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Rising interest rates and liquidity risk in the life insurance sector*

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Abstract

This paper sheds light on the life insurance sector's liquidity risk exposure. Life insurers are important long-term investors on financial markets. Due to their long-term investment horizon they cannot quickly adapt to changes in macroeconomic conditions. Rising interest rates in particular can expose life insurers to run-like situations, since a slow interest rate pass-through incentivizes policyholders to terminate insurance policies and invest the proceeds at relatively high market interest rates. We develop and empirically calibrate a granular model of policyholder behavior and life insurance cash flows to quantify insurers' liquidity risk exposure stemming from policy terminations. Our model predicts that a sharp interest rate rise by 4.5pp within two years would force life insurers to liquidate 12% of their initial assets. While the associated fire sale costs are small under reasonable assumptions, policy terminations plausibly erase 30% of life insurers' capital due to mark-to-market accounting. Our analysis reveals a mechanism by which monetary policy tightening increases liquidity risk exposure of non-bank financial intermediaries with long-term assets.

Keywords: Insurance companies; Liquidity risk; Systemic risk; Monetary policy transmission; Financial stability; Mark-to-market accounting

JEL Classification: G22; E52; G32; G28

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”[...] 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.”¹

Life insurance is a primary tool for individuals to absorb household risk and save for retirement. In 2016, roughly 142 million individual life insurance policies with a total face value of USD 12 billion were in force in the US ([American Council of Life Insurers \(2017\)](#)), and life insurance policy cash values are roughly 47% of the median US household’s net worth². The total life insurance sector’s size is substantial, even compared to banks.³

Similar to demand-deposit contracts provided by banks (e.g., [Goldstein and Pauzner \(2005\)](#)), life insurance savings policies enable policyholders to participate in profitable long-term investments but respond to early liquidity needs by termination, called *surrender*.⁴ Policyholders are in particular incentivized to surrender when market interest rates rise. The reason is a slow pass-through of interest rate shocks to policyholder returns (called *crediting rates*). Slow pass-through is driven by the long duration of life insurers’ investment portfolio, which hedges interest rate risk of long-term insurance policies but dampens the increase in insurers’ investment income upon an interest rate rise.⁵ Thus, a sharp interest rate rise can motivate an excessively large number of policy surrenders, exposing life insurers to liquidity risk.

Can excessive policy surrenders threaten the stability of the life insurance sector and spill over to financial markets? Under what circumstances do policy surrenders impose costs to life insurers?

¹Introductory statement by Mario Draghi, hearing before the committee on economic and monetary affairs of the European parliament, 26 November 2018.

²Excluding Equity in Own Home. *Source: US census Wealth and Asset Ownership for Households: 2014* (<http://www.census.gov>).

³In 2016, US life insurers held USD 6.8 trillion in financial assets, which is roughly one third of US depository institutions’ holdings in financial assets. Life insurers’ investment volume in mutual funds, corporate, and foreign bonds was roughly 6 times larger than that of banks. *Source: Board of the Governors of the Federal Reserve System (2017)*.

⁴The situation that a policyholder actively terminates her life insurance policy and receives a cash (surrender) value in turn is typically called *surrender*, while she could also let her policy *lapse* by not paying premiums. Sometimes, the latter case does not involve a surrender payment. Life insurance savings policies (also called *traditional endowment policies* and *deferred annuities*) are used particularly for retirement saving. Life insurers typically promise a fixed guaranteed annual rate of return. At maturity, savings are paid to policyholders as a lump-sum or converted into a regular payment stream.

⁵The modified duration of insurers’ fixed income assets (representing 67% of EU insurers’ asset investments) in the European Union (EU) is 7.85 years on average, and ranges from 3.6 to 12.45 years across EU countries as of 2016 ([European Insurance and Occupational Pensions Authority \(EIOPA\) \(2016\)](#)).

In this paper, we explore these questions by developing and calibrating a dynamic theoretical model of policyholder behavior and life insurer cash flows.

Regulators and previous studies stress that policy surrenders might collectively drain life insurers' free cash flow and solvency (e.g., [Russell et al. \(2013\)](#); [European Systemic Risk Board \(ESRB\) \(2015\)](#); [European Central Bank \(ECB\) \(2017\)](#)). Due to the life insurance sector's substantial size and significant impact on financial markets, massive asset liquidations upon policy surrenders might contaminate financial markets by depressing asset prices.⁶ Moreover, costs from excessive policy surrenders might undermine life insurers' ability to provide liquidity in financial markets and absorb household risk.⁷ Despite policymakers' awareness of life insurers' liquidity risk exposure, the mechanics and dynamics of run-like situations in life insurance as well as their effect on life insurers' cash flows and net worth are still ambiguous. Our study contributes to the literature by filling this gap. We focus on two channels for liquidity risk exposure, namely (I) fire sale costs due to asset liquidations and (II) direct surrender costs from an increase in surrender rates (which clearly depend on accounting regime). Both channels are important determinants for the life insurance sector's liquidity risk exposure. Fire sales may also transmit shocks to financial markets, raising life insurers' systemic risk contribution.

(I) Our model predicts that a sharp interest rate rise by 4.5pp within two years increases the annual share of surrendered policies (i.e., the *surrender rate* relative to the number of existing policies) from 2.86% p.a. to more than 20% p.a.. These excessive policy surrenders would force life insurers to sell roughly 12% of their initial assets over a time horizon of 10 years (and 3% during a gradual interest rate rise by 30bps p.a.). Analogously to [Greenwood et al. \(2015\)](#) and [Ellul et al. \(2018\)](#), such asset liquidations may result in fire sale costs to insurers. They could also depress asset prices on other intermediaries' balance sheets, as in [Allen and Carletti \(2006\)](#), and thus they might contribute to systemic risk. However, since asset sales are spread over a period of 10 years, the model predicts for our baseline calibration that accumulated fire sale costs do not exceed 2%

⁶[Ellul et al. \(2011, 2015\)](#) provide empirical evidence that asset liquidations by regulatorily constrained insurers significantly depress asset prices. [Greenwood and Vissing-Jorgensen \(2018\)](#) show that insurers' and pension funds' demand for long-dated assets drives the long end of yield curves.

⁷[Hombert and Lyonnet \(2018\)](#) document that life insurers smooth crediting rates over time and over generations of policyholders, thereby, (partially) protecting them from financial market volatility, in line with life insurers' role as asset insulators ([Chodorow-Reich et al. \(2018\)](#)). [Foley-Fisher et al. \(2018\)](#) provide empirical evidence that the shutdown of AIG's securities lending program in 2008 significantly reduced market liquidity of corporate bonds previously held by AIG.

of insurers' equity capital and that the impact on asset prices stays below 1.3%.

(II) Excessive policy surrenders result in direct surrender costs for life insurers if insurance reserves (i.e., liabilities) increase with surrender rates. Then, an increase in surrender rates reduces equity capital. We show that this can be the case under mark-to-market (MtM) accounting. In our model, surrender costs upon a sharp interest rate rise (by 4.5pp within two years) reduce life insurers' equity capital ratios by up to 30%. Capital ratios (particularly under MtM accounting) are reasonable measures for distance to default from investors' perspective. Therefore, we argue that excessive policy surrenders are likely to increase investors' assessment of their counterparty risk exposure toward life insurers, which transmits shocks in surrender rates to insurers' counterparties and might impair funding liquidity in the life insurance sector. In the most extreme case, a funding liquidity dry-up (as in the case of AIG in September 2008) could disrupt life insurers' role in absorbing and sharing risk as well as providing liquidity to financial markets. Hence, our model suggests that, in contrast to bank runs, run-like situations in life insurance are more likely to spread via counterparty risk (driven by surrender costs) to life insurers' counterparties than via fire sales. We argue that aligning surrender values to MtM insurance reserves is an adequate tool to mitigate surrender costs and associated risk spillovers.

We also compare MtM accounting (the prevailing information source for investors and for insurance regulators in the EU) with historical cost accounting (HCA; the prevailing generally accepted accounting principles (GAAP) in many countries, such as the US and Germany). HCA prevents insurance reserves to fall below surrender payouts. Thus, everything else equal, an increase in surrender rates unambiguously reduces insurers' HCA liabilities - in contrast to MtM liabilities. This discrepancy highlights that life insurers' incentives to manage policy surrender risk highly depend on accounting regimes. Moreover, the discrepancy between the impact of surrender rates under HCA and MtM accounting may fuel investor uncertainty about the financial health of life insurers that report under both accounting regimes.

By exploiting counterfactual calibrations of our model, we show that both fire sale and surrender costs are substantially driven (a) by long-dated asset investments, which directly affect interest rate pass-through to crediting rates, and (b) by the sensitivity of surrender rates toward differences in crediting and market interest rates, which directly affects surrender costs per contract. Increasing these two components in our model (to still empirically justified levels) boosts fire sale and surrender

costs. In this case, the impact of fire sales on asset prices increases up to 6% (and fire sale costs up to 18% of insurers' equity capital), which is clearly economically significant. Although it is often argued that, due to longer-term liabilities than assets, life insurers should unambiguously benefit from rising interest rates (e.g., [Samuelson \(1945\)](#)), our results highlight that rising interest rates come with the (potentially severe) drawback of policy surrenders. Thus, life insurance is subject to an inevitable trade-off between long-term interest rate risk and short-term surrender risk. For this reason, life insurers do *not* unambiguously benefit from either decreasing or increasing interest rates - but instead from stable interest rates.

Life insurers' exposure to policy surrenders is a key determinant for life insurers' ability to provide liquidity (e.g., [Chodorow-Reich et al. \(2018\)](#); [Foley-Fisher et al. \(2018\)](#)) and absorb household risk (e.g., [Kojen and Yogo \(2018\)](#)). Due to the interdependence between life insurers' interest rate and liquidity risk exposure, we also contribute to an understanding of monetary policy transmission via financial intermediaries.

The insights from our results are not restricted to life insurers. More generally, the model rationalizes that financial intermediaries with long-dates asset investments may be exposed to increased liquidity risk if their creditors' payout depends on the intermediaries' investment income. This mechanism also applies to banks, since average loan rates slowly respond to monetary policy shocks and depositors earn the *average* rate of return on bank loans (at least in a competitive banking market; see, e.g., [Neumark and Sharpe \(1992\)](#)). Indeed, vast empirical research finds that bank deposit rates react sticky to an increase in market interest rates (e.g., [Neumark and Sharpe \(1992\)](#); [Driscoll and Judson \(2015\)](#)). For this situation, our model predicts depositors to withdraw funds and invest in more profitable projects. This pass-through to depositors complements studies on the pass-through of monetary policy to bank lending (e.g., [Kashyap and Stein \(2000\)](#)) and contrasts the typical assumption that bank deposit demand is inelastic toward rate changes (e.g., [Berlin and Mester \(1999\)](#)).⁸ The mechanism is also similar to the sticky limits on nominal deposit rates granted by Savings & Loans banks during the 1960s and 1970s, which prevented the banks from increasing deposit rates upon accelerating inflation in the 1970s, upon which they suffered from substantial outflows of bank deposits (e.g., [Field \(2017\)](#)).

⁸Nonetheless, demand for bank deposits is likely much less elastic toward interest rate changes than insurance demand since assets with levels of liquidity and risk similar to deposits are much harder to find.

In life insurance, the payout after surrendering a policy is called *surrender value* and equals the amount of current savings (accumulated according to past crediting rates) minus a small surrender penalty.⁹ Analogously to a put option that is in-the-money, the independence of surrender values from interest rates provides an incentive to surrender when market interest rates increase (and thus the present value of holding the policy falls). Indeed, various studies provide empirical evidence that market interest rates positively correlate with surrender rates (e.g., [Pesando \(1974\)](#); [Dar and Dodds \(1989\)](#); [Kuo et al. \(2003\)](#); [Kim \(2005\)](#); [Kiesenbauer \(2012\)](#)). For example, a sharp rise in US interest rates in the late 1970s and early 1980s triggered a large number of life insurance surrenders ([Russell et al. \(2013\)](#)). A recent survey among German life insurance policyholders finds that an increase in attractive alternative investment opportunities is the second-most important reason to surrender life insurance policies - closely following policyholder illiquidity as the most important reason.¹⁰

We develop a granular and dynamic model of life insurer cash flows, policyholder behavior, and a stochastic financial market. A central element of our model is a decision-criterion for policyholders to surrender insurance policies. In line with empirical evidence that income and unemployment shocks are key determinants for surrender decisions (e.g., [Fier and Liebenberg \(2013\)](#), [Gemmo and Götz \(2016\)](#)), we develop a simple but insightful model for surrender decisions that is driven by policyholders' liquidity needs. After facing a liquidity shock, policyholders may either surrender their life insurance policy or engage in costly borrowing. Surrendering becomes relatively more favorable when the present value of holding the insurance policy until maturity falls relative to the (interest rate-independent) surrender value. This mechanism results in excessive policy surrenders if market interest rates approach crediting rates.

We calibrate the model for a representative German life insurer in 2015, while our basic results also apply in other markets.¹¹ The choice of 2015 as calibration year enables us to draw policy

⁹50% of EU life insurers' liabilities come without surrender penalties, another 40% with a penalty below 15% of current savings ([European Systemic Risk Board \(ESRB\) \(2015\)](#)). [Paulson et al. \(2012\)](#) report that more than 50% of US life insurers' liabilities in 2011 are moderately to highly liquid in the sense that the contract terms have few to moderate limitations on or penalties for early withdrawal of policyholder funds.

¹⁰See <https://www.presseportal.de/pm/122258/4114966>. 35% of the respondents report not being able to pay premiums as a reason for policy surrender, 31% report more attractive investment opportunities as a reason.

¹¹Life insurance savings policies are particularly popular in Germany. For example, life insurance reserves (excluding unit- and index-linked policies, where policyholders bear the investment risk) per capita are roughly USD 7.1 thd in the US and USD 10.9 thd in Germany as of 2016 ([Board of the Governors of the Federal Reserve System \(2017\)](#), [German Federal Financial Supervisory Authority \(BaFin\) \(2016b\)](#)). The share of traditional endowment life insurance policies with financial guarantees (as the one we study in this paper) among newly sold policies in Germany

implications in the context of the current debate about tightening monetary policy after ultra-low interest rates since the 2008/09 financial crisis. While the recent decline in interest rates has substantially challenged life insurers to serve guaranteed payouts (e.g., [Berdin and Gründl \(2015\)](#); [International Monetary Fund \(IMF\) \(2016\)](#)), we show that increasing interest rates are not a panacea. In line with this rationale, our model predicts that both fire sale and surrender costs in the life insurance sector are smaller upon a gradual than upon a sharp interest rate rise. This result provides (an additional) rationalization for the practice of monetary authorities of slow, steady increases in interest rates during recoveries.

Nonetheless, even a gradual interest rate rise by 30bps p.a. substantially increases surrender rates and life insurers' surrender costs due to slow interest rate pass-through. Therefore, policy-makers should have stabilizing measures that prevent massive surrenders at their disposal - even during slow monetary tightening. Our results suggest that, among the possible set of such measures, an increase in surrender penalties (life insurers' main liquidity management tool; see, e.g., [Geneva Association \(2012\)](#)) does not necessarily reduce surrender costs. Instead, the marginal reduction in surrender rates due to higher penalties is larger for less costly policies and, thus, might increase total surrender costs under reasonable assumptions and particularly during a slow and gradual interest rate rise. Instead, temporarily suspending surrenders (as suggested by the [European Systemic Risk Board \(ESRB\) \(2017\)](#)) would allow crediting rates to catch up with interest rates and, thereby, reduce surrender costs - with the drawback of constraining consumers' liquidity.¹²

This paper makes a contribution to the literature about liquidity risks of financial institutions (in particular life insurers), their exposure and transmission of monetary policy shocks, and, more generally, systemic risk along several dimensions. First, we contribute to a growing literature on the role of financial intermediaries in providing liquidity to financial markets and absorbing household risk. [Chodorow-Reich et al. \(2018\)](#) propose that the long-term investment focus of life insurers enables them to provide liquidity in times of market stress. We identify an important drawback of this long-term nature, namely that it slows down interest rate pass-through to crediting rates and, thereby, exposes life insurers to liquidity risk. [Kojen and Yogo \(2018\)](#) develop an equilibrium

has been roughly 70% between 2005 and 2015 according to the German Insurance Association (GDV).

¹²Indeed, the French *Sapin 2* law allows French regulators to temporarily (for up to 3 month) limit the payment of surrender values. This legislation is specifically designed to strengthen financial stability in the event that a sudden rise in interest rates threatens to destabilize life insurers as a result of massive surrender rates (*Source: <https://m.ca-assurances.com/en/magazine/sapin-2-law-what-it-will-change-insurance-sector>*).

model to explain the variable annuity market. Similar to traditional life insurance savings policies, variable annuities provide financial guarantees, while the variable return component is linked to the performance of mutual funds. Their model predicts that financial frictions, particularly capital regulation, affect policy characteristics and drive fees and guaranteed rates. Its implications are consistent with our rationale that an increase in insurance reserves due to a surge in policy surrenders would increase life insurance prices and might even lead to disintermediation in the life insurance sector (to the extent that variable annuities resemble traditional life insurance savings policies). [Gottlieb and Smetters \(2016\)](#) develop a competitive market model in which life insurers endogenously price contracts to encourage policyholders to surrender life insurance policies since the insurers (ex-post) profit from policy surrenders. We complement their analysis by studying an unexpected (i.e., not ex ante priced) increase in surrender rates for life insurance savings contracts with profit participation. We show that the profitability of policy surrenders heavily depends on accounting regimes and macroeconomic conditions. Insurers have stronger incentives to encourage surrenders under historical cost accounting (for which surrenders are unambiguously profitable) than mark-to-market accounting, and stable or decreasing rather than increasing interest rates (since (expected) surrender costs are larger in the latter case).

