_{A,t}$(NL,L) $\leq \max(A_t - S_{B,t}; 0)$	,	$\tilde{V}^L_{B,t}$(NL,L) $= \min(S_{B,t}; A_t)$
	L	$\tilde{V}^L_{A,t}$(L,NL) $= \min(S_{A,t}; A_t)$	,	$\tilde{V}^C_{B,t}$(L,NL) $\leq \max(A_t - S_{A,t}; 0)$	$\tilde{V}^L_{A,t}$(L,L) $= \frac{S_{A,t}}{S_{A,t}+S_{B,t}}\tilde{A}_t$	,	$\tilde{V}^L_{B,t}$(L,L) $= \frac{S_{B,t}}{S_{B,t}+S_{B,t}}\tilde{A}_t$

Consequently, a customer run is rational if the cash values promised to customers are not fully covered by a pool of assets. It is important to note that other properties of the contracts, such as guaranteed minimum returns, do not impact this decision. In arbitrage-free markets, guarantees of any kind lose credibility if the sum of promised liquidation values (or cash values) exceeds the market value of the pooled assets backing these guarantees.

The general mechanism of fundamental-based runs proposed here is thus applicable to all financial institutions which (i) serve cash requests according to the 'first come, first served' principle and offer contracts with (ii) a nominal cash value which is (iii) backed by a common pool of assets. If these three necessary conditions are fulfilled and markets are free of arbitrage, all customers will have a joint incentive to request the nominal cash value if the financial institution is underfunded.

4 A reverse stress test

The finding made in the previous section - that underfunded financial institutions are at risk of experiencing a customer run - is used to construct a reverse stress test. Reverse stress tests identify scenarios that threaten the stability of a financial institution. This paper focuses on interest rate risk as the main source of market risk for life insurers. Critical interest rates are thus identified for individual life insurers. Life insurers would be at risk if they were exposed to a shock that increases interest rates beyond their company-specific critical level.

4.1 Data

Data on the life insurers' investments (book and market values) and balance sheets is provided by the Federal Financial Supervisory Authority (BaFin)[13] and, since 2016, published by the companies in their Solvency and Financial Condition Reports (SFCR). The modified asset durations of individual life insurers are estimated using non-public BaFin projections.[14]

Numerous checks have shown that there are virtually no data errors for the larger life insurers. Outliers in the estimated modified durations and other variables (e.g. asset

[13] These data are taken from the BaFin reporting templates "Formblatt 100" and "Nachweis 101". They are also contained in the insurers' financial statements prepared according to the German Commercial Code (HGB), which are publicly available.

[14] These projections are conducted at least once a year. BaFin asks all German insurance enterprises which are supervised at the national level to predict selected positions of their financial statements at year-end under different scenarios. The life insurers mostly have to simulate the consequences of a decline in a stock market index and an increase in interest rates.

growth and relative buffers) are confined to smaller enterprises and mostly result from special business models. To avoid potential bias, life insurers which each have less than €1 billion in premium reserves are disregarded. This confines the sample to about 98% of the total assets in the GA of the German life insurance sector.[15]

4.2 Critical interest rate

As shown in the previous section, a customer run is rational if the promised cash values on aggregate are underfunded. This situation arises if the market value of assets in the GA of one life insurer falls below the aggregated surrender values of its customers.

A life insurer's capital buffer $\Delta A_{i,t}^{crit}$ shall be defined as the difference between the aggregated surrender values of its customers and the assets in the life insurer's GA at market values. By this definition, life insurers are underfunded at market values, if the market value of assets in their GA decreases by at least the amount of the capital buffer, for example due to a positive interest rate shock. Using the modified duration of life insurers' assets $DurA_{i,t}$, it is possible to estimate the critical interest rate shock $\Delta r_{i,t}^{crit}$ which would cause the buffer to be depleted:

$$\Delta A_{i,t}^{crit} \approx DurA_{i,t} \cdot \Delta r_{i,t}^{crit} \cdot A_{i,t}.$$

[15]The data analyses showed that virtually all the outliers in the empirical analysis could be traced back to small life insurers. Some of these small firms had specialized business models, while others were growing or shrinking strongly, having already tailored their equity to fit the new target size of the enterprise. Instead of applying arbitrary filters, the smallest life insurers as a whole were excluded. The market share of the disregarded life insurers in terms of total assets in the general account is negligible (2005: 2%, 2015: 3%), whereas the number of excluded firms is relatively high (e.g. 2005: 32 out of 96, 2015: 25 out of 83).