Second, we add to studies that explore asset interconnectedness and fire sales as a transmission channel for systemic risk. For example, in the theoretical models of [Allen and Carletti \(2006\)](#) and [Allen et al. \(2012\)](#), asset similarity across firms provides a channel for contagion, since asset sales depress prices on other firms' balance sheets. In the empirically calibrated models of [Greenwood et al. \(2015\)](#) and [Ellul et al. \(2018\)](#), banks and insurers seek to deleverage by selling assets upon an exogenous income shock, respectively, which increases systemic risk. We add in particular to [Ellul et al. \(2018\)](#)'s model, in which life insurers try to sell off (or terminate) existing variable annuity policies in order to increase their capital position. We complement their approach as deleveraging occurs endogenously in our model, driven by policy surrenders. An important distinction is that an increase in surrender rates in our model changes the value of insurance reserves and, thereby, might result in surrender costs that do not occur in [Ellul et al. \(2018\)](#)'s model since they assume that insurers repay insurance policies exactly with the value of insurance reserves.

Third, we complement the literature on run-like situations at non-banking institutions. Thereby, our approach contrasts the classical mechanism of bank runs due to fear of bank failure. Tradi-

tionally, bank runs emerge due to a combination of short-term liabilities and (partially) illiquid, long-dated assets (e.g., [Diamond and Dybvig \(1982\)](#), [Goldstein and Pauzner \(2005\)](#), [Gertler and Kiyotaki \(2015\)](#)). We complement this rationale by showing that a long asset duration results in sticky returns to creditors which endogenously incentivize them to run. The risk of policy surrenders upon an interest rate rise is also similar to prepayment risk in mortgage transactions: when interest rates rise, homeowners face less incentives to prepay mortgages since loan rates become smaller compared to market interest rates. Thus, the duration of mortgages increases, while their market value decreases, causing losses for banks (e.g., [Green and Shoven \(1986\)](#); [Deng et al. \(2000\)](#)). We explore the reversed phenomenon in life insurers' liabilities, for which an interest rate rise leads to more premature terminations that reduce the duration of liabilities and may cause losses.

To the best of our knowledge, [Förstemann \(2018\)](#) is the only study about insurance runs. In a theoretical model, he shows that it is optimal for all rationale policyholders to surrender if they doubt a life insurer's ability to serve contractually guaranteed commitments. This is the case, in particular, when an extreme interest rate rise in his model impairs an insurer's solvency. In contrast, a policyholder in our model surrenders since alternative investments become relatively more attractive upon an interest rate rise, while the life insurer may still be solvent. Thereby, our model allows to empirically calibrate the dependence between surrender rates and interest rates. In contrast, [Förstemann \(2018\)](#) provides a benchmark beyond which full surrender is optimal for all policyholders, and life insurers become insolvent.

Our analysis on surrender costs and the sensitivity of insurance policy values (i.e., reserves) also adds to the debate about pros and cons of historical cost vs. mark-to-market accounting (e.g., [Laux and Leuz \(2009, 2010\)](#); [Allen and Carletti \(2008\)](#)) and complements related evidence during stress times. [Kojen and Yogo \(2015\)](#) show that regulatory frictions (particularly the slow adjustment of discount factors for insurance reserves that is driven by similar dynamics as crediting rates in our model) have incentivized life insurers to sell long-term policies at a deep discount relative to actuarial values during the 2008/09 crisis. [Ellul et al. \(2015\)](#) document that historical cost accounting provided an incentive for insurers to sell bonds with the highest unrealized gains in order to improve their capital position during the 2008/09 financial crisis. We show that surrender costs differ substantially across accounting regimes, highlighting that accounting standards have an important impact on life insurers' incentives to manage liquidity risk.

The remainder of this paper proceeds as follows. Section 1 briefly reviews the historical evolution of surrender rates, motivating our model. Section 2 presents the model of life insurance savings policies, life insurer cash flows, policyholders' surrender decisions, and the financial market. Section 3 studies life insurer cash flows and quantifies the impact of surrenders on asset liquidations and fire sale costs. Section 4 explores the direct impact of surrenders on life insurer capital, i.e., surrender costs. Section 5 reviews several sensitivity analyses and Section 6 concludes.

1 A brief history of (excessive) policy surrenders

Surrender rates for life insurance savings policies typically range between 2% to 10% per year. For example, the average annual surrender rate between 2001 and 2016 was 3.6% in Germany, with a standard deviation of 0.4%.¹³ During the same time, the average annual US surrender rate was 6.7%, with a standard deviation of 1.04% ([American Council of Life Insurers \(2012, 2017\)](#)). As a result, from the USD 1.7 trillion premium income during that time, USD 583 billion (35%) were paid out to surrendering policyholders ([American Council of Life Insurers \(2017\)](#)). Thus, surrender payouts are not only economically significant but also an important determinant for life insurers' liquidity.

Based on historical surrender experience, we regard annual surrender rates as excessively large if they significantly exceed 10%.¹⁴ Two primary factors can drive excessive policy surrenders, namely (A) fear of insurer illiquidity and (B) a low value of insurance policies compared to other investment opportunities. An example for the first, fundamental-based, case is the US insurer *General American*, that experienced a run-like situation after it was downgraded in 1999 ([Paulson et al. \(2012\)](#)). Similarly, large investment losses of the German insurer *Mannheimer Leben* in 2003/04 pushed up surrender rates to 15% p.a. for this insurer. Capital losses and a downgrade of the Belgian insurer *Ethias* in 2008 incentivized its policyholders to withdraw EUR 110mil within three days.

Korean life insurers faced a non-fundamental-based surge of surrender rates in 1998. Analogously to our model, Korean market interest rates sharply increased (by roughly 4pp within a few

¹³Source: *German Insurance Association (GDV)*, www.gdv.de.

¹⁴This classification naturally depends on the market of interest. For example, annual surrender rates have not exceeded 4.12% in Germany since 1974 and, thus, even a surrender rate close to 10% is excessively large for the German market.

months) and, thereby, reduced the value of life insurance policies. As a result, surrender rates increased from 1% to 6.3% for long-term savings policies, gross premium income fell by 26%, life insurers were forced to liquidate assets, and roughly one third of Korean life insurers exited the market ([Geneva Association \(2012\)](#)). Similarly, the surge in US interest rates in the late 1970s and early 1980s triggered high surrender rates, upon which US life insurers suffered high surrender costs and liquidated a large share of their asset investments ([Russell et al. \(2013\)](#)). Importantly, changes in interest rates collectively affect life insurers, while a fundamental-based surge in surrender rates is typically constrained to one insurer. In the following, we will develop a model that helps to understand the dynamics, costs, and risks of interest rate-driven policy surrenders. Based on an empirical calibration of the model, we will quantify fire sale (asset liquidation) costs and direct surrender costs.

2 Model

In this section, we specify the dynamics of insurance policies, the insurer’s balance sheet and cash flows, and policyholder behavior.

2.1 Life insurance savings policies

We consider life insurance savings policies that are typically used by individuals for retirement saving. These policies comprise two phases. In the accumulation phase, policyholders contribute to their account by paying regular premiums, which are subsequently invested by the insurer. Policyholders can surrender (i.e., terminate) the policy, upon which they withdraw the cash value of the policy, subject to a surrender penalty. In the payout phase, policyholders can typically choose between receiving either the policy’s total cash value as a lump-sum or regular payments (annuities). Due to our focus on liquidity risk, we concentrate on the accumulation phase and assume that all policyholders receive a lump-sum at policy maturity.

During the accumulation phase, insurers credit investment returns to policyholders. For a policy cohort h sold at the end of year $t = h$, the cash (i.e., account) value V_t^h grows by crediting rates \tilde{r}_{t+1}^h and additional premiums P_{t+1}^h paid by policyholders during year $t + 1$, such that the cash value

at the end of $t + 1$ is

$$V_{t+1}^h = (1 + \tilde{r}_{t+1}^h)V_t^h + P_{t+1}^h. \quad (1)$$

For simplicity, we fix annual premium payments to $P_t^h \equiv p$, where p scales the insurer's balance sheet size. Policyholders also pay fees to the insurer. We assume that such fees exactly match insurers' costs of selling and managing policies (e.g., for salaries, IT, etc.) and, thus, are irrelevant for the insurer's balance sheet and cash flow dynamics. At policy maturity T^h , policyholders receive the cash value $V_{T^h}^h$. If a policyholder surrenders before maturity, she receives the share $\vartheta \in (0, 1]$ of the cash value, i.e., she pays the relative surrender penalty $\bar{\vartheta} = 1 - \vartheta$. We set the surrender penalty equal to $\bar{\vartheta} = 2.5\%$, which coincides with surrender penalties in practice according to anecdotal evidence from the German life insurance industry.

In a cliquet-style fashion, each year's crediting rate \tilde{r}_t^h is locked in by the policy's minimum guaranteed rate r_G^h , that is fixed over the policy's lifetime, $\tilde{r}_t^h \geq r_G^h$ for all $h + 1 \leq t \leq T^h$.¹⁵ In addition to the guaranteed rate, policyholders participate in the insurer's investment profit. The profit participation rate of return is $r_{P,t}^h$, such that $\tilde{r}_t^h = \max\{r_G^h, r_{P,t}^h\}$. $r_{P,t}^h$ depends on the insurer's total investment income R_t^a , which includes fixed income coupon payments, dividends, and rents minus depreciations on the GAAP (historical cost accounting) balance sheet (as described in Section 4.2; it excludes unrealized market value gains), such that

$$r_{P,t}^h = \xi \frac{R_t^a}{\sum_{h=1}^H V_{t-1}^h}, \quad (2)$$

where $\xi = 0.9$ according to German regulation and H are all active policy cohorts.¹⁶

Motivated particularly by life insurer insolvencies in the 1980/90s, regulators (particularly in Europe and Japan) set (explicit and implicit) maximum levels for guaranteed rates, which depend on

¹⁵A reason for insurers to hold guaranteed rates fixed during a policy's lifetime is that insurers hedge financial guarantees with long-term fixed income investments. Given such hedging, an increase in the guaranteed rate during a policy's lifetime would result in a loss for the insurer.

¹⁶Profit participation is very common in the European market, although its institutional setting varies across countries. The general underlying principle foresees that policyholders participate over time in the profits generated by a pool of assets in which their premiums are invested in. The pool of assets can be analogously thought of as representing a mutual fund. Life insurance policies in which policyholders can choose a mutual fund to invest in are known as *variable annuities*. Such policies are popular in the US and typically involve financial guarantees as well (e.g., Ellul et al. (2018); Kojien and Yogo (2018)).

long-term interest rate averages (Grosen and Jorgensen (2002)). Our model is calibrated to German regulation. As can be observed in practice, we assume that (due to competition) life insurers offer policies at the maximum discount rate for German life insurance policies under German GAAP accounting, which follows 60% of the 10-year moving average of 10-year German sovereign bonds in 50bps steps (Eling and Holder (2012)).¹⁷

2.2 Life insurer’s policy portfolio

We consider a representative insurance company, calibrated to the average German life insurer in 2015. The insurer sells life insurance savings policies and invests the proceedings in financial assets. Its policy portfolio consists of several cohorts, i.e., generations of insurance policies. Each year, the insurer sells a fixed number of policies N and collects premiums Np (net of fees).¹⁸ Based on the average lifetime of German policies’ accumulation phase, all policies in our model have a total lifetime of 30 years but differ according to age and (potentially) according to the guaranteed rate. Each cohort assembles all non-surrendered insurance policies that were sold in the same year. We identify cohorts by their policies’ begin h .

At the begin of our model (the end of year $t = 0$, calibrated to 2015), the insurer’s portfolio features 30 cohorts. The oldest cohort $h = -29$ was sold at year end $t = -29$ (i.e., 1986) with guaranteed rate $r_G^{-29} = 3.5\%$, and the latest was sold in $t = 0$ (i.e., 2015) with $r_G^0 = 1.25\%$, in line with the historical evolution of r_G^h . We assume that each year (from 1986 to 2014) the same number of policies has been sold, and determine their cash value at $t = 0$ by using historical profit participation rates and surrender rates. As a result, the policy portfolio very much resembles that of an average German life insurer in 2015, particularly in terms of the average guaranteed rate and duration (as discussed in the next section).

¹⁷In the internet appendix, we illustrate the historical evolution of German maximum technical rates. While the German regulator has recently changed this computation to a 5-year moving average to faster adopt to the low interest rate environment, we do not expect our results to be qualitatively affected by this change. In particular to stabilize life insurers, one can expect regulators to prevent a fast increase in new policies’ guaranteed rates upon an interest rate rise. Indeed, the German Association of Actuaries regularly suggests different maximum discount rates each year to the German government, based on different moving averages of sovereign bonds, from which the German government chooses the actually binding discount rate (*Source: www.aktuar.de*).

¹⁸Time-varying demand is implicitly captured by policyholders’ ability to surrender policies in the first year after purchase.

2.3 Life insurer’s asset investments and initial calibration

The insurer invests in four different asset classes: (1) German, French, Dutch, Italian, and Spanish sovereign bonds, (2) AAA, AA, A, and BBB-rated corporate bonds, German, French, Dutch, Italian, and Spanish (3) stocks and (4) real estate. The relative weights (in market values) and duration of each asset class are calibrated based on [German Insurance Association \(GDV\) \(2016\)](#) and [European Insurance and Occupational Pensions Authority \(EIOPA\) \(2014a\)](#).¹⁹ The portfolio allocation is reported in Table 1.²⁰ Sovereign and corporate bonds are by far the largest investment class, which is similar to other jurisdictions like the US ([McMenamin et al. \(2013\)](#)). During the evolution of the model, we assume that the relative portfolio weights remain constant in terms of market values. This investment strategy is plausible for insurers to maintain a similar level of investment risk and asset duration over time.

Entire Investment Portfolio	Weight	Modified Duration
Sovereigns w_{sov}	55.3%	9.4
Corporate w_{corp}	34.1%	5.5
Stocks w_{stocks}	6.7%	-
Real Estate $w_{\text{real estate}}$	3.9%	-

Table 1: Investment portfolio allocation.

The table depicts the weights and average modified duration of each asset class in the insurer’s investment portfolio.

The calibration is based on [European Insurance and Occupational Pensions Authority \(EIOPA\) \(2014a\)](#) and [German Insurance Association \(GDV\) \(2016\)](#) as described in the internet appendix.

All bonds are purchased at par and pay annual coupons. Consistent with life insurers tendency to hedge long-term liabilities with long-term investments, we assume that sovereign bonds have 20 years and corporate bonds have 10 years remaining to maturity at purchase. Bonds differ by the time of purchase, such that the oldest bond in the sovereign (corporate) bond portfolio is due in 1 year and the youngest in 20 (10) years. Stocks pay dividends and real estate investments pay rents at each year’s end. Dividends and rents equal the maximum of zero and 50% of a current year’s

¹⁹[European Insurance and Occupational Pensions Authority \(EIOPA\) \(2014a\)](#)’s stress test provides the most granular available data source about EU insurers’ investment portfolio. Most importantly, we use its documentation of the duration of investments in different bond classes. The stress test mostly includes life and health insurers: only 9% of insurance reserves in the stress test’s sample are for non-life insurance, 62% are for life (excluding unit-linked) insurance. To calibrate the weights of the general investment classes, we rely on the [German Insurance Association \(GDV\) \(2016\)](#) as described in the internet appendix.

²⁰The weights within bond portfolios are chosen in order to represent the modified duration of single bond classes as reported by [European Insurance and Occupational Pensions Authority \(EIOPA\) \(2014a\)](#) by following the methodology of [Berdin et al. \(2017\)](#). Due to the absence of granular data, we calibrate real estate and stock weights in order to yield a plausible home bias of 60% for German real estate and stocks, and distribute the remaining weights equally. Sub-portfolio weights are reported in the internet appendix.

price change in the national stock and real estate index, respectively.

Given the investment portfolio weights, insurance policy portfolio, and asset prices (as implied by the financial market model described in the next section) at time $t = 0$, we determine the total market value of assets (and, thus, the initial equity capital ratio) such that the life insurer satisfies a target solvency ratio (of equity capital relative to the total capital requirement) according to the risk-based EU insurance regulation Solvency II. We set the initial solvency ratio to 120%, which roughly corresponds to the average solvency ratio of German life insurers at the introduction of Solvency II in early 2016.²¹

The resulting initial calibration, as reported in Table 2, closely matches the balance sheet of German life insurers in 2015. For example, Förstemann (2018) reports an equity capital ratio of 8-15% of German life insurers in 2015 (depending on the treatment of other liabilities) under German GAAP historical cost accounting (HCA), while our calibration is 14.5%. The European Insurance and Occupational Pensions Authority (EIOPA) (2016) reports 8.7% equity capital relative to total assets under mark-to-market accounting for German life insurers in January 2016, while our calibration is 7.7%. Assekurata Cologne (2016) reports an average guaranteed rate of roughly 3% for 2015, while that in our model is 2.86% (per policy; and 3.41% weighted by cash value). The asset and liability duration of 8 and 11.5 years in our model, respectively, is in line with reports from the German Insurance Association (GDV) and European Insurance and Occupational Pensions Authority (EIOPA) (2014a, 2016).²²

2.4 Stochastic financial market

We use a stochastic financial market model to simulate (1) short rates, (2) spreads for different bond categories, and (3) stock and real estate investment. Short rates evolve according to Hull and

²¹European Insurance and Occupational Pensions Authority (EIOPA) (2016) reports an average solvency ratio of 145% for German life insurers for January 2016. German Federal Financial Supervisory Authority (BaFin) (2016a) reports a solvency ratio of ca. 180% for January 2016 and 120% for March 2016 for the median German life insurer. We include the (for life insurers most relevant) capital requirement modules for interest rate, equity, property, spread, and lapse risk in the Solvency II standard model as described by European Insurance and Occupational Pensions Authority (EIOPA) (2014b). We exclude transitional measures that were introduced to ease the transition from the previous regulatory regime, Solvency I, to Solvency II.

²²Note that the small deviation between the asset portfolio's target duration in Table 1 and the actual duration in Table 2 results from assigning weights within each bond portfolio (e.g., within the portfolio of DE or FR bonds) in order to minimize the deviation between target and actual duration. The optimization procedure is described by Berdin et al. (2017).

Parameter	Initial value
Average surrender rate	2.86%
Surrender penalty ($\bar{\nu}$)	2.5%
Average guaranteed rate (per policy)	2.86%
Average guaranteed rate (weighted by cash value)	3.41%
Policy lifetime	30
Average remaining policy lifetime	17.65
Equity capital / assets (HCA)	14.47%
Equity capital / assets (MtM)	7.7%
Modified duration (Assets)	7.98
Modified duration (Liabilities; scaled to assets)	11.5

Table 2: Calibration of key parameters and initial balance sheet at model begin $t = 0$.

MtM refers to the balance sheet under mark-to-market accounting as described in Section 4.1. *HCA* refers to the balance sheet under historical cost accounting as described in Section 4.2. The asset duration only considers fixed income investments. We compute the modified duration of liabilities (insurance policies) by treating each insurance policy as a zero coupon bond with a present value equal to its MtM value, $L_{T^h}^{MtM,h}$ (as described in Section 4.1).

Then, we scale the liability duration to assets by multiplying with the initial MtM asset/liability ratio.

White (1990)'s model and drive the evolution of risk-free interest rates.²³ Short rate dynamics are

$$dr(t) = \alpha_r(\theta_r(t) - r(t))dt + \sigma_r dW_r(t), \quad (3)$$

where $r(t)$ the short rate at time t , $W_r(t)$ is a standard Brownian motion, $\alpha_r > 0$ the speed of mean reversion, $\sigma_r > 0$ the volatility, and $\theta_r(\cdot)$ a function for the level of mean reversion. Under the assumption of arbitrage-free interest rates, (3) specifies the term structure of (annually compounded) risk-free interest rates at time t for maturities τ , $\{r_{f,\tau}(t)\}_{\tau \geq 0}$. In order to simulate rising interest rates, we explicitly specify $\theta_r(\cdot)$ as an increasing function given by²⁴

$$\theta_r(t) = \gamma + (\beta - \gamma) \left(1 - \frac{1}{1 + e^{-bt}} \right). \quad (4)$$

We calibrate two different interest rate environments as reported in Table 3. The first interest rate environment displays a gradual long-term increase in interest rates, during which the median risk-free rate with a maturity of 10 years (*10-year risk-free rate* in the following) starts at approximately 0.5% in $t = 0$ and increases on average by roughly 30bps each year (see Figure 1

²³We treat German interest rates as risk-free since Germany is AAA rated and serves as safe haven for capital markets.

²⁴ β and γ are the initial and long-term levels of mean reversion, respectively, and b describes the skewness of the mean reversion level over time. We describe the calibration process in the internet appendix in detail.

Parameter \ Environment	Gradual	Sharp
$r(0)$	3.8%	-135.59%
α_r	0.0095	2
σ_r	0.3%	1.31%
β	-0.75	1.4224
γ	0.4167	0.575
b	10	5

Table 3: Calibration of the short-rate model.

$r(0)$ is the initial short rate, α_r the speed of mean reversion, σ_r the volatility, β and γ the initial and long-term level of mean reversion, respectively, and b a skewness parameter. We calibrate gradually and sharply increasing interest rates, respectively.

(1)).

The second environment displays a sharp short-term increase in interest rates. In the first two years of this environment, interest rates increase by roughly 4.5pp. In subsequent years, interest rates stabilize. Such a sharp rise might be unlikely but not unrealistic, as historically we have seen increases in long-term rates by up to 7.6pp within 2 years.²⁵

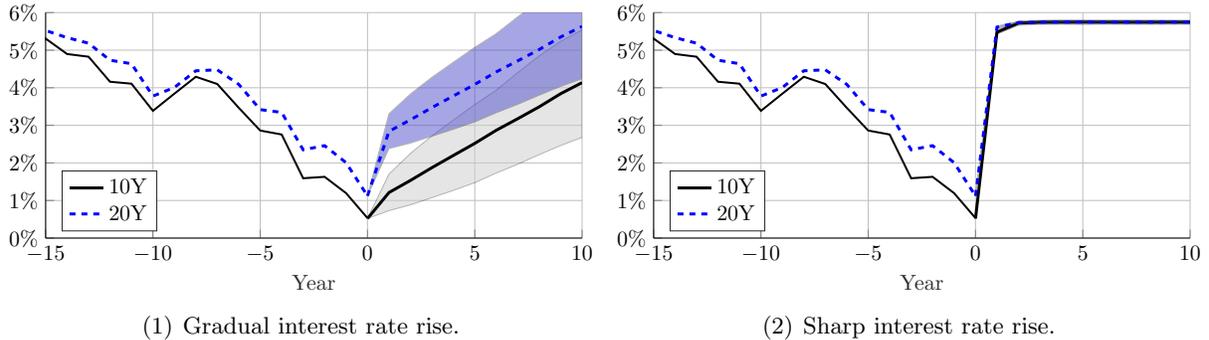


Figure 1: Interest rate environments.

Figures depict the median and 90% confidence interval for 10-year and 20-year simulated risk-free interest rates from year 0 on. Prior to year 0, we show German sovereign bond yields from 2000 to 2015, where the value at time 0 corresponds to the value in 2015.

Spreads for sovereign and corporate bonds are modeled by truncated Ornstein-Uhlenbeck processes, such that

$$s^j(t) = \max(k^j(\bar{s}^j - s^j(t))dt + \sigma^j dW^j(t))^+ \quad (5)$$

²⁵US 10-year sovereign bond yields increased from 7.2% in 1976 to 14.8% in 1981, and that of France increased from 9.7% in 1979 to 17% in 1982. (Source: OECD long term interest rates). The 10-year Japanese sovereign bond yield increased from 4.6% in December 1988 to 8.1% in September 1990 upon an increase in the key interest rate (Source: Ministry of Finance, Japan).

describes the evolution of a bond class j 's spread, and $\{r_{f,\tau}(t) + s^j(t)\}_{\tau \geq 0}$ is its term structure at time t , which is used to determine bond prices.²⁶ To capture both high and low interest rates, the calibration of the financial market model is based on the pre-2008/09 crisis time. We calibrate bond spreads and stocks and real estate returns by using bond yields and the main national stock and real estate indices on a monthly basis from January 1999 to December 2007.²⁷

2.5 Policyholder behavior

In this section, we present a simple model for policyholder behavior that allows us to calibrate the sensitivity of surrender rates toward market interest rates, policy crediting rates, and policy age. Consistent with empirical evidence as well as [Gottlieb and Smetters \(2016\)](#)'s model for surrender of term life policies, liquidity shocks incentivize policyholders to surrender in the model. Examples for such shocks include unemployment, medical expenses, real estate prices, new consumption opportunities, and the needs of dependents. Interest rates affect surrender decisions since a smaller present value of holding a policy until maturity relative to its surrender (cash) value increases the likelihood of surrender.²⁸

Each policyholder has the possibility to surrender her policy at the beginning of each year. Consider a risk-neutral policyholder with wealth W_0 at the beginning of year t who owns a life insurance savings policy that was purchased at the end of year h , $h < t$. As in [Gottlieb and Smetters \(2016\)](#), wealth W_0 is illiquid and, thus, cannot be used to rebalance liquidity shocks. The insurance policy has the current cash value V_{t-1}^h and surrender value SV_{t-1}^h (based on year-end $t-1$). Without loss of generality, we assume that policyholders pay accumulated fees at the earlier of surrender and maturity date. The accumulated fees since policy purchase are $e^{-c(t-h-1)}$ relative to the cash (or surrender) value, where $c(\cdot)$ is a non-negative and increasing function. Thus, the surrender value net of fees is $SV_{t-1}^h e^{-c(t-h-1)}$.

The policyholder faces a (random) liquidity shock $\mathcal{L} > 0$ at the begin of t . She can choose between two actions. Either she borrows \mathcal{L} , which comes with relative (e.g., administrative and

²⁶For the main part of the study, we assume that bond prices are equal to the present value of their future cash flows. We will departure from this assumption when studying fire sales in Section 3.

²⁷The data used for calibration as well as the detailed calibration procedure is reported in the internet appendix.

²⁸[Bauer et al.](#) discuss the challenges to model policyholder behavior with respect to surrender decisions in life insurance.

interest) costs b (at present value). In this case, her current wealth is

$$W^B = W_0 - \mathcal{L}(1 + b) + \mathcal{M}_{t-1}^h e^{-c(T^h-h)}, \quad (6)$$

where $\mathcal{M}_{t-1}^h e^{-c(T^h-h)}$ is the current net (of fees) value of holding her life insurance policy until its maturity T^h . We assume that the policyholder values her life insurance policy by the present value of the maturity cash flow $V_{T^h}^h$ based on past premium payments and conditional on receiving the current crediting rate \tilde{r}_{t-1}^h each future year, i.e., $\mathcal{M}_{t-1}^h = V_{t-1}^h \left(\frac{1+\tilde{r}_{t-1}^h}{1+r_{f,T^h-(t-1)}(t-1)} \right)^{T^h-(t-1)}$. This assumption is consistent with the observation that life insurers mainly compete over crediting rates in practice. Moreover, numerous studies highlight the low level of financial literacy among consumers (e.g., [Lusardi and Mitchell \(2014\)](#)). Particularly due to the high complexity of insurance policies and companies, policyholders are unlikely to extrapolate the trend and volatility of crediting rates. Instead, it seems reasonable that policyholders rely on current crediting rates as an estimate for a policy's future performance.²⁹

Alternatively to borrowing, the policyholder can surrender her policy, upon which she receives the current net surrender value $SV_{t-1}^h e^{-c(t-h-1)} = \vartheta V_{t-1}^h e^{-c(t-h-1)}$. In this case, wealth equals

$$W^S = W_0 - \mathcal{L} + SV_{t-1}^h e^{-c(t-h-1)}. \quad (7)$$

Thus, the it is optimal to surrender if

$$\log \left(1 + \frac{\mathcal{L}b}{SV_{t-1}^h e^{-c(t-h-1)}} \right) + \Delta c > \log \left(\frac{\mathcal{M}_{t-1}^h}{SV_{t-1}^h} \right), \quad (8)$$

where $\Delta c = c(T^h - h) - c(t - h - 1)$ are future policy fees from holding the contract until maturity.

The LHS of (8) reflects the sum of borrowing costs relative to the net surrender value and future

²⁹[Nolte and Schneider \(2017\)](#) provide empirical evidence that surrender rates are significantly correlated with the level of policyholders' financial literacy. [Hambel et al. \(2017\)](#) simulate term life insurance demand in a calibrated rational-expectations lifecycle model, which produces much lower surrender rates than empirically observed. Predicting future crediting rates is particularly complicated for policyholders as these rates depend not only on market conditions and investment behavior but also on the evolution of the insurer's full balance sheet and managerial decisions. For simplicity, we assume that the policyholders does not take into account the value of future premium payments (and the maturity cash flow these generate). Incorporating future premiums will not change the basic insights from the model since the surrender decision would still depend on the gap between crediting and market interest rates. However, the calibration would be complicated as it would depend on the whole term structure of interest rates.

policy fees. The RHS is the value of the policy's payout at maturity relative to its surrender value. The relative policy value equals

$$\frac{\mathcal{M}_{t-1}^h}{SV_{t-1}^h} = \vartheta^{-1} \left(\frac{1 + \tilde{r}_{t-1}^h}{1 + r_{f, T^h-(t-1)}(t-1)} \right)^{T^h-(t-1)} \quad (9)$$

and thus boils down to a comparison between crediting rate \tilde{r}_{t-1}^h and risk-free rate $r_{f, T^h-(t-1)}(t-1)$.

Equation (8) implies that smaller future policy fees Δc , e.g., due to higher policy age, reduce the incentive to surrender. Annual fees for life insurance policies are typically decreasing with policy age, which is consistent with [Gottlieb and Smetters \(2016\)](#)'s empirical findings. Decreasing marginal fees imply that $c(\cdot)$ is concave, i.e., $c''(\cdot) < 0$.³⁰ We assume that $c(x) = k \log(2 + x)$ with $k > 0$ for policy age $x = t - h - 1 \geq 0$.

A smaller surrender rate for older policies is also consistent with empirical evidence (e.g., [Belth \(1968\)](#); [Cerchiara et al. \(2009\)](#); [Milhaud et al. \(2010\)](#); [Eling and Kiesenbauer \(2014\)](#)). This pattern is not necessarily only due to the impact of policy fees, but might also reflect policyholders' age as younger policyholders are likely more exposed to large liquidity shocks. For example, in a sample of term life policies issued by large Canadian life insurers, [Gottlieb and Smetters \(2016\)](#) find that young policyholders lapse almost three times more often than older policyholders. The pattern might also reflect more general incentives for policyholders to stick with old policies. For example, at younger policy age policyholders are more likely to recognize whether they can bear period premium payments or whether they have been correctly advised about the policy. Moreover, surrendering older policies may come with additional costs to become informed about changes in the supply of long-term savings products, as in the model of [Kim et al. \(2016\)](#). Large marginal fees $c'(\cdot)$ may also reflect these additional motives by raising the differential costs of late surrender.

If $\mathcal{L} \approx 0$ and $\Delta c \approx 0$, the model boils down to a comparison between a policy's present value and surrender value, analogously to [Förstemann \(2018\)](#)'s model. In his model, the market value of assets and liabilities is perfectly correlated. Thus, each policyholder in cohort h surrenders if, and only if, $SV_{t-1}^h > \mathcal{M}_{t-1}^h$, in which case the insurer is underfunded. In our model, heterogeneous liquidity shocks \mathcal{L} result in heterogeneous surrender incentives among policyholders within each

³⁰German life insurers must deduct fees from surrender values evenly distributed across a policy's first 5 years (see German Insurance Contract Law Section 169). In the US, surrender penalties are typically large in the first years of a policy and decrease subsequently ([Gottlieb and Smetters \(2016\)](#)).

cohort h , which enables us to calibrate the model to empirically observed surrender rates.

To incorporate policyholder behavior in our cash flow model, we make the simplifying assumption that the LHS of (8) is normally distributed with expected value $\mu_L + \Delta c$ and variance σ_L^2 independently across policyholders and time. Then, the expected surrender rate is given by

$$\lambda_t^h = 1 - \Phi \left(\underbrace{\frac{-c(T^h - h) - \mu_L}{\sigma_L}}_{=\beta_0} + \underbrace{\frac{1}{\sigma_L}}_{=\beta_1} \log(\mathcal{M}_{t-1}^h / SV_{t-1}^h) + \underbrace{\frac{k}{\sigma_L}}_{=\beta_2} \log(2 + (t - h - 1)) \right). \quad (10)$$

We calibrate β_0, β_1 , and β_2 by using the following three constraints. (1) The average surrender rate at model begin implied by the policy structure in our model should match the 2015 German surrender rate, 2.86%. (2) In line with empirically observed surrender rates (e.g., reported by [Ho and Muise \(2012\)](#)), we assume that the surrender rate during the first policy year of a 30-year policy equals 10%, calibrated to crediting and interest rates from 2015,

$$\lambda_{h+1}^h = 1 - \Phi \left(\beta_0 + \beta_1 \log \left(\vartheta^{-1} \left(\frac{1 + \tilde{r}_h^h}{1 + r_{f,30}(h)} \right)^{30} \right) + \beta_2 \log(2) \right) \stackrel{!}{=} 0.1. \quad (11)$$

We use the average profit participation rate of return and the average 30-year German sovereign bond yield from 2015, $\tilde{r}_h^h = 3.3\%$ and $r_{f,30}(h) = 1.22\%$. We set the surrender penalty to $\bar{\vartheta} = 1 - \vartheta = 2.5\%$, which corresponds to the calibration in our model and is consistent with surrender penalties in the German market.

(3) With the third calibration constraint we make an assumption about mass surrenders. If risk-free rates approach current crediting rates, each dollar invested in a risk-free bond yields the same expected return as invested in the insurance policy (before fees), giving policyholders a high incentive to surrender upon liquidity shocks. In line with this rationale, we assume that the surrender rate during the first year of a policy for which the present value of future crediting rates equals the cash value (i.e., with $\frac{\mathcal{M}_{t-1}^h}{SV_{t-1}^h} = \vartheta^{-1}$) equals 30%.³¹

The resulting calibration is $(\beta_0, \beta_1, \beta_2) = (0.1132, 1.2408, 0.5479)$ and is illustrated in Figure 2.

³¹A 30% surrender rate for the case that $\frac{\mathcal{M}_{t-1}^h}{SV_{t-1}^h} = \vartheta^{-1}$ is relatively conservative in comparison to the mass surrender scenario of 40% in Solvency II. We take a more conservative rate since the mass surrender scenario in Solvency II is calibrated to reflect an extreme situation similar to bank runs ([Committee of European Insurance and Occupational Pensions Supervisors \(CEIOPS\) \(2009\)](#)). We will also assess the robustness of our results for a counterfactual calibration with 60% instead of 30% in the third calibration constraint.