This duration is then used to estimate the critical interest rate shock (CIRS)

$$CIRS_{i,t} = \Delta r_{i,t}^{crit} \approx \frac{\frac{\Delta A_{i,t}^{crit}}{A_{i,t}}}{DurA_{i,t}}. \tag{5}$$

Equation (5) is straightforward if it is decomposed into two elements. In the numerator, the capital buffer is related to the market value of all assets in the life insurer's GA. The numerator thus measures the extent to which the life insurers' assets in the GA at market values exceed the cash values being promised to their customers. The denominator contains the interest rate sensitivity of the market value of assets. The whole term reveals which positive interest rate shock would diminish the market value of assets by more than the size of the buffer.

These critical interest rate *shocks* (CIRS) are then added to the yields on listed Bunds with a residual maturity of ten years (IR) to give critical interest rate *levels* (CIR). The enterprise-specific CIR thus depend on the enterprise-specific CIRS and the interest rate level. If interest rates were to rise above the enterprise-specific CIR, it may be equally rational for any customer to lapse their life insurance policy.

Table 2 shows that the CIR have generally declined over the last decade, the mean value decreasing from 5.9% in 2005 to 3.8% in 2011. The onset of the financial crisis in 2008 and the emergence of the European sovereign debt crisis in the years 2010 and 2011 both had a negative impact. Despite the challenges presented by the low-interest-rate environment, the CIR has only decreased slightly since then to 3.3% at year-end 2017.

Table 2: Critical interest rates of German life insurers

	Buffer	Duration	CIRS	IR	CIR
2005	12.5	4.9	2.6	3.3	5.9
2006	12.0	5.5	2.2	4.0	6.2
2007	9.7	5.1	1.9	4.4	6.3
2008	8.5	4.8	1.8	3.2	5.0
2009	10.1	5.7	1.8	3.5	5.3
2010	10.5	6.2	1.7	3.1	4.8
2011	11.8	6.3	1.9	1.9	3.8
2012	17.9	6.9	2.6	1.3	3.9
2013	15.3	7.2	2.1	2.0	4.1
2014	23.4	8.1	2.9	0.6	3.5
2015	21.6	8.6	2.5	0.7	3.2
2016	29.3	9.5	3.1	0.2	3.3
2017	24.9	8.9	2.8	0.5	3.3

Notes. The table reports the critical interest rate level (CIR) and its components for the aggregate of the approximately 55 largest German life insurers which each had more than €1 billion in premium reserves from the end of 2005 to year-end 2017.

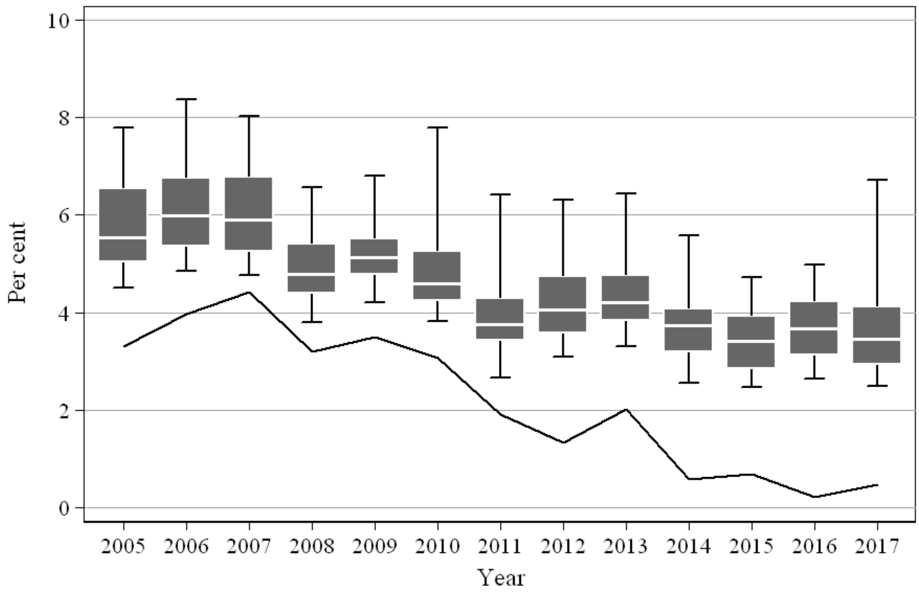
Variables: *Buffer* stands for the insurers' own funds under Solvency I, the additional interest provision (Zinszusatzreserve) and net hidden reserves on assets under the German Commercial Code (HGB) over total assets in the GA in €billion, *Duration* is the modified duration of the total assets in the GA, *CIRS* is the critical interest rate shock, *IR* is the yield on listed Bunds with a residual maturity of ten years and *CIR* is the critical interest rate level.

Since 2008, two trends with opposing effects have been in evidence. First, life insurers have increased their asset duration, nearly doubling it from 4.8 in 2008 to 8.9 in 2017. This 'hunt for duration' (Domanski et al. (2017)) mirrors the life insurers' efforts to match the durations of their assets and liabilities. With the interest sensitivity of life insurers' assets rising, their vulnerability to an increase in interest rates (both the CIRS, and CIR) has increased, too.[16] The other trend is an increase in buffers, in a reflection of both valuation effects and reduced profit distributions to customers and shareholders. The low market rates have raised the value of the legacy fixed-income assets in the life insurers' GA and

[16]In 2017 the aggregate duration of life insurers' assets decreased for the first time since 2008. According to anecdotal evidence, this development relates to the expectation of rising market rates and - in all modesty - to the dissemination of an earlier version of this paper, which clearly pointed to the risks involved in life insurers' investment strategies.

thus boosted their buffers. Furthermore, the German government has provided relief to life insurers in form of the 'Life Insurance Reform Act' (*Lebensversicherungsreformgesetz, LVRG*) in 2014.[17] This increase in buffers has nearly compensated for the increasing duration of life insurers' assets.

Figure 1: Critical interest rate levels and actual interest rate level (in per cent)



Notes. The boxplots show the critical interest rate level of the approximately 55 largest German life insurers which each had more than €1 billion in premium reserves from the end of 2005 to year-end 2017. Above the critical interest rate levels, the market value of the life insurers' total assets would no longer be sufficient to cover customers' surrender values and other liabilities. The critical interest rate levels relate to Bunds with a residual maturity of 10 years. They assume a parallel upward shift in the entire yield curve.
The outer lines (whiskers) start at the 5th and 95th percentiles. The inner boxes denote the median, the 25th and the 75th percentiles.
The line below shows the historical yield of Bunds with a residual maturity of 10 years.

The boxplots in Figure 1 show the distribution of the CIR and its evolution over time. The negative effect of the financial crisis in 2008 and the European sovereign debt crisis in the years 2010 and 2011 is clearly visible. The distribution of the CIR has been rather

[17] Partly due to the LVRG, German life insurers reduced their profit distributions to shareholders and customers to preserve their regulatory own funds. Furthermore, they are required by law to set aside an additional interest provision in a low-interest-rate environment as of 2011.

stable since the LVRG came into force in 2014. In 2017, the 25% most vulnerable life insurers might have been at risk if interest rates had hiked from 0.5% to 2.9%, while the median stood at 3.4%.

5 Potential market impact and amplification effect of fire sales

It has been shown that a significant hike in interest rates could cause a customer run on life insurers. In this event, the affected life insurers would face significant capital outflows and be forced to liquidate their assets. The resulting fire sales could depress the prices of fixed-income assets further and, thereby, amplify the initial interest rate shock. A simple example shows that the German life insurers could amplify interest rate shocks by as much as 15%.