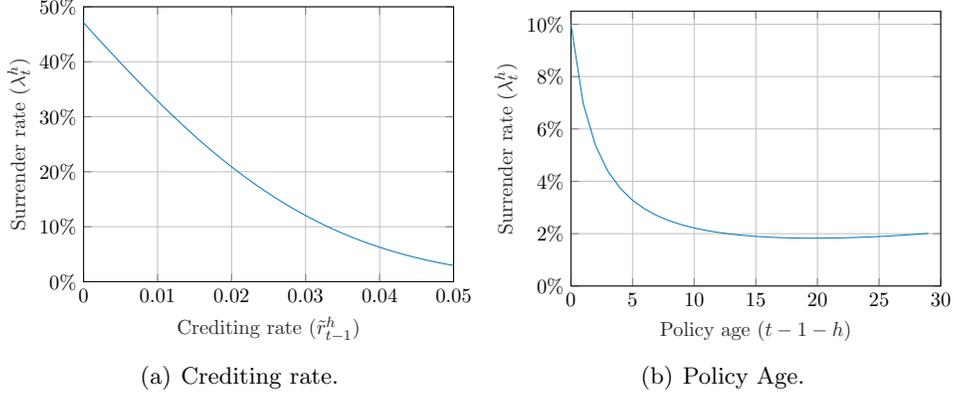


Figure 2: Surrender rate calibration.

Figures depict the likelihood for a policyholder to surrender a policy with current crediting rate \tilde{r}_{t-1}^h (set to $\tilde{r}_{t-1}^h = 3.3\%$ in (b)) with policy age $t-1-h$ (at the begin of year t for a policy purchased at the end of year h ; set to 0 in (a)). In the figure, we assume a flat risk-free rate of $r_f = 1.22\%$ and surrender penalty $\bar{\vartheta} = 1 - \vartheta = 2.5\%$.

Surrender rates are monotonically declining with the crediting rate in Figure 2 (a), since a higher crediting rate increases the opportunity cost of surrendering. The calibration clearly satisfies the second constraint described above, since surrender rates are equal to 30% if the crediting rate coincides with the risk-free rate at 1.22%.

Surrender rates are steeply decreasing in the first policy years in Figure 2 (b), which results from large future policy fees Δc . The calibration satisfies the third constraint described above, since surrender rates are equal to 10% in the first policy year (i.e., at age zero). For older ages, surrender rates are slightly increasing with age since the gap between \mathcal{M}_{t-1}^h and SV_{t-1}^h becomes smaller.³²

2.6 Timing

At the end of each year t , (1) the insurer pays out surrendered policies based on last year's surrender values, (2) financial market and investment returns realize, (3) crediting rates realize for non-surrendered policies, (4) active (i.e., non-surrendered and non-maturing) policyholders pay premiums, (5) a new policy cohort (given the current guaranteed rate) is sold, (6) the insurer's free cash flow realizes. The free cash flow is the difference between cash inflow (from premiums,

³²More specifically, it is $\frac{\partial \lambda_t^h}{\partial t} = C \times (\beta_1 (\log(1 + \tilde{r}_{t-1}^h) - \log(1 + \tilde{r}_{f,T-(t-1)}(t-1))) - \beta_2 / (2 + (t-h-1)))$, with $C > 0$. If $\tilde{r}_{t-1}^h > \tilde{r}_{f,T-(t-1)}(t-1)$, the surrender rate's sensitivity toward policy age t is a trade-off between the first term (the marginal change in the policy value relative to the surrender value), implying an increase in the surrender rate, and the second term (the marginal change in paid policy fees), implying a decrease.

fixed income coupon and principal payments, dividends, and rents) and cash outflow (for maturing and surrendered policies). A negative free cash flow is compensated by selling assets, maintaining the same portfolio weights in terms of market values. If the free cash flow is positive, the insurer pays out part of (or the total) free cash flow in form of dividends up to the maximum amount to maintain a solvency ratio of 100% (calculated as described in Footnote 21). Such dividend policies are common in practice.³³

For each interest rate environment calibration (i.e., gradually and sharply rising), we simulate 1,000 financial market and surrender decision paths with a length of 10 years in yearly time steps.

3 Cash flows and fire sale costs

In the following, we examine the impact of an interest rate rise and policy surrenders on life insurer cash flows. We start with an analysis of surrender rates, which are driven by crediting rates, i.e., the growth of policyholders' savings.

3.1 Surrender rates and the insurer's liquidity

Three main features of life insurance savings policies govern the evolution of crediting rates. First, the guaranteed rate r_G^h granted to policyholders is fixed at policy begin $t = h$ and does not change during a policy's lifetime. Second, due to regulation, the guaranteed rate for new policies adjusts with a considerable time lag to current interest rates. Third, the insurer's investment return (i.e., coupon, rent, and dividend payments) adjusts very slowly to interest rate changes, as well, which is due to the insurer's assets' long duration (8 years in our model). As a consequence, the profit participation rate of return granted to policyholders, $r_{P,t}^h$, and the total crediting rate $\tilde{r}_t^h = \max(r_G^h, r_{P,t}^h)$ take considerable time to adjust to higher interest rates. We call this phenomenon *slow interest rate pass-through*.

Figure 3 (1) illustrates crediting and guaranteed rates in the average policy cohort upon a gradual interest rate rise.³⁴ Because both profit participation and guaranteed rates for new policies

³³For example, Allianz SE pays out 50% of the net income only if it can maintain a solvency ratio above 160% (https://www.allianz.com/en/investor_relations/share/dividend). Note that this solvency ratio includes transitional measures and other mechanisms like (partial) internal models that increase the solvency ratio compared to the Solvency II standard model that we use. Therefore, we choose a smaller minimum solvency ratio.

³⁴Note that the average crediting rate per cohort may differ from the average crediting rate per policyholder because policyholders are not necessarily uniformly distributed across cohorts. For example, if policyholders in

reflect considerably slow interest rate pass-through. The average crediting rate declines for almost the whole model horizon of 10 years. As a result, the average crediting rate in excess of the risk-free market interest rate, $\frac{1}{H} \sum_h \tilde{r}_t^h - r_{f,10}(t)$, declines over time and even becomes negative after six years. In other words, the opportunity costs of holding on to an insurance policy (instead of surrendering and investing into a risk-free bond) increase for an average cohort’s policyholder over time.

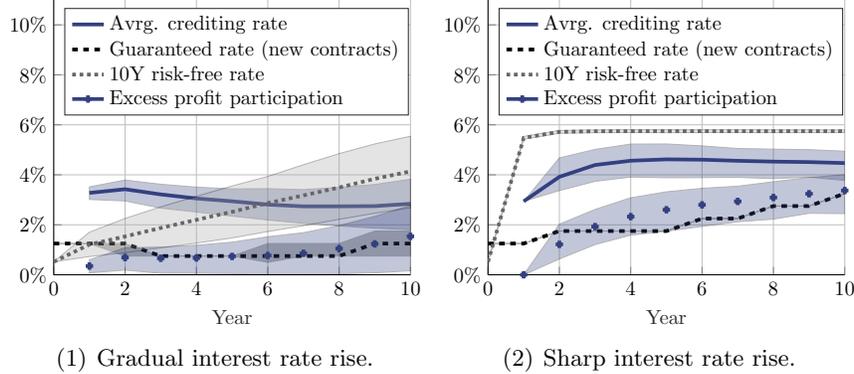


Figure 3: Guaranteed, crediting, and market interest rates.

Figures depict the average crediting rate per cohort, $\frac{1}{H} \sum_h \tilde{r}_t^h$ (straight line), the average profit participation rate in excess of the guaranteed rate per cohort, $\frac{1}{H} \sum_h (\tilde{r}_t^h - r_G^t)$ (crosses), the guaranteed rate for new policies, r_G^t , (dashed line), and the 10-year risk-free interest rate, $r_{f,10}(t)$ (dotted line). We show the median as well as 90% confidence interval for each interest rate environment.

Upon a sharp interest rate rise in Figure 3 (2), the average crediting rate increases until $t = 4$. This increase is driven mainly by an increase in the profit participation rate, which raises the crediting rate above guaranteed rates. After $t = 4$, a further increase in crediting rates due to rising profit participation is set off by the changing cross-section of the policy portfolio - with old high-guarantee cohorts maturing and new lower-guarantee cohorts being sold.³⁵ As a result, the average crediting rate is relatively stable (and slightly decreases) in later years, reflecting slow interest pass-through, as well.

The lower crediting rates relative to market interest rates, the more likely policyholders surren-

cohorts with lower crediting rates surrender more likely, then the average crediting rate per policyholder is larger than the average crediting rate per cohort. Average crediting rates per cohort illustrate policyholder incentives to surrender since they reflect the opportunity cost of surrender prior to surrender decisions.

³⁵Note that the same trade-off between maturing high-guarantee and new low-guarantee policies also widens the gap between crediting and market interest rates in case of a gradual rise interest rate rise. The average guaranteed rate (per cohort) is 3.04% ($t = 0$), 2.61% ($t = 5$), and 2.16% ($t = 10$) upon a gradual interest rate rise, and 3.04% ($t = 0$), 2.73% ($t = 5$), and 2.56% ($t = 10$) upon a sharp interest rate rise. In the internet appendix, we show the distribution of guaranteed rates across cohorts for both interest rate environments.

der their policies. Figure 4 illustrates policyholders’ likelihood to surrender, i.e., surrender rates. If interest rates gradually increase over time, the gap between crediting and market interest rate widens (cf. Figure 3 (1)), and thus surrender rates increase as in Figure 4 (1). Due to slow interest rate pass-through, even a sharp and fast interest rate rise as in Figure 4 (2) pushes up surrender rates for several years.

RESULT 1. *Due to slow interest rate pass-through, a gradual as well as a sharp short-term interest rate rise persistently increase surrender rates.*

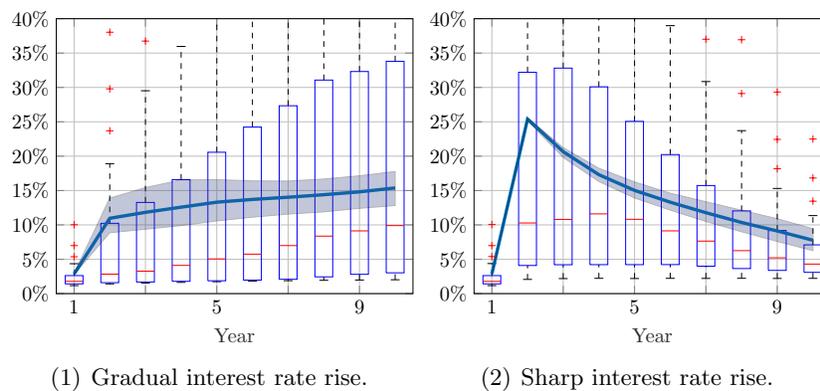


Figure 4: Annual surrender rates.

Figures depict the share of surrendered policies in each year (median and 90% confidence interval; straight lines) and the distribution of each cohort’s median surrender rate across cohorts (boxplots).

Accumulated over five years, 47% of the initial policyholders that exist in $t = 0$ surrender their policies until the end of year $t = 5$ (on average) if interest rates sharply rise.³⁶ From $t = 5$ to $t = 10$, the 5-year accumulated surrender rate is even larger, namely 71%. Surrender rates are thus excessively large upon a sharp interest rate rise, particularly in comparison to a five-year accumulated surrender rate of 16.75% in case each policyholder’s surrender rate was fixed to 3.6% (which is the average annual German surrender rate between 2001 to 2016). Due to an initially smaller gap between crediting and market interest rates, the accumulated surrender rate is intuitively smaller during the first five years of a gradual interest rate rise, namely 29%. This still high surrender rate increases with a widening gap between crediting and interest rates, resulting in a five-year accumulated surrender rate of 51% in the last five years of our model (i.e., between

³⁶Note that this accumulated surrender rate does not exactly correspond to the one implied by Figure 4, since it only considers the lifetime of policies that are in place at $t = 0$, while the surrender rates in Figure 4 consider all existing policies in a given year.

$t = 5$ and $t = 10$). Thus, regardless of its pace, an interest rate rise results in an excessively large number of policy surrenders if it endures sufficiently long.

RESULT 2. *A gradual long-term as well as sharp short-term interest rate rise can result in excessive policy surrenders, with more than 50% of existing policyholders surrendering their policies within 5 years.*

Surrender rates are very heterogeneous across cohorts. This heterogeneity stems from differences in policy age and guaranteed rates. Due to a decline in interest rates (and, thus, of policies' guaranteed rates) in years $t < 0$ (i.e., before 2015), the youngest policies are those with the smallest guaranteed rates. These have the largest incentive to surrender because (a) they are young (and thus policyholders can save on policy fees upon surrendering) and (b) the gap between market and crediting interest rate is particularly large. Vice versa, older policies with larger guaranteed rates have a lower incentive to surrender.

RESULT 3. *Policyholders face very heterogeneous incentives to surrender, stemming from differences in policy age and guaranteed rates.*

Policy surrenders trigger surrender payments to policyholders. In our model, more than half of the insurer's cash outflows comprise payments for maturing policies, while (in most periods) surrender payments account for roughly one third.³⁷ The reason for a relatively small share of surrender payments is that the cash value of surrendered policies is, on average, smaller than the cash value of maturing policies, since policies are younger at the time of surrender than at maturity.

An increase in surrender rates raises surrender payments, and thereby the insurer's cash outflow. To quantify the impact of excessive policy surrenders, we re-run our model with a counterfactual calibration that fixes surrender rates in all years to 2.86% for all policyholders (which is the average surrender rate in the baseline calibration's first year $t = 1$ and corresponds to the average German surrender rate in 2015). Then, we compare the results of this counterfactual calibration to those of the baseline calibration.

³⁷This composition of cash outflows is consistent with empirical evidence for German life insurers whose surrender payments accounted for roughly 25% of overall premium income in 2015 ([German Federal Financial Supervisory Authority \(BaFin\) \(2016b\)](#)) and for US life insurers whose surrender payments accounted for 34% of premium income between 2000 and 2016 (with an annual minimum of 23% and maximum of 49%; [American Council of Life Insurers \(2017\)](#)).

Figure 5 reports the relative change in total cash outflows due to policy surrenders. Mimicking the evolution of annual surrender rates, the impact of policy surrenders on cash outflows increases with an interest rate rise due to an increase in surrender payments.³⁸ A sharp interest rate rise pushes up cash outflows by up to 57% due to policy surrenders. Even in the case of a gradual rise, policy surrenders significantly and persistently increase the insurer’s cash outflows by roughly 13% per year.

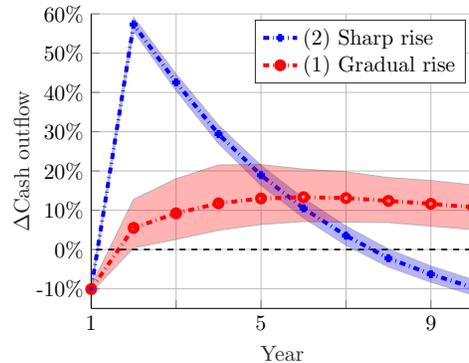


Figure 5: Impact of excessive policy surrenders on cash outflow. The figure depicts the median and 90% confidence interval of the relative difference in cash outflows between the baseline calibration compared to a counterfactual calibration with surrender rates fixed to 2.86%.

Policy surrenders also reduce the insurer’s future premium income, and thereby also the total investment volume and thus future cash inflow. The interaction of an increase in surrender payments and reduction in premium income reduces the insurer’s liquidity, as measured by its free cash flow (FCF), the difference between cash in- and outflow. Upon a sharp short-term or gradual long-term interest rate rise, the median FCF becomes negative (see Figure 6 (a)), reflecting that the insurer requires additional liquidity.³⁹ This liquidity need is met by selling assets. For example, during the two years following a sharp interest rate rise, the insurer is forced to sell more than 2% of its initial assets per year (at present value). Analogously to Greenwood et al. (2015) and Ellul et al. (2018), we assume that the insurer sells assets proportionally, maintaining the same asset weights in terms of market values. The accumulated liquidity need (summed up over time) is illustrated in Figure

³⁸Cash outflows in the first year $t = 1$ are smaller in the baseline than in the counterfactual calibration, since policyholders with older policies (that have large accumulated surrender values) are relatively less likely to surrender their policies in the baseline calibration, while surrender rates do not depend on policy age in the counterfactual calibration.

³⁹A negative FCF also implies that the insurer does not pay dividends. We illustrate the distribution of dividend payments in the internet appendix. Excessive policy surrenders (in the baseline calibration) reduce cumulative dividend payments (assuming reinvestment over 10 years) by (1) 74% upon a gradual and by (2) 92% upon a sharp interest rate rise.

6 (b). A gradual interest rate rise results in 2% of initial assets sold over 10 years. A sharp rise results in 12% of assets sold. This liquidity need is significant and economically sizable. It results exclusively from excessive policy surrenders and disappears if surrender rates are fixed to 2.86%.