The potential fire sales of bonds by German life insurers in the event of an interest rate shock are presented in the second column of Table 3. If, for example, market rates had increased by 300 basis points at the end of 2017, the critical interest rate levels would have been exceeded for a whole string of life insurers. According to their Solvency and Financial Condition Reports (SFCR), these affected life insurers held fixed-income assets in their GAs whose market value would, ceteris paribus, have decreased from €612 billion to about €436 billion.[18]

[18] The average modified duration of fixed-income assets in the GA of German life insurers is 9.6 (cf. Table 1). Under the assumption that German life insurers have a similar portfolio structure, an increase in market rates of 300 basis points would have depressed the market value of fixed-income assets held by affected life insurers by 28.8% to €435.7 billion (€612 billion·(1-3·0.096) = €435.7 billion).

Table 3: Potential fire sales of bunds by German life insurers and amplification effect

Initial shock in bps	Bond Sales in €bn.	Overall shock in bps	Amplification in %
200	25	203	1.3
250	145	265	6.0
300	436	345	15.1

Notes. The table reports potential fire sales of bonds by German life insurers and gives a stylized example of the resulting amplification effect.

Variables: *Initial shock* is the assumed initial interest rate shock, *Bond Sales* is the market value of bonds in billion Euro which are held in the GA of the affected German life insurers whose critical interest rate would be exceeded in the event of a hypothetical interest rate shock at the end of 2017, *Overall shock* is the estimated interest rate shock after fire sales of all bonds of the affected life insurers and *Amplification* is the relation between the initial shock and the amplified shock after fire sales in per cent.
Sources: Own calculations based on the Solvency and Financial Condition Reports (SFCR).

In the event of a customer run, the affected life insurers would have been forced to liquidate these assets. For the purpose of simplification, it is assumed that, on average, the price of fixed-income assets decreases by one basis point if their supply is increased by €1 billion.[19] Consequently, bond sales of €436 billion would reduce bond prices by 4.36%. This impact on bond prices can be translated into a change in market yields. Because the average modified duration of fixed-income assets is 9.6 (cf. Table 1), the effect on bond yields is about 10 times smaller than the effect on bond prices. Bond sales of €436 billion would thus increase bond yields by 45 basis points to 345 basis points.[20] The initial shock would thus be amplified by 15%.

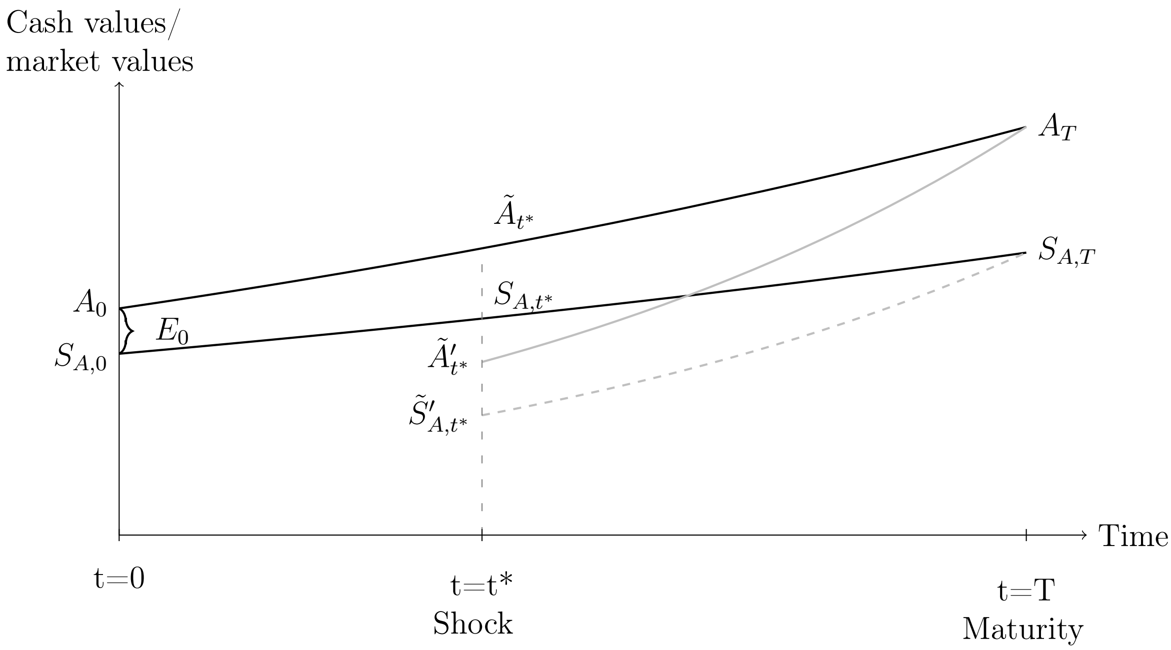
[19]This assumption is in line with Greenwood et al. (2015) and close to estimates by Ellul et al. (2011).