RESULT 4. *Excessive policy surrenders significantly reduce an insurer’s free cash flow, resulting in up to 12% of initial assets sold over 10 years in our baseline calibration.*

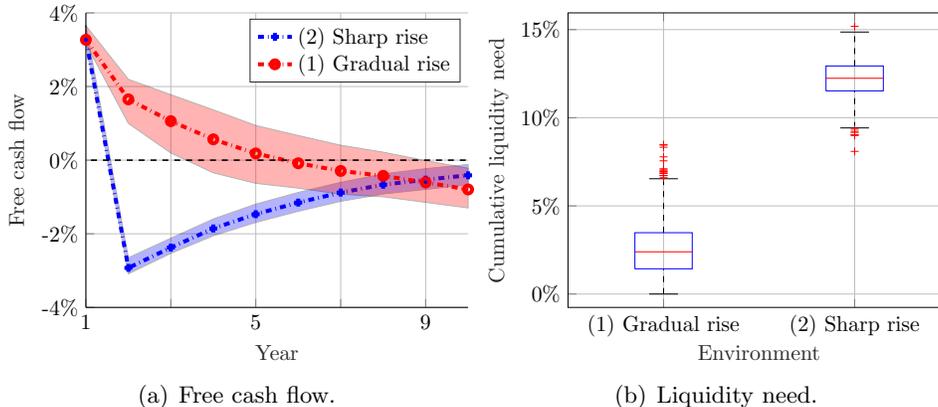


Figure 6: Free cash flow and cumulative liquidity need.

(a) Free cash flow scaled by the market value of assets at time $t = 0$. We show the median and 90% confidence interval over time for the two interest rate environments (1) gradual rise and (2) sharp rise. (b) Accumulated amount of assets sold over time: distribution of the accumulated liquidity need, $-\sum_{t=1}^T FCF_t \mathbb{1}_{\{FCF_t < 0\}}$, scaled by the market value of assets at time $t = 0$. Negative free cash flows reflect the size of forced asset sales.

3.2 Fire sale costs

Interest rate changes systematically affect all life insurers with a similar interest rate exposure. These insurers are collectively forced to liquidate assets. Due to the substantial size of life insurers as well as high correlation of their trades (Girardi et al. (2018); Chiang and Niehaus (2019)), collective asset liquidations might result in fire sale costs in the sense of Shleifer and Vishny (1992). This rationale is analogous to fire sales due to (active) de-leveraging by banks (Greenwood et al. (2015)) or insurers (Ellul et al. (2018)), as well as to fire sales to improve capital ratios upon rating downgrades (Ellul et al. (2011, 2015)).

In the following, we quantify fire sale costs arising from excessive policy surrenders, treating the insurer in our model as representative for (part of) the life insurance sector and, thus, $\max(-FCF_t, 0)$ as the life insurance sector’s total liquidity need. If there was no price impact of asset sales, the volume of asset sales s_t (in terms of market values before fire sales) would equal

insurers' liquidity need, which is $s_t = \max(-FCF_t, 0)$. However, if assets' liquidation value is subject to a fire sale discount δs_t upon selling EUR s_t , the volume of asset sales s_t satisfies

$$\max(-FCF_t, 0) = s_t(1 - \delta s_t). \quad (12)$$

Equation (12) reflects the contagious effect of fire sales: the more assets s_t insurers sell, the higher the price discount δs_t at which the assets trade, and the more assets s_t insurers must sell in order to meet their liquidity need. Given a positive price impact $\delta > 0$, the volume of asset sales is the solution to this fire sale spiral, which is given by

$$s_t = \frac{1 - \sqrt{1 - 4\delta \max(-FCF_t, 0)}}{2\delta}. \quad (13)$$

If, and only if, $1 - 4\delta \max(-FCF_t, 0) < 0$, then no solution to the fire sale spiral exists, implying that insurers are not able to receive the desired cash in order to satisfy their liquidity need. Then, fire sale costs result in insolvency, analogously to [Diamond and Dybvig \(1982\)](#). This case occurs if assets are sufficiently illiquid and the liquidity need sufficiently large (i.e., with large δ and $\max(-FCF_t, 0)$). Since insurers sell s_t (in market value before fire sales occur) but only receive $\max(-FCF_t, 0)$ (after fire sales), the total fire sale costs (discounted to $t = 0$) are⁴⁰

$$\text{Fire sale costs} = \sum_{t=1}^T \frac{s_t - \max(-FCF_t, 0)}{(1 + r_{f,t}(0))^t}. \quad (14)$$

To calibrate δ , we follow [Greenwood et al. \(2015\)](#) and assume that every EUR 1 billion asset sale leads to a price reduction by 1bps. This calibration is consistent with the price impact of US insurers' fire sales upon corporate bond downgrades ([Ellul et al. \(2011\)](#)). We assume that the price impact in one particular year is absorbed during the following year. This assumption is in line with empirical evidence from [Newman and Riersen \(2003\)](#), who estimate that the price impact associated with a EUR 16 billion bond issuance by Deutsche Telekom was 10bps on the same day, but quickly phased out of the market in the subsequent days. The assumption is also consistent with [Ellul et al. \(2011\)](#)'s results, who find that the price impact of insurers' fire sales upon bond

⁴⁰It is straightforward to show that $s_t > \max(-FCF_t, 0)$ if, and only if $\delta > 0$, and $s_t = \max(-FCF_t, 0)$, otherwise. Thus, fire sale costs are non-negative.

downgrades vanishes after at least 30 weeks.

We re-scale the insurer’s balance sheet to estimate the total life insurance sector’s total liquidity need and fire sale costs. We first focus on EU life insurers and, second, also include US life insurers. Since life insurers do not only sell savings policies with financial guarantees (but, e.g., also term life insurance and immediate annuities), taking the total life insurance sector as reference point would largely overestimate fire sale costs. Instead, we assume that 50% of EU life insurance reserves (excluding health, unit- and index-linked policies) match with those in our model. We regard this assumption as conservative for mainly two reasons: first, the [European Systemic Risk Board \(ESRB\) \(2015\)](#) reports that 90% of all liabilities of large EU life insurers can be surrendered with a penalty less than 15%, and 50% can be surrendered without surrender penalty. Since this number includes unit- and index-linked policies, we likely underestimate the size of liabilities with a large surrender risk exposure. Moreover, the [European Insurance and Occupational Pensions Authority \(EIOPA\) \(2016\)](#) reports that a very large share of EU life insurers’ liabilities include financial guarantees similar to the one in our model, while, to the best of our knowledge, no quantitative measure on the share of liabilities with guarantees is available.⁴¹ EU insurers’ life insurance reserves were EUR 5.238 trillion in the third quarter of 2016 ([European Insurance and Occupational Pensions Authority \(EIOPA\) \(2018b\)](#)), of which we assign 50% to the insurer in our model.⁴²

Additionally, we also calculate fire sale costs that include both EU and US life insurers. Our motivation is that (1) US life insurers offer financial guarantees similar to those offered by EU insurers (e.g., [Kojien and Yogo \(2017, 2018\)](#); [Ellul et al. \(2018\)](#)) and (2) interest rate shocks are likely to spill over between open economies such as the US and EU (e.g., [Clarida et al. \(2002\)](#)). We assume that 25% of US insurers’ technical reserves and pensions entitlements are similar to those in our model.⁴³ Because of differences in life insurance reserve calculation between the US and

⁴¹In Germany, roughly 71% of life insurers’ liabilities are interest rate sensitive, according to the German Federal Financial Supervisory Authority (BaFin). The liabilities for German life (excluding health, index-, and unit-linked) policies are roughly 19% of that of all EU life insurers ([European Insurance and Occupational Pensions Authority \(EIOPA\) \(2018b\)](#)).

⁴²While our model is calibrated to 2015, the earliest available details on EU life insurance reserves by [European Insurance and Occupational Pensions Authority \(EIOPA\) \(2018b\)](#) are from the third quarter of 2016. Since the volatility of EU life insurance reserves over time is very low (the standard deviation of EU life insurance reserves between 2016 Q3 and 2018 Q1 is roughly 2% relative to 2016 Q3), we use the value from 2016 Q3 to calculate fire sale costs. The value of life insurance reserves is calculated at MtM value (as described in Section 4).

⁴³This estimate is conservative. For example, [Ellul et al. \(2018\)](#) report that US life insurers have USD 1,655 billion only in guaranteed variable annuity gross reserves and account values in 2015. This already corresponds to roughly 30% of all life insurance liabilities in 2015 according to ([Board of the Governors of the Federal Reserve System \(2017\)](#)).

EU, we scale our model by US life insurers’ assets under historical cost accounting (that resembles German historical cost accounting as described in Section 4.2).⁴⁴

We extract the effect of policy surrenders by computing the fire sale costs in the baseline calibration in excess of those in a counterfactual calibration with a fixed 2.86% surrender rate.⁴⁵ We report the results in Table 4. We find that EU-wide excessive policy surrenders upon a sharp interest rate rise result in roughly EUR 1.9 billion of fire sale costs (0.8% of life insurers’ equity capital). Considering the US and EU life insurance sector, fire sale costs are roughly EUR 3.9 billion (1.2% of insurers’ equity).

RESULT 5. *Excessive policy surrenders result in significant fire sale costs of up to 1.2% of insurers’ equity capital, given our baseline calibration.*

In the EU as well as the EU and US case, fire sale costs are statistically significant but economically relatively small relative to insurer equity - although 12% of initial assets are sold upon a sharp interest rate rise.⁴⁶ The reason for relatively small fire sale costs is that fire sales are staggered over time since policyholders do not surrender simultaneously but have heterogeneous surrender incentives. For example, if the same cumulative asset volume was sold at once, the median fire sale costs were EUR 28.23 billion (8.9% of insurers’ equity) instead of EUR 3.91 billion (1.23% of insurers’ equity) upon a sharp interest rate rise (accounting for EU and US life insurers).

Staggered fire sales are a major difference between life insurance liquidity risk and bank runs. During a bank run, it is optimal for all depositors to run if some depositors run (Diamond and Dybvig (1982)). The reason for the immediacy of a bank run is that bank assets (primarily loans) are particularly illiquid, which results in high insolvency risk borne by non-running depositors. Such a fundamental-based run is possible in insurance as well: Förstemann (2018) proposes a model, in

⁴⁴73.5% of US life insurers liabilities are technical reserves and pensions entitlements. Therefore, we assign the insurer in our model (additionally to the share resulting from EU liabilities) $0.25 \times 0.735 \times 100\%$ of US life insurers’ total assets from 2015 at HCA value, which are EUR 4.268 trillion at the average exchange rate in 2015, EUR/USD=1.109729.

⁴⁵With this counterfactual calibration, the insurer in our model does not sell any assets but holds them until maturity. Thus, all fire sale costs in our baseline results are attributable to an increase in policy surrenders. Note that we compute fire sale costs ex post, i.e., upon obtaining our results with the insurer in our model selling assets at market value. Incorporating fire sale costs in each period of the model slightly increases the total fire sale costs since it decreases the next period’s asset investment volume and, thereby, future cash inflow from fixed income payments. However, the effect is negligible. The results are available on request.

⁴⁶The amplification effect of fire sales is also relatively small. Fire sales reduce asset prices by less than 1.3%. Given a modified duration of 8 years, a 1.3% reduction in asset prices has the same effect as a 16bps interest rate increase. We report the yearly amplification effect of fire sales in the internet appendix.

	(1) Gradual interest rate rise	(2) Sharp interest rate rise
(A1) Baseline (EU)		
Total (in billion EUR)	0.12 (0.06, 0.2)	1.85 (1.72, 2)
Share of equity (in %)	0.05 (0.03, 0.09)	0.84 (0.79, 0.91)
(B1) Baseline (EU and US)		
Total (in billion EUR)	0.25 (0.12, 0.42)	3.91 (3.63, 4.24)
Share of equity (in %)	0.08 (0.04, 0.13)	1.23 (1.15, 1.34)
(A2) No surrender penalty (EU)		
Total (in billion EUR)	0.17 (0.08, 0.27)	2.41 (2.26, 2.56)
Share of equity (in %)	0.08 (0.04, 0.14)	1.22 (1.15, 1.29)
(B2) No surrender penalty (EU and US)		
Total (in billion EUR)	0.35 (0.18, 0.58)	5.13 (4.83, 5.45)
Share of equity (in %)	0.12 (0.06, 0.2)	1.78 (1.68, 1.9)
(A3) Large surrender penalty (EU)		
Total (in billion EUR)	0.07 (0.03, 0.14)	1.34 (1.23, 1.46)
Share of equity (in %)	0.03 (0.01, 0.06)	0.6 (0.55, 0.65)
(B3) Large surrender penalty (EU and US)		
Total (in billion EUR)	0.15 (0.07, 0.29)	2.83 (2.61, 3.09)
Share of equity (in %)	0.05 (0.02, 0.09)	0.88 (0.81, 0.95)

Table 4: Fire sale costs of excessive policy surrenders.

This table reports the median and 50% confidence interval (in parentheses) of total fire sale costs, given by $\sum_{t=0}^T \frac{s_t - \max(-FCF_t, 0)}{(1+r_{f,t}(0))^t}$, in billion EUR and as a share of life insurers' initial equity capital (at mark-to-market accounting as described in Section 4.1). We consider (A) European (EU) life insurers, assuming that 50% of EU life insurers' insurance reserves (excluding health, unit- and index-linked policies) match those from our model, and (B) EU and US life insurers, additionally assuming that 25% of US life insurers' life insurance reserves and pension entitlements match those in our model. We report fire sale costs for 3 different calibrations, namely the baseline calibration (A1 and B1), calibrations with no surrender penalty (A2 and B2), and a surrender penalty of 5% instead of 2.5% (A3 and B3), everything else equal. For each calibration, the fire sale costs are equal to zero if surrender rates are fixed to 2.86%. Thus, fire sale costs entirely result from an increase in surrender rates.

which all policyholders optimally surrender once a sharp interest rate rise depresses the insurer's total market value of assets below surrender values, upon which the insurer is (economically) underfunded. However, even the sharp interest rise by roughly 4.5pp in our model is not sufficient for the market value of the insurer's assets to fall below surrender values, i.e., to result in illiquidity and insolvency (as shown in Section 4.2). Instead, staggered but excessive surrender rates result from a small present value of holding the life insurance policy.

RESULT 6. *Due to heterogeneous surrender incentives among policyholders, fire sales upon an excessive increase in surrender rates are staggered over time, contrasting bank runs.*

Surrender penalties are life insurers' primary tool to manage surrender risk (Geneva Association (2012)). A higher surrender penalty reduces surrender rates, surrender payments, and thereby fire

sale costs, and vice versa. We assess the effect of surrender penalties with two counterfactual calibrations: for results (A2) and (B2) in Table 4 we remove the surrender penalty. As a result, cumulative asset liquidations rise by 55% (20%) in case of a gradual (sharp) interest rate rise. Fire sale costs are roughly 40% (30%) larger and increase up to EUR 0.35 (5.13) billion (0.12% (1.78%) of insurers' equity) upon a gradual (sharp) interest rate rise for the EU and US life insurance sector (compared to a 2.5% surrender penalty). Vice versa, we increase the surrender penalty from 2.5% to 5% for results (A3) and (B3). The higher surrender penalty reduces asset sales by roughly 15% and, as a consequence, fire sale costs fall by 40% (28%) upon a gradual (sharp) interest rate rise. Thus, surrender penalties are not only an important tool to manage insurers' liquidity risk but also a macro-prudential instrument that can dampen fire sale costs arising from excessive policy surrenders. This insight supports the [European Systemic Risk Board \(ESRB\) \(2017\)](#)'s recent effort to allow EU insurance resolution authorities to reduce life insurance surrender values to prevent fire sale costs from excessive policy surrenders.

RESULT 7. *Surrender penalties can significantly reduce fire sale costs of excessive policy surrenders. An increase (decrease) in surrender penalties by 2.5pp reduces (increases) fire sale costs by roughly 30-40%, relative to a baseline surrender penalty of 2.5%.*

For the previous results, we assume that the price impact of EUR 1 billion asset sales is 1bps. Depending on life insurers' asset liquidity, the price impact might also be larger. For example, [European Insurance and Occupational Pensions Authority \(EIOPA\) \(2018a\)](#) reports that, for half of EU insurers, more than 32% of asset investments are illiquid (for 25% of EU insurers, more than 43% of assets are illiquid). Following the calibration of [Ellul et al. \(2018\)](#) (which is based on [Duarte and Eisenbach \(2015\)](#)'s empirical estimates for non-agency MBS), we may assume that these illiquid assets have a price impact of 2.06 bps per EUR 1 billion asset sales.⁴⁷ Assuming that 32% of life insurers' asset sales are illiquid (while the remaining share is liquid with 1bps price impact as in [Greenwood et al. \(2015\)](#)), the total price impact per EUR 1 billion asset sales is $\delta = 0.32 \times 2.06 + (1 - 0.32) \times 1 = 1.3392\text{bps}$. With this calibration, total fire sale costs for EU and US life insurers increase roughly linearly from EUR 3.91 billion to EUR 5.27 billion (from 1.23% to 1.66% of insurers' equity) upon a sharp interest rate rise; and analogously to EUR 0.34

⁴⁷[Ellul et al. \(2018\)](#)'s calibration is a price impact of 18.6bps per USD 10 billion asset sales. We transform this price impact from USD to EUR by using the average exchange rate from 2015, EUR/USD=1.109729.

billion (0.11% of insurers' equity) upon a gradual interest rate rise. Thus, while asset illiquidity may significantly increase fire sale costs, the total size of fire sale costs remains small relative to life insurers' equity capital under realistic assumptions.

4 Surrender costs and insolvency risk

Leaving aside fire sale costs, it is not obvious whether policy surrenders are costly for life insurers - particularly since surrender values do not exceed policies' cash values. Life insurers recognize cash values under historical cost accounting (HCA), which is the basis for national GAAP (statutory) accounting for life insurers in the US as well as in many EU countries (such as Germany). Thus, one can expect policy surrenders to increase an insurer's HCA equity capital position, which is supported by our results below. However, international (IFRS) accounting, the prevalent information source for investors, as well as EU regulatory (Solvency II) accounting for life insurers are both based on mark-to-market (MtM).⁴⁸ Our analysis will show that the impact of policy surrenders on MtM equity capital can be reversed to that on HCA equity capital, implying that life insurers may face surrender costs from a MtM perspective.