[20]The modified duration can be interpreted as the marginal decrease in bond prices in per cent if interest rates increase by one percentage point. Consequently, its reciprocal is the marginal increase in the interest rate in percentage points if the price of fixed-income assets falls by one per cent. If bond sales of €436 billion reduced bond prices by 4.36%, they would, consequently, increase the average interest rate level by 4.36% / 9.6 = 0.454 percentage points or 45.4 basis points.

6 Instruments for managing the risk of a customer run

Life insurers can reduce the risk of a run by means of increasing their capital buffers or decreasing their asset duration. Furthermore, surrender fees can act to reduce the exposure of the life insurance sector to market risk. They lower the surrender value and thus have a bearing on the costumers' choice as to whether or not to liquidate their contracts. In the U.S.A., life insurance contracts sometimes provide for interest-dependent market value reductions (MVRs) on the promised cash values. MVRs align the customers' surrender values with the market value of the life insurers' fixed-income assets.[21]

Figure 2: Evolution of cash values with and without an interest rate shock



The following example illustrates how MVRs work. Going back to the model presented in Subsection 3.1, we assume that a life insurer has sold one contract for a net single premium $S_{A,0} = K^*_{A,0}$. The lower solid black line in figure 2 shows how the policy accrues

[21]MVRs are usually determined using a reference rate, for example, the yield on a 10-year T-Bill. For some contracts, MVRs work symmetrically and raise the cash value if interest rates decrease.

interest at a rate of $\lambda \cdot y_{0,T}$ from $S_{A,0}$ up to the face value $S_{A,T}$ at maturity T. The life insurer invests the premium received $K^*_{A,0}$ and the shareholders' equity E_0 in a portfolio $A_0 = K^*_{A,0} + E_0 = X_0$. The life insurer's assets A_t accrue interest along the upper solid black line at the market rate of $y_{0,T}$ and pay A_T at maturity T. As long as market rates remain unchanged, the surrender value of the policy $S_{A,t}$ will never exceed the market value of the investment portfolio A_t. The life insurer can always fulfill the customer's claim S_t by selling its investments A_t if the contract is terminated.

If in $t = t^*$ the market rates increase to $y'_{t^*,T} > y_{0,T}$, however, the market value of the life insurer's investment falls from $\tilde{A}_{t^*}$ to $\tilde{A}'_{t^*}$. Over time, the market value of assets still converges from $\tilde{A}'_{t^*}$ to A_T (solid gray line), leaving the life insurer hedged at maturity T. In the short term, however, the market value of assets can fall below the cash value S_{A,t^*} being promised to the customer. If the customer surrenders their contract before maturity in $t = t^*$, the proceeds from selling the investments are insufficient to cover the customer's claim. Owing to the hike in interest rates, the life insurer may thus be underfunded in the short term, although it is still hedged when the contract matures. At the same time, the customer has an incentive to surrender their contract. The proceeds from surrendering the policy $\min[S_{A,t*}; \tilde{A}'_{t^*}] = \tilde{A}'_{t^*}$ invested at the new market rate $y'_{0,T}$ would yield the higher future value A_T at maturity (solid gray line) compared with $S_{A,T}$. MVRs align the surrender value with the market value of the investment portfolio in the event of a hike in market rates. For example, the surrender value in equation (1) could be adjusted to