Under both HCA and MtM accounting, the insurer's balance sheet is computed at each year's end and comprises asset investments (bonds, stocks, and real estate) and life insurance reserves (i.e., liabilities) as illustrated in Figure 7. Equity capital is the value of assets net of liabilities.

Assets	Liabilities and Capital
Asset Investments MtM: A_t^{MtM} HCA: A_t^{BV}	Equity
	Insurance Reserves MtM: L_t^{MtM} HCA: L_t^{BV}

Figure 7: Life insurer's balance sheet.

Stylized illustration of life insurer's balance sheet and notation of asset and liability values under mark-to-market (MtM) accounting and book values under historical cost accounting (HCA) in our model.

An insurer's equity capital position is also a measure for distance to default and, thus, for

⁴⁸The revised international accounting standard for insurers, IFRS 17, requires a market-consistent valuation not only for assets but also for insurance policies. IFRS 17 was introduced in 2017 and will be effective for reporting periods from 2022 on.

insolvency risk. Investors may particularly focus on the MtM balance sheet due to its present value perspective. A collective increase in investors' assessment of insolvency risk might trigger a downward spiral in life insurers' funding liquidity, driven by an increase in (expected) counterparty risk, which might ultimately result in actual insolvency and disintermediation. For example, the investment losses of AIG in early 2008 triggered large margin calls related to its securities lending and derivatives business, that ultimately led to AIG's failure in late 2008 (e.g., [Harrington \(2009\)](#); [McDonald and Paulson \(2015\)](#)).

4.1 Mark-to-market accounting

Mark-to-market (MtM) accounting seeks to recognize market values whenever possible. Life insurers' assets are typically publicly traded and, thus, market prices are readily available, which does not apply to life insurance policies. Hence, instead of observing policies' market prices, insurers estimate their value, which results in a *market-consistent value* (MCV).⁴⁹ Insurance policies' MCV reflects the size of insurance reserves on life insurers' MtM balance sheet, i.e., the value of life insurers' liabilities (as illustrated in Figure 7). In our model, we follow the valuation approach of EU insurance regulation, Solvency II (specified by the [European Insurance and Occupational Pensions Authority \(EIOPA\) \(2014b\)](#)). The MCV for cohort h at time t is given by⁵⁰

$$L_t^{MtM,h} = V_t^h \times \underbrace{\frac{\mathbb{E}[\text{future cumulative rate of return}]}{(1 + r_{f,T^h-t}(t))^{T^h-t}}}_{=\text{Best Estimate}} \times (1 + RM_t^h). \quad (15)$$

The MCV consists of three main elements: (1) V_t^h is the cash value, that grows with the crediting rate, $\tilde{r}_t^h = \max(r_G^h, r_{P,t}^h)$. (2) The policy's *best estimate* reflects the expected future cash flow to policyholders by extrapolating profit participation rates of return. (3) The risk margin RM_t^h is an adjustment to value non-hedgeable risks. For simplicity, we assume that the risk margin is a constant share of the best estimate, $RM_t^h \equiv RM$. The calibration is based on [European Insurance and Occupational Pensions Authority \(EIOPA\) \(2011\)](#), $RM = 1.83\%$.⁵¹

⁴⁹[Jorgensen \(2004\)](#) provides a discussion of MtM valuation techniques for insurance contracts.

⁵⁰In the internet appendix, we illustrate the accounting of life insurance policies with an example, and we discuss more details about the components of market-consistent valuation and the way we include these in our model.

⁵¹The risk margin calibration is also consistent with the risk margin for German life insurance liabilities (excluding health, index- and unlit-linked contracts) in 2016 as reported by [European Insurance and Occupational Pensions Authority \(EIOPA\) \(2018b\)](#).

The first-order effect of an interest rate rise is an increase in discount rates, reducing the MtM value of both assets and liabilities. Typically, the MCV of life insurance policies is more sensitive toward interest rates than life insurers' assets, stemming from long policy lifetimes. This interest rate risk mismatch is typically called *negative duration gap*.⁵² As a consequence, an interest rate rise reduces insurance policies' MCV relatively more than the value of assets, and thereby increases the MtM equity capital ratio. We call the effect of interest rates changes on the equity capital ratio *valuation effect*.

RESULT 8 (MtM valuation effect). *The MtM equity capital ratio increases upon an interest rate rise due to a negative duration gap between life insurers' assets and liabilities.*

The second-order effect of an interest rate rise is an increase in surrender rates. Policy surrenders affect the balance sheet in two ways: first, by paying out policyholders, surrenders reduce the total size of the balance sheet and thereby have a de-leveraging effect analogously to Ellul et al. (2018). De-leveraging increases the insurer's equity capital ratio, everything else equal. While in Ellul et al. (2018)'s model, life insurers seek to de-leverage due to an exogenous equity market shock, in our model the life insurer is forced to de-leverage as the exogenous interest rate rise incentivizes policy surrenders.

Second, changes in surrender rates can result in profit (or loss) by decreasing (or increasing) the MtM value of liabilities (i.e., insurance policies' MCV). In our model, we assume that the insurer estimates a cohort h 's future annual surrender rates based on the current year t 's observed surrender rate $\bar{\lambda}_t^h$, i.e., its estimate is $\hat{\lambda}_{t+i}^h = \bar{\lambda}_t^h$ for years $t + i > t$.⁵³ By following (15), cohort h 's MCV equals

$$L_t^{MtM,h}(\bar{\lambda}_t^h) = V_t^h \left[\vartheta \sum_{i=1}^{T^h-t} \frac{\bar{\lambda}_t^h (1 - \bar{\lambda}_t^h)^{i-1} \prod_{j=1}^{i-1} (1 + \hat{r}_{t+j}^h)}{(1 + r_{f,i-1}(t))^{i-1}} + \frac{(1 - \bar{\lambda}_t^h)^{T^h-t} \prod_{j=1}^{T^h-t} (1 + \hat{r}_{t+j}^h)}{(1 + r_{f,T^h-t}(t))^{T^h-t}} \right] (1 + RM), \quad (16)$$

⁵²Our model starts with a duration gap of roughly 3 years, which is consistent with German and EU life insurers in practice (as reported, e.g., by European Insurance and Occupational Pensions Authority (EIOPA) (2014a) and International Monetary Fund (IMF) (2017)).

⁵³In other words, we make the - arguably reasonable - assumption that surrender dynamics are unknown to the insurer. As in practice, the insurer must hence estimate future surrender rates based on historical observations. We do not expect our results to change with different assumptions about the insurer's knowledge of future surrender rates as long as predicted surrender rates are positively correlated with current surrender rates. Then, an increase in current surrender rates leads to an increase in predicted surrender rates and, thereby, changes insurance policies' MCV as described in this section. For the newly sold cohort $h = t$, we assume $\hat{\lambda}_{t+i}^h = \bar{\lambda}_t^{t-1}$.

where \hat{r}_{t+j}^h is the predicted crediting rate for year $t + j$. The first summand in (16) is the value of future surrender cash flows during the policies' remaining lifetime, while the second summand is the value of the maturity cash flow.

The sensitivity of $L_t^{MtM,h}$ toward the surrender rate $\bar{\lambda}_t^h$ depends on the ratio between crediting rates $\{\hat{r}_{t+j}^h\}_{j=1,\dots,T^h-t}$ and discount (interest) rates $\{r_{f,j}(t)\}_{j=1,\dots,T^h-t}$. For example, consider a policy with one year remaining to maturity ($T^h - t = 1$), for which the MCV is

$$L_t^{MtM,h}(\bar{\lambda}_t^h) = V_t^h \left[\vartheta \bar{\lambda}_t^h + (1 - \bar{\lambda}_t^h) \frac{1 + \hat{r}_{t+1}^h}{1 + r_{f,1}(t)} \right] (1 + RM). \quad (17)$$

The sensitivity toward the surrender rate is given by

$$\frac{\partial L_t^{MtM,h}}{\partial \bar{\lambda}_t^h} = V_t^h \left[\vartheta - \frac{1 + \hat{r}_{t+1}^h}{1 + r_{f,1}(t)} \right] (1 + RM). \quad (18)$$

The smaller the predicted crediting rate \hat{r}_{t+1}^h relative to the discount rate $r_{f,1}(t)$, the less valuable is the policy's future cash flow (which is $V_t^h(1 + \hat{r}_{t+1}^h)$) relative to the surrender value (which is $V_t^h\vartheta$). If $(1 + \hat{r}_{t+1}^h)/(1 + r_{f,1}(t)) < \vartheta$, the insurance policy's MCV increases with a larger surrender rate $\bar{\lambda}_t^h$, $\frac{\partial L_t^{MtM,h}}{\partial \bar{\lambda}_t^h} > 0$, which reduces the insurer's MtM equity capital ratio.⁵⁴ The smaller the value of future crediting rates, the higher are surrender costs.

Since the risk margin RM is not paid out to policyholders, dissolving the risk margin reserve reduces realized surrender costs. Ultimately, the relative change in the value of insurance liabilities (including actual surrender payouts) upon a ε percentage point increase in surrender rates between (predicted surrender rates at) year-end t and (actual surrender rates at) year-begin $t + 1$ is given by

$$R_{surrender,t}^{MtM,h} = \frac{L_t^{MtM,h}(\bar{\lambda}_t^h) - L_t^{MtM,h}(\bar{\lambda}_t^h + \varepsilon) + (\bar{\lambda}_t^h + \varepsilon)\vartheta V_t^h RM}{L_t^{MtM,h}(\bar{\lambda}_t^h)}. \quad (19)$$

We call $R_{surrender,t}^{MtM,h}$ the *surrender return*. It is the relative reduction in insurance liabilities (including surrender cash flows at year-begin of $t + 1$) when realized surrender rates at year-begin $t + 1$ are larger than expected at year-end t . The insurer accounts a loss upon an increase in surrender

⁵⁴Since $\vartheta \leq 1$, it is $\frac{\partial L_t^{MtM,h}}{\partial \bar{\lambda}_t^h} > 0$ only if $\hat{r}_{t+1}^h < r_{f,1}(t)$, i.e., if the net present value of holding the policy is negative.

rates if $R_{surrender,t}^{MtM,h} < 0$, and vice versa.

Figure 8 depicts the surrender return for an increase in surrender rates by one percentage point ($\varepsilon = 0.01$). The smaller (i.e., the more negative) the surrender return, the more vulnerable is the insurer toward an increase in surrender rates. Both a gradual as well as sharp interest rate rise result in a negative surrender return for more than 25% of the insurer’s cohorts. In these cohorts, the value of future crediting rates is particularly small, resulting from crediting rates’ lagged reaction to an interest rate rise. We call the effect of a surrender rate-increase on the insurer’s equity capital the *surrender effect*. In contrast to the MtM valuation effect, the surrender effect may reduce an insurer’s MtM equity capital ratio. Both effects accumulate (and interact) over time.

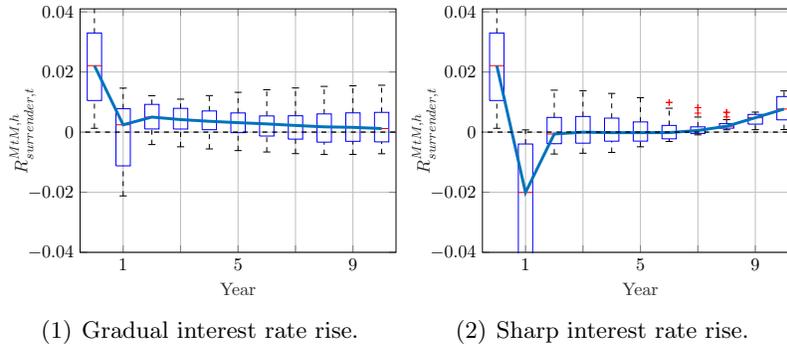


Figure 8: MtM surrender return.

Figures depict the distribution of the median surrender return $R_{surrender,t}^{MtM,h}$ across cohorts h at year-end t in different interest rate environments. $R_{surrender,t}^{MtM,h}$ reflects the relative reduction in the market-consistent value (MCV) of life insurance policies when surrender rates increase by 1pp. The straight and thick line depicts the median (across cohorts) median (across simulations) surrender return. If $R_{surrender,t}^{MtM,h} < 0$, an increase in surrender rates results in a loss.

In case of a gradual interest rate rise, the surrender return is persistently negative for at least 25% of the insurer’s cohorts for $t \geq 5$ since the gap between crediting and interest rates widens over time (see Figure 8 (1)). A sharp interest rate rise sharply reduces the surrender return particularly at $t = 1$ when interest rates are substantially larger than crediting rates. The surrender return becomes positive for all cohorts roughly seven years after a sharp interest rate rise (see Figure 8 (2)) since (current and predicted) crediting rates catch up with interest rates.

RESULT 9 (MtM surrender effect). *If the value of insurance policies’ (current and predicted) crediting rates is sufficiently small, an increase in surrender rates reduces MtM equity capital.*

Critically, as long as guaranteed rates are binding for crediting rates in early years t (when profit

participation rates are low), surrender returns are inversely related to surrender rates across cohorts: in this situation, surrender returns reflect the value of guaranteed rates relative to surrender values, which roughly coincides with the criterion for surrender-decisions (as described in Section 2.5). For example, the correlation between median surrender rates (at year-begin $t+1$) and surrender returns (at year-end t) across cohorts at $t = 1$ is -57% for a gradual interest rate rise, and -63% for a sharp interest rate rise. Thus, policyholders surrender particularly in those cohorts for which surrendering is most costly for the insurer.⁵⁵ Over time, surrender rates are also inversely related to surrender returns, as can be seen by comparing Figures 4 and 8.⁵⁶

RESULT 10. *An increase in surrender rates is positively correlated with MtM surrender costs, both across cohorts and time.*

Figure 9 depicts the ultimate effect of an interest rate rise and policy surrenders on the MtM equity capital ratio. In general, we observe that an interest rate rise lifts up the capital ratio, which is due to the valuation effect. For example, a sharp interest rate rise pushes up the median equity capital ratio from 7.9% at $t = 0$ to 17% at $t = 1$ in the counterfactual "No run" calibration (i.e., with surrender rates fixed to 2.86%). The additional increase in surrender rates (in the run-like baseline calibration) reduces the equity capital ratio in years with negative surrender return. If interest rates sharply rise, the subsequent increase in surrenders reduces the median capital ratio by 8-28% (or, equivalently, 1.6-5.4pp) in the first five years. This reduction in the capital ratio is driven by the surrender return, which is negative for half of the insurer's cohorts. The surrender return becomes positive from year $t = 8$ on (see Figure 8 (2)), which reverses the surrender effect.

The increase in policy surrenders upon a gradual rise persistently reduces the insurer's median equity capital ratio by roughly 13-17% (or, equivalently, 1.6-3.2pp) for 10 years. This persistent reduction in the capital ratio results from a widening gap between gradually increasing interest rates and slow interest rate pass-through. As this gap steadily reduces the surrender return (as in Figure 8 (1)), it increases surrender costs. Therefore, surrenders have a significant and economically relevant impact on a life insurer's MtM equity capital - even during a very slow interest rate rise.⁵⁷

⁵⁵In later years, the correlation is smaller (in absolute value) since differences in crediting rates become smaller (driven by larger profit participation rates) and thus surrender rates depend more on policy age.

⁵⁶The average (across cohorts) correlation between surrender rates and surrender returns over time is -63% upon a gradual interest rate rise and -44% upon a sharp interest rate rise.

⁵⁷As discussed in Footnote 45, we do not incorporate fire sale costs in this analysis, which allows us to attribute the

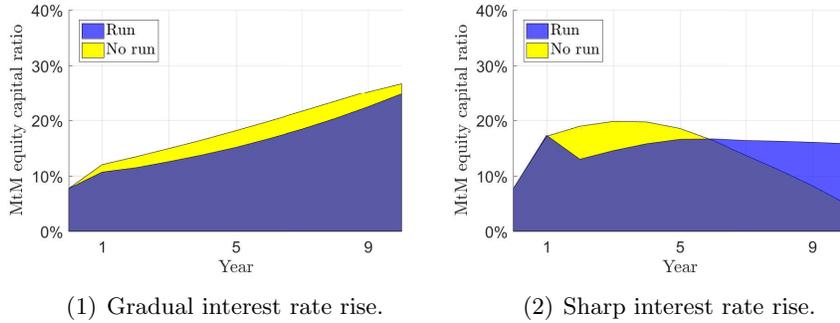


Figure 9: Equity capital ratio under mark-to-market accounting.

Figures depict the MtM equity capital ratio, i.e., the value of equity relative to total assets on the MtM balance sheet, at year-end t . We show the median equity capital ratio based on our baseline calibration (“Run”) as well as based on a counterfactual calibration with surrender rates fixed to 2.86% (“No run”).

RESULT 11. *An increase in surrender rates upon an interest rate rise reduces an insurer’s MtM equity capital ratio. The impact is economically significant - even upon a slow and gradual interest rate rise.*

Overall, the valuation effect’s positive impact on MtM capital ratios compensates for the surrender effect’s negative impact, such that capital ratios increase upon both a gradual as well as sharp interest rate rise. The valuation effect is driven by the insurer’s negative duration gap, i.e., imperfect hedging of interest rate risk. As [Kojen and Yogo \(2018\)](#) point out, life insurers could theoretically perfectly hedge interest rate risk on the MtM balance sheet by matching the duration of assets and liabilities. This is not the case in practice. Instead, most US and EU life insurers exhibit a negative duration gap (e.g., [International Monetary Fund \(IMF\) \(2017\)](#)). [Kojen and Yogo \(2018\)](#) attribute the empirically observed risk mismatch mainly to basis and counterparty risk from hedging, agency conflicts, and life insurers’ ability to bear aggregate risk. We provide an alternative explanation for life insurers’ interest rate risk mismatch: a negative duration gap protects insurers from excessive policy surrenders by increasing equity capital ratios in times when surrenders are most costly.⁵⁸

RESULT 12. *A negative duration gap, due to imperfect interest rate risk matching, protects insurers from an interest rate-based surge in policy surrender rates. Surrender costs are then compensated*

impact of excessive policy surrenders exclusively to the surrender effect. Fire sale costs further reduce the insurer’s capital ratio. However, the effect is quantitatively negligible. The results are available on request.

⁵⁸This result complements [Förstemann \(2018\)](#)’s rationale that a smaller asset duration reduces the likelihood that insurers become underfunded upon an interest rate rise - and thereby provoke a fundamental-based insurance run.

by valuation gains due to an interest rate rise.

The previous results reveal important insights about run-like situations in life insurance vis-à-vis banking: during bank runs, fire sale losses fuel insolvency risk due to particularly illiquid assets (i.e., loans). In contrast, the relevant transmission channel for excessive policy surrenders (in our baseline calibration) is not asset illiquidity, since in Section 3 we find fire sale costs to be small relative to insurers' equity capital (less than 2%). Instead, surrender costs due to MtM accounting of insurance liabilities are substantially larger (8-28%). Importantly, a negative surrender return is not directly implied by policy surrenders, but depends on MtM accounting and is only realized upon an increase in surrender rates - which contrasts bank runs, where fire sale costs are a mere consequence of the run.

RESULT 13. *Under reasonable assumptions, surrender costs due to the sensitivity of MtM insurance liabilities toward surrender rates are larger than fire sale costs.*

Taking an outside investor's perspective, MtM equity capital reflects the insurer's current economic (*fair*) value and, thus, reflects of investors' stake in the insurer. A reduction in the MtM equity capital ratio upon excessive policy surrenders is, hence, likely to increase insurers' funding costs. For example, credit spreads might increase, reflecting an increase in (expected) default risk. Investors might also call for additional collateral in derivatives and securities lending transactions (as was the case for AIG in the 2008/09 financial crisis) and raise capital issuance cost for insurers. These costs of policy surrenders are dampened by the valuation effect, but might increase with a larger sensitivity of MtM insurance liabilities and surrender rates toward interest rates. In particular, surrender rate sensitivity may be amplified by modern technology and social networks that enable the instantaneous flow of information (Ho and Muise (2012)), driven, e.g., by expert recommendations and largely broadcasted rumors that spread easily through the world wide web. The sensitivity of MtM insurance liabilities toward surrender rates is large when insurers expect relatively small surrender rates ex ante, increasing the unexpected share of policies surrendered ex post (as we examine in Section 5).

We also assess how surrender penalties affect surrender costs. Generally, a larger surrender penalty reduces the surrender value of each contract and, thereby, surrender rates. However, its marginal effect is heterogeneous across policyholders. From (10) a marginal increase in the surrender

penalty $\bar{\vartheta} = 1 - \vartheta$ changes the surrender rate by

$$\frac{\partial \lambda_t^h}{\partial \bar{\vartheta}} = \frac{(-\beta_1)}{\vartheta} \varphi \left(\beta_0 + \beta_1 \log \left(\vartheta^{-1} \left(\frac{1 + \tilde{r}_{t+1}^h}{1 + r_{f,T-(t-1)}(t-1)} \right)^{T-(t-1)} \right) + \beta_2 \log(2 + t - h - 1) \right), \quad (20)$$

where $\varphi(\cdot)$ is the standard normal distribution's pdf. The larger the crediting rate \tilde{r}_{t+1}^h , the higher the surrender rate's sensitivity toward the surrender penalty $\bar{\vartheta}$, i.e. $\left| \frac{\partial^2 \lambda_t^h}{\partial \bar{\vartheta} \partial \tilde{r}_{t+1}^h} \right| > 0$. Therefore, an increase in $\bar{\vartheta}$ reduces surrender rates of policyholders with larger crediting rates (and thus larger surrender returns) relatively more. As a result, the average cost per surrendered policy increases, (partially) setting off an increase in the MtM equity capital ratio due to smaller surrender values.

Our results show that an increase in the surrender penalty by 2.5 pp (from 2.5% to 5%) is beneficial upon a sharp but not upon a gradual interest rate rise. In the case of a sharp rise, the larger surrender penalty reduces MtM surrender costs by up to 20%.⁵⁹ Here, the positive effect of surrender penalties in reducing surrender rates and surrender payouts dominates. In contrast, in the case of a gradual rise, the larger surrender penalty increases MtM surrender costs by roughly 5%. In this case, the negative effect of surrender penalties dominates and biases the cross-section of surrendered policies toward more costly policies (with lower surrender return). Therefore, while on the one hand, surrender penalties are a useful macro-prudential tool to reduce fire sale costs (as Section 3 shows), on the other hand, surrender penalties may increase surrender costs - particularly upon a gradual interest rate rise.

RESULT 14. *Surrender penalties reduce surrender rates and payouts but increase the average cost of surrendered policies. As a result, a larger surrender penalty can increase MtM surrender costs, particularly upon a gradual interest rate rise.*

4.2 Historical cost accounting

Historical cost accounting (HCA) recognizes the historical cost of purchasing assets and the cash value of insurance policies. The value of an HCA balance sheet's item is called *book value*.

HCA is typically combined with *Other-Than-Temporary-Impairments* (OTTI) for assets: if an

⁵⁹We measure MtM surrender costs by the relative difference between the median MtM equity capital ratio with the baseline calibration compared to that with surrender rates fixed to 2.86%.

asset’s market value permanently falls below its current book value, firms recognize this OTTI by depreciating the asset’s book value on the HCA balance sheet. OTTI is common for most of life insurers’ asset investments in a large number of jurisdictions, including the US and Germany (e.g., [Ellul et al. \(2015\)](#) and the German Commercial Code (HGB)).⁶⁰ We implement OTTI in our model by treating reductions as permanent if an asset’s market value falls below 90% of its current book value.⁶¹ If a previously depreciated asset’s market value increases above the current book value, then the book value appreciates (up to the historical acquisition cost). Thus, an asset i ’s book value at time t , BV_t^i , is generally determined by

$$BV_t^i = \begin{cases} MV_t^i, & \text{if } MV_t^i < 0.9 \times BV_{t-1}^i \\ \min(MV_t^i, HC^i), & \text{if } MV_t^i > BV_{t-1}^i, \\ BV_{t-1}^i, & \text{else,} \end{cases} \quad (21)$$

where MV_t^i is asset i ’s market value at time t , and HC^i is the historical acquisition cost.

OTTI channels fixed income investments’ market value reductions upon an interest rate rise into a drop in asset book values. In our model, the book value of total assets depreciates persistently by roughly 0.5% each year upon a gradual interest rate rise. In contrast, upon a sharp interest rate rise, assets depreciate by 8% in the first year, 2% in the second year, and remain constant in following years. The main reason for these relatively small depreciation rates are initially existing unrealized gains at time $t = 0$.⁶² Unrealized gains emerge when an asset’s market value exceeds its book value (which is possible only if $MV_t^i > HC^i$). In our model, the market value of the insurer’s total assets exceeds the book value by 20% at $t = 0$ due to previously decreasing interest rates. These unrealized gains provide a buffer for a subsequent decline in market values.⁶³

⁶⁰OTTI is called *Niederstwertprinzip* (in English: *lower of cost and market*) in Germany.

⁶¹This modeling is consistent with accounting principles, e.g., put forward by the *Institute of German Auditors* (IDW) that deem a market value reduction as permanent if the average daily market value over one year is below 90% of the book value (*Source: IDWRS VFA 2, April 2002*). Since firms, nevertheless, have some discretion over the timing of recognizing OTTIs ([Huizinga and Laeven \(2012\)](#)), in the internet appendix we conduct a sensitivity analysis with a more moderate OTTI principle. The results are similar, but HCA asset values decline more smoothly over time.

⁶²Depreciations are small compared to the total drop in market values. For example, a 4.5pp reduction in interest rates implies the market prices fall by $8 \times 0.045 = 36\%$ given a duration of 8 years.

⁶³The value of unrealized gains is consistent with the situation of an average German life insurer in 2015. For example, [Förstemann \(2018\)](#) reports 18% unrealized gains relative to the aggregate book value of German life insurers’ assets. Over time, market values of fixed income investments increase up to their face values, which also dampens depreciation rates.

Life insurance policies are recognized by cash values on the HCA balance sheet, $L_t^{BV,h} = V_t^h$.⁶⁴ Consequently, the book value of insurance liabilities is isolated from changes in interest rates. The valuation effect of an interest rate rise, thus, reduces the HCA equity capital ratio.

RESULT 15 (HCA valuation effect). *Due to OTTI, an interest rate rise reduces an insurer's HCA equity capital ratio, everything else equal.*

As regards the surrender effect, note that surrender values are equal to a fixed share of insurance policies' accumulated value and, thus, of HCA insurance reserves, $SV_t^h = \vartheta V_t^h = \vartheta L_t^{BV,h}$. The insurer thus earns a non-negative surrender return

$$R_{surrender,t}^{HCA,h} = (\lambda_t^h + \varepsilon)(1 - \vartheta) \quad (22)$$

upon a ε pp-increase in the surrender rate λ_t^h . Therefore, the surrender effect leads to an increase in the HCA equity capital ratio. Both the valuation and surrender effect are, thus, reversed on the HCA balance sheet compared to the MtM balance sheet: the former leads to a reduction and the latter to an increase in the HCA equity capital ratio.

RESULT 16 (HCA surrender effect). *Since HCA insurance liabilities strictly exceed surrender values, an increase in surrender rates raises an insurer's HCA equity capital ratio.*

Figure 10 depicts the ultimate effect of an interest rate rise and policy surrenders on the HCA equity capital ratio. In the first year upon a sharp interest rate rise, the insurer's median HCA capital ratio drops by more than 60%, driven by the valuation effect (i.e., depreciations of assets' book values). Due to smaller depreciations, the gradual interest rate rise becomes more favorable in terms of the HCA equity capital ratio, which even increases over time. This is in sharp contrast to the valuation effect on the MtM balance sheet, where a sharp interest rate rise is more beneficial.

Due to a positive surrender return, we find that excessive policy surrenders increase the insurer's HCA capital ratio (1) by up to 30% (equivalently, 6pp) during a gradual interest rate rise and (2) by up to 63% (7pp) during a sharp interest rate rise. Thus, an increase in policy surrenders is beneficial from an HCA perspective. This finding holds if we additionally incorporate fire sale

⁶⁴The German regulator introduced an additional interest rate reserve (IRR) in 2011, the *Zinszusatzreserve*. This reserve increases the book value of life insurance liabilities. We do not include the IRR in our baseline analysis to make the results more broadly applicable. Results that include the IRR are available on request.

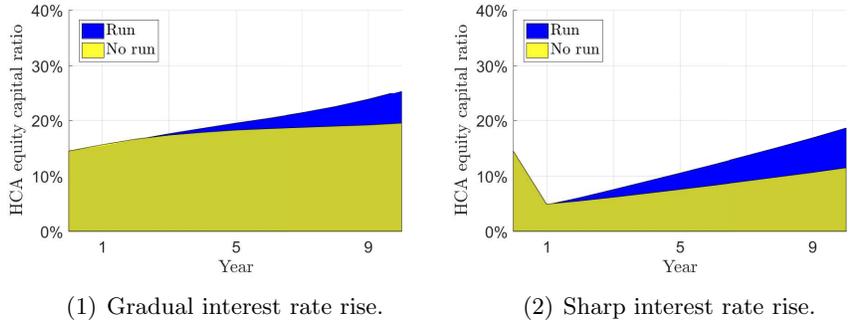


Figure 10: Equity capital ratio under historical cost accounting.

Figures depict the HCA equity capital ratio, i.e., the value of equity capital relative to total assets on the HCA balance sheet, at year-end t . We show the median equity capital ratio based on our baseline calibration (“Run”) as well as based on a counterfactual calibration with surrender rates fixed to 2.86% (“No run”).

costs in our model.⁶⁵ The positive surrender return compensates the adverse valuation effect of an interest rise and, thereby, stabilizes the insurer’s HCA equity capital ratio. The effect of excessive policy surrenders on the HCA balance sheet is thus in stark contrast to that on the MtM balance sheet, where policy surrenders depress the insurer’s capital ratio.

4.3 Policy implications

The opposing effect of policy surrenders on the HCA and MtM balance sheet implies that accounting shapes life insurers’ incentives to manage liquidity risk. While MtM accounting incentivizes insurers to restrain surrender rates (and their sensitivity), policy surrenders are beneficial under HCA. Indeed, accounting standards differ across countries: while EU life insurers must report under MtM accounting according to EU regulators, US life insurers face statutory accounting based on HCA. International (IFRS) accounting (typically adopted by large life insurers) is currently in line with US statutory accounting, which will change with the implementation of MtM-based IFRS 17 accounting in 2020.

Moreover, life insurers can be subject to both HCA and MtM accounting at the same time. For example, German life insurers report under HCA for national GAAP accounting and under MtM for regulatory reporting in the EU. In this case, life insurers’ counterparties (including policyholders), investors, and regulators are faced with two different measures to assess insolvency risk, namely the equity capital ratio on the HCA and MtM balance sheet. As the two capital ratios provide opposing

⁶⁵For this purpose, we incorporate both EU and US life insurers as described in Section 3.

signals about the impact of both an interest rate rise as well as policy surrenders, an assessment of insurers' actual financial health requires to understand the underlying assumptions to calculate the MtM and HCA capital ratio. However, insurers have large discretion about the application and disclosure of accounting rules, making it different for investors, policyholders, and regulators to assess insurers' financial health (e.g., [Jorgensen \(2004\)](#); [Guillen et al. \(2006\)](#)). For example, firms have large discretion over recognizing OTTI ([Huizinga and Laeven \(2012\)](#)). Life insurers do also not publicly disclose the methods and underlying assumptions for forecasts of crediting rates that are used to calculate MtM insurance liabilities. Therefore, opposing signals from HCA and MtM accounting may result in uncertainty about insurers' financial condition for outside investors and counterparties.

Such uncertainty likely amplifies an increase in life insurers' funding costs (in particular if outside investors are risk averse), implying more costly capital issuance as well as a reduction in demand for life insurance policies.⁶⁶ Moreover, an insurer's counterparties in securities lending and derivative transactions are likely to demand additional collateral from the insurer. Exactly such margin calls were the ultimate reason for AIG's failure in 2008 (e.g., [Harrington \(2009\)](#); [McDonald and Paulson \(2015\)](#)).⁶⁷ Therefore, excessive policy surrenders may contaminate financial markets due to a rise in (expected) counterparty risk.

RESULT 17. *The effects of an interest rate rise and policy surrenders on the HCA equity capital ratio are reversed to that on the MtM equity capital ratio. Due to insurers' discretion about capital ratio calculation, opposing signals from the HCA and MtM capital ratio are likely to increase life insurers' funding costs.*

The key transmission channel for surrender costs is an increase in MtM insurance liabilities due to larger surrender rates. In order to increase life insurers' resilience, one must thus dampen the sensitivity of MCV insurance liabilities toward surrender rates. This can be achieved essentially in two ways, namely by changing (A) the accounting of insurance policies or (B) surrender values

⁶⁶Several studies show that an insurer's default risk is negatively related to insurance demand (e.g., [Wakker et al. \(1997\)](#); [Epermanis and Harrington \(2006\)](#); [Zimmer et al. \(2018\)](#)). [Lee and Masulis \(2009\)](#) provide empirical evidence that uncertainty about a firm's financial condition for outside investors (in their case due to poor accounting quality) lowers demand for a firm's new equity and raises underwriting costs and risk.

⁶⁷Derivatives and reinvested collateral from securities lending transactions was 1.5% of large US insurers' assets in 2017 at book/adjusted carrying value (i.e., for US insurers with more than USD 10 billion assets under management; [National Association of Insurance Commissioners \(NAIC\) \(2018\)](#)).

paid out to policyholders.

In the first case, one may set MtM insurance liabilities equal to the surrender value of policies. However, analogously to the HCA balance sheet, this would only shift economic costs from the surrender effect to the valuation effect, since an interest rate rise would then depreciate the value of assets but not that of liabilities. Thus, it seems unrealistic that static insurance reserves increase life insurer stability.

In the second case, one may remove ex-ante guarantees for surrender values. Instead of guaranteeing the payout of (a fixed share of) cash values upon surrender, life insurers could simply pay out the present value (i.e., MCV) of future policy cash flows (i.e., the second summand in Equation (16)).⁶⁸ For example, US life insurers sometimes apply interest-dependent market value reductions on promised cash values (Förstemann (2018)). In this case, excessive policy surrenders would not affect the MtM value of insurance liabilities but only deleverage the insurer's balance sheet and, thus, increase the MtM equity capital ratio. Market value reductions of surrender values are, thus, an effective risk management tool - for both life insurers as well as regulators - to reduce life insurers' surrender costs and diminish spillovers from run-like situations in the life insurance sector to the broader financial system.