$$\tilde{S}'_{A,t} = \frac{S_{A,t}}{(1 + \tilde{y}_{t,T})^{T-t}} = K^*_{A,0} \cdot \frac{(1 + \lambda_A \cdot y_{0,T})^t}{(1 + \tilde{y}_{t,T})^{T-t}}, \quad \forall t \in \{1, 2, \ldots, T-1\}. \tag{6}$$

It obviously follows from equation (2) and $X_0 > K^*_{A,0}$ that the market value of the life insurer's asset can never fall below the adjusted surrender value in equation (6):

$$\tilde{X}_t = X_0 \cdot \frac{(1 + y_{0,T})^t}{(1 + \tilde{y}_{t,T})^{T-t}} > K^*_{A,0} \cdot \frac{(1 + \lambda_A \cdot y_{0,T})^t}{(1 + \tilde{y}_{t,T})^{T-t}} = \tilde{S}'_{A,t} \tag{7}$$

In the above example with an increase in market rates to $y'_{0,T} > y_{0,T}$ in Figure 2, MVRs would reduce the surrender value of the policy to $\tilde{S}'_{A,t^*}$. The higher market rate would then be reflected in a steeper increase in the surrender value over time from $\tilde{S}'_{A,t^*}$ to $S_{A,T}$ (dashed gray line). The surrender values would remain lower than the market value of the life insurer's investment portfolio at any point in time (solid gray line). As a consequence, a rational customer's choice as to whether or not to surrender the contract would be unaffected by changes in the market rates.[22]

7 Conclusion

Life insurance products are designed as long-term savings products which offer a protection against market risk. However, they typically allow customers to withdraw funds if this protection becomes overstretched. Consequently, life insurers have a stable funding base during normal macroeconomic conditions. During these times, they can act as 'asset insulators' which pursue a buy-and-hold investment strategy and provide stable long-term funding to the broader financial system and the real economy. However, life insurers may lose this function in times of severe macroeconomic shocks. If their protection against

[22]It has to be noted that, in our model, the profit participation of a fairly priced life insurance product with an MVR will equal the market rate at inception of the contract, i.e. $\lambda_A = 1$. The reason is that the life insurance product has been modeled as an investment product which has the sole purpose of protecting customers against market risk. If this risk is fully transferred to customers by means of a market value reduction, fees will have to be reduced to zero.

market risk loses credibility, all customers have a common incentive to call liquidity and lapse their contracts. Life insurers would then have to liquidate their assets. Given the importance of life insurers as long-term investors, these fire sales could induce a downward spiral of asset prices.

This paper derives a model of a customer run, and it estimates enterprise-specific critical interest rates, beyond which such a run would be rational. Using the German case as a laboratory, it turns out that the resilience of life insurers to a positive interest rate shock has suffered during the financial and sovereign debt crisis and in the low-interest-rate environment. The mean critical interest rate decreased from 5.9% in 2005 to 3.3% in 2017. The 25% most vulnerable German life insurers might have been at risk if interest rates had hiked from 0.5% to 2.9% in 2017.

Life insurers which experience a customer run would be forced to liquidate their assets. If, for example, interest rates were to hike by 300 basis points, German life insurers might have to liquidate bonds worth €436 billion. These fire sales might amplify the initial shock by 15% to about 345 basis points.

Instruments for life insurers to reduce the risk of a customer run are higher capital buffers, lower asset durations and higher surrender fees, most notably market value reductions (MVRs) which some U.S. life insurers already offer in their contracts.

The analysis is intentionally designed to be sparse and comprehensible, but future research may extend it in different respects. Most importantly, further research could consider security mechanisms such as protection schemes and regulatory interventions which would add a redistributive channel between different life insurers as well as assumptions on supervisory behavior to the problem. Furthermore, other behavioral aspects could be added to the model.

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