5 Sensitivity analysis

The baseline mechanism underlying our results is a slow interest rate pass-through. We examine to what extent the insurer's long investment horizon drives this slow pass-through. For this purpose, we re-run our model with a higher (but still reasonable) asset duration, namely 10.2 years, which reduces the duration gap to almost one year. As a result, the insurer's return on assets and thus crediting rates adjust even slower to an interest rate rise. Therefore, surrender rates are larger than in the baseline calibration. The insurer's cumulative liquidity substantially increases, which results in EUR 9.84 billion (2.84% of insurers' equity) and EUR 20 billion (5.78% of insurers' equity) fire sale costs in case of a gradual and sharp rise, respectively (accounting for EU and US insurers). Thus, fire sale costs become economically significant. Moreover, policy surrenders reduce the insurer's MtM equity capital by up to (59%) 20% in case of a gradual (sharp) interest rate rise.

⁶⁸A similar proposal has been made by Förstemann (2018).

We also run a counterfactual calibration with a larger sensitivity of surrender rates and insurance reserves to interest rates.⁶⁹ We assume that the insurer estimates future surrender rates for each cohort by the total surrender rate across all policyholders, thereby underestimating surrender rates in young cohorts. In comparison to the baseline calibration, surrender costs are larger in times with particularly large, negative surrender returns. This is the case in the first year upon a sharp interest rate rise (cf. Figure 8 (1)), for which surrender costs increase from 31% (baseline calibration) to 50% (high surrender sensitivity) of the MtM equity capital ratio. This effect is driven by an increase in the annual surrender rate from 25% (baseline calibration) to 54% (high surrender sensitivity). This large surrender rate also significantly increases fire sale costs up to EUR 56 billion (18% of insurers' equity) in case of a sharp interest rate rise (and jointly considering EU and US insurers), reducing asset prices by 6%.

We conclude that life insurers' vulnerability toward policy surrenders and liquidity risk is primarily driven by (a) long-dated assets and (b) the sensitivity of surrender rates toward interest rates. (a) The longer the asset duration, the larger are surrender rates and, thus, fire sale and surrender costs. (b) The more sensitive surrender rates are, the larger are fire sale and surrender costs. Under still reasonable assumptions, these effects may increase fire sales up to the point that excessive policy surrenders contaminate financial markets via an economically significant volume of asset liquidations.

6 Conclusion

This paper explores liquidity risk in the life insurance sector. The key motivation is that the life insurance sector is both large and important for absorbing household and providing liquidity on financial markets. Run-like situations might impair life insurers' stabilizing role and might even negatively affect financial markets via fire sales. An interest rate rise, in particular, incentivizes policyholders to surrender their insurance policies, draining life insurers' liquidity. This mechanism is especially relevant for central banks that are currently tightening monetary policy, and highlights the life insurance sector's contribution in transmitting monetary policy shocks.

⁶⁹The calibration is analogous to Section 2.5 but assumes that the surrender rate is 60% instead of 30% during a policy's first year for which the present value of future crediting rates equals the accumulated cash value. The resulting calibration of the surrender rate model (10) is $(\beta_0, \beta_1, \beta_3) = (-0.8, 2.51, 0.7)$.

To quantify the risks and costs associated with life insurance policy surrenders, we present a theoretical model that enables us to realistically forecast cash flows in the life insurance sector for a given evolution of interest rates. The dynamic model builds on a granular calibration of life insurance cash flows, policyholder behavior, and a stochastic financial market.

Our analysis focuses, on the one hand, on life insurers' asset liquidations through which policy surrenders might contaminate financial markets and, on the other hand, on direct surrender costs due to an increase in surrender rates. We simulate two interest rate rise environments, namely a gradual, long-term (by 0.3pp per year) and sharp, short-term (by 4.5pp within two years) interest rate rise. A key insight is that in both cases asset liquidations are large if accumulated over time (up to 12% of initial assets), but small within each year (up to 2% of initial assets). Assuming that asset sales are absorbed within one year, fire sale costs and the price impact of fire sales are relatively small (less than 2% of insurers' equity capital and less than 1.3%, respectively) in our baseline calibration for an average German life insurer. We argue that it is in particular the heterogeneity of different policy generations' surrender rates that dampens annual fire sale costs.

We identify direct surrender costs to be substantially larger than fire sale costs. The model predicts that policy surrenders substantially reduce life insurers' capital position by up to 30% under mark-to-market (MtM) accounting, which is the basis for international financial reporting and for EU regulatory reporting. In contrast to historical cost accounting (HCA), policy reserves under MtM accounting are sensitive toward surrender rates, raising insurers' liabilities if surrender rates increase upon an interest rate rise. Thus, it is MtM accounting which channels policy surrenders into the largest costs for life insurers.

Consequently, regulatory policies with the objective to dampen life insurers' exposure to policy surrenders should aim to reduce the dependence between MtM policy reserves and surrender rates. One suitable measure are reductions in surrender payouts upon a drop in the present value of future policy cash flows. Surprisingly, we find that the most prominent risk management measure to prevent high surrender rates, namely surrender penalties, does not necessarily reduce life insurers' surrender costs (particularly not upon a gradual interest rate rise). The reason is that the impact of surrender penalties is heterogeneous across policies: a higher surrender penalty reduces surrender rates of policies with larger surrender costs relatively less. This heterogeneity leads to larger total surrender costs for a larger surrender penalty in case of a gradual interest rate rise. Our analysis

is, thus, highly relevant for policymakers to design micro- and macro-prudential regulation that increases life insurers' resilience toward liquidity risk (e.g., [European Systemic Risk Board \(ESRB\) \(2017\)](#)).

Both fire sale and surrender costs significantly depend on life insurers' asset duration and the sensitivity of surrender rates. Increasing these two components in our model (to still reasonable levels), results in substantially larger fire sale costs (and price amplification effects) as well as surrender costs. It is in particular the long-term nature of the life insurance business that makes it vulnerable toward run-like situations. Thus, while life insurers' long-term business insulates them from exposure to financial markets ([Chodorow-Reich et al. \(2018\)](#)), our analysis highlights that it also increases life insurers' liquidity risk exposure: the longer the duration of life insurers' balance sheets, the more vulnerable they are toward run-like situations due to macroeconomic changes and, in particular, an interest rate rise. Importantly, this mechanism is not a result of imperfect interest rate risk hedging but, instead, reversed to it. The better life insurers hedge interest rate risk, the longer is their assets' duration and the slower is interest rate pass-through to policyholders, incentivizing more policy surrenders.

Our results provide a number of highly relevant insights, that are not limited to the life insurance sector but also apply to other financial intermediaries with long-term contracts: the basic mechanism that results in run-like situations in our model is a slow pass-through of an interest rate rise to investor (i.e., policyholder) returns due to the intermediary's (i.e., the insurer's) long asset duration. We are aware of several limitations of the model. For example, we rely on stylized assumptions about life insurers' asset investment and policyholders' surrender behavior. We also focus on only one particular life insurance savings policy. These simplifications allow us to clearly identify the mechanisms underlying our results. We have also described several extensions that are readily implemented in the model and support our results.

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Internet Appendix

A Calculation of life insurance reserves: Example

In the following, we provide an example on how traditional life insurance savings policies are recognized on the HCA and MtM balance sheet, based on one sample path in the gradual interest rate rise environment. Consider an insurance policy sold to 10,000 policyholders at the end of 2015 (i.e., $t = 0$), each with a premium of 1 EUR and a guaranteed interest rate $r_G = 1.25\%$ (which coincides with the guaranteed rate in 2015 in Germany and our model). Then, at $t = 0$ the life insurer recognizes the value $L_t^{BV,h} = V_t^h = 10,000$ EUR on the HCA balance sheet.

Estimating the future profit participation rate of return for MtM insurance reserves is complicated by the fact that its level depends on the realization of the insurer's investment return as well as the portfolio and accounting balance dynamics of the insurance company. We assume that the insurer does not know the distributional characteristics we impose in our model. As in practice, the insurer hence needs to rely on its own estimation of the future profit participation $r_{P,t+j}^h$. For this purpose, the insurer assumes the same rate of profit participation $r_{P,t+j}^h \equiv r_{P,t+j}$ for each cohort h and extrapolates at each point in time t the average profit participation during the past 10 years, $\bar{r}_{P,t+j}$ with $j = -9, \dots, 0$, according to the following model:

$$\bar{r}_{P,t+j} = \beta_{t,0} + \beta_{t,1}f(j), \quad (23)$$

where $f(\cdot)$ is a real-valued function.⁷⁰ Given OLS estimates $\hat{\beta}_{t,0}$ and $\hat{\beta}_{t,1}$, the predicted profit participation is $\hat{r}_{P,t+j} = \hat{\beta}_{t,0} + \hat{\beta}_{t,1}f(t+j)$. By choice of $f(\cdot)$, the insurer is able to control the degree of conservatism in the prediction. The larger $|f'|$, the more severe are predicted changes in the profit participation. For example, if $f' \equiv const$, then the profit participation evolves linear over time. Since it seems unreasonable to predict severe changes for years that are far ahead, we require that $f'(x) \rightarrow 0$ for $x \rightarrow \infty$, i.e., that future changes in profit participation are small. In line with this rationale, we choose $f(x) = \log(10+x)$.

The average profit participation rate from 2006 to 2015 was

⁷⁰In practice, life insurers also rely on models that simulate future profit participation calibrated on historical data, e.g. the simulation model developed by the German Insurance Association (GDV).

$\bar{r}_{P,-9,\dots,0} = (0.0424, 0.0423, 0.0434, 0.0426, 0.0419, 0.0408, 0.0394, 0.0368, 0.0353, 0.0330)$. Then, the fitted OLS coefficients of the model

$$\bar{r}_{P,t+j} = \beta_{t,0} + \beta_{t,1} \log(10 + j), \quad j = -9, \dots, 0 \quad (24)$$

are $\hat{\beta}_{t,0} = 0.0453$ and $\hat{\beta}_{t,1} = -0.0037$, and the predicted profit participation rate for the following 30 years is $\hat{r}_{P,t+j} = 0.0453 - 0.0037 \times \log(10 + j)$ for $j = 1, \dots, 30$. The average surrender rate in 2015 is $\bar{\lambda}_0^h = 0.0286$. Thus, the MtM value of insurance policies in this cohort $h = t = 0$ is given by

$$L_t^{MtM,h} = V_t \times \left[\vartheta \sum_{i=1}^T \frac{\bar{\lambda}(1-\bar{\lambda})^{i-1} \prod_{j=1}^{i-1} (1 + \hat{r}_{t+j}^h)}{(1 + r_{f,i-1}(t))^{i-1}} + \frac{(1-\bar{\lambda})^{T-t} \prod_{j=1}^{T-t} (1 + \hat{r}_{t+j}^h)}{(1 + r_{f,T-t}(t))^{T-t}} \right] \times 1.0183, \quad (25)$$

where $\hat{r}_{t+j}^h = \max\{0.0125, 0.0453 - 0.0037 \times \log(10 + j)\}$ is the predicted return in year $t + j$, 0.0183 is the risk margin relative to the present value of policies, and $r_{f,\tau}(t)$ is the risk-free rate for maturity τ . In this example, it is $L_t^{MtM,h} = V_t^h \times 1.5179 = 15,179$ EUR.

Suppose that $\lambda_{t+1}^h = 17.22\%$ of these policyholders surrender in 2016, leaving 8,278 policyholders remaining in the cohort. Assume that the rate of profit participation with these policyholders is 2.66% in 2016. Moreover, policyholders pay new total premiums of 8,278 EUR. Thus, the new book value on the HCA balance sheet is $L_{t+1}^{BV,h} = 8,278 \times 1.0266 + 8,278 = 16,776$ EUR.

The historical profit participation rate from 2007 to 2016 is

$\bar{r}_{P,-8,\dots,1} = (0.0423, 0.0434, 0.0426, 0.0419, 0.0408, 0.0394, 0.0368, 0.0353, 0.0330, 0.0266)$, resulting in the fitted coefficients $\hat{\beta}_{t,0} = 0.0467$ and $\hat{\beta}_{t,1} = -0.0056$ for the predicted profit participation rate. Together with the average surrender rate in the cohort, $\bar{\lambda}_{t+1}^h = 0.1722$, and current interest rates, this implies $L_{t+1}^{MtM,h} = V_{t+1}^h \times 1.0751 = 18,036$ EUR.

B Calibration

B.1 Calibration of the short-rate model

The stochastic differential equation (3) can be solved, which yields (cf. [Brigo and Mercurio \(2006\)](#))

$$r(t) = r_0 e^{-\alpha_r t} + \alpha_r \int_0^t e^{-\alpha_r(t-u)} \theta_r(u) du + \sigma_r \int_0^t e^{-\alpha_r(t-u)} dW_r(u). \quad (26)$$

Thus, the short-rate is normally distributed, i.e., $r(t) \sim \mathcal{N}(\mu_t, \sigma_t^2)$, with parameters

$$\mu_t = \mathbb{E}[r(t)] = r(0)e^{-\alpha_r t} + \alpha_r \int_0^t \theta_r(u) e^{-\alpha_r(t-u)} du \quad (27)$$

$$\sigma_t^2 = \text{var}(r(t)) = \frac{\sigma_r^2}{2\alpha_r} (1 - e^{-2\alpha_r t}). \quad (28)$$

The price $P(t, \tau)$ of a zero-coupon bond at time t with time to maturity τ is given by (cf. [Hull and White \(1990\)](#) and [Brigo and Mercurio \(2006\)](#))

$$P(t, t + \tau) = A(t, t + \tau) e^{-r(t) B(\tau)}, \quad (29)$$

where

$$B(\tau) = \frac{1 - e^{-\alpha_r \tau}}{\alpha_r},$$

$$A(t, t + \tau) = \exp \left(\frac{\sigma_r^2}{2\alpha_r^2} (\tau - B(\tau)) - \frac{\sigma_r^2}{4\alpha_r} B^2(\tau) - \alpha_r \int_t^{t+\tau} \theta_r(u) B(t + \tau - u) du \right).$$

Hence, the continuously compounded spot rate at time t for time to maturity τ is given by

$$\hat{r}_{f,\tau}(t) = -\frac{1}{\tau} \log P(t, t + \tau) = \frac{B(\tau)r(t) - \log A(t, t + \tau)}{\tau} \quad (30)$$

and the equivalent annually-compounded spot rate is given by

$$r_{f,\tau}(t) = e^{\hat{r}_{f,\tau}(t)} - 1 = \left(\frac{e^{B(\tau)r(t)}}{A(t, t + \tau)} \right)^{1/\tau} - 1. \quad (31)$$

To yield rising interest rates, we choose the mean reversion level to be

$$\theta_r(t) = \gamma + (\beta - \gamma) \left(1 - \frac{1}{1 + e^{-bt}} \right). \quad (32)$$

We select parameters for the short rate model in order to imply gradually increasing interest rates (by choosing $b = 5$) and sharply increasing interest rates (by choosing $b = 10$). Thereupon, we calibrate the initial short-rate $r(0)$, speed of mean reversion α_r , volatility σ_r , and mean reversion parameters γ , β , and b with historical data in order to match (a) the short rate volatility at a given point in time \bar{t} , $\text{var}(r(\bar{t}))$, with the daily volatility of the Euro OverNight Index Average (EONIA) from January 1999 to March 2016⁷¹, (b) the yield of 10-year and 20-year German sovereign bonds in 2015 as a proxy for the term structure of risk-free rates at $t = 0$ ⁷², and (c) a predetermined target level for the risk-free interest rate $r_{f,10}(t)$ that determines the interest rate rise severity.⁷³ For this purpose, we minimize the weighted sum of squared deviations between (a) EONIA volatility and short rate model-implied volatility, (b) long-term yields, and (c) target risk-free rate. The results are reported in Section 2.4.

B.2 Calibration of financial market securities' processes

We calibrate bond spreads and stock and real estate returns based on monthly data from January 1999 to December 2007. Corporate bond yields are from the effective yield of the AAA/AA/A/BBB-subset of the ICE BofAML US Corporate Master Index (obtained from *FRED St. Louis*), which tracks the performance of US dollar denominated investment grade rated corporate debt publicly issued in the US domestic market. To take different inflation (expectations) between the EU and US into account, we calculate bond spreads with respect to the yield of US treasuries with a maturity of 10 years (obtained from *FRED St. Louis*).⁷⁴ Sovereign bond spreads are calibrated based on the spread to German bond yields from January 1999 to December 2007 (obtained from *Bloomberg*),

⁷¹EONIA is the weighted rate for the overnight maturity, calculated by collecting data on unsecured overnight lending in the Euro area provided by banks belonging to the EONIA panel. Data source: *ECB Statistical Data Warehouse*. The descriptive statistics are: mean=1.96%, sd=1.58%, (p25,p5,p75)=(0.34%, 2.07%, 3.3%). We set $\bar{t} = 5$ and calculate the EONIA volatility based on the deviation of EONIA from its weighted exponential moving average.

⁷²Initial long-term risk-free rates are $r_{f,10}(0) = 1.2\%$ and $r_{f,20}(0) = 2\%$. German sovereign bond yields are retrieved from the *German Bundesbank*.

⁷³We choose $r_{f,10}(20) = 10\%$ for gradually increasing and $r_{f,10}(10) = 5\%$ for sharply increasing rates.

⁷⁴Results are similar if we take German sovereign bonds, instead.

averaged across maturities from 1 to 20 years.

Table 5 describes the sample of bond spreads. Note that we retrieve bond yields (and spreads) for maturities 1 to 20 years for each sovereign bond, while corporate bond spreads are calculated by comparing the effective yield of the ICE BofAML US Corporate Index to the 10-year yield. Since we assume the same spread for each maturity, we calibrate the spread process

$$s^j(t) = k^j(\bar{s}^j - s^j(t))dt + \sigma^j dW^j(t) \quad (33)$$

for the average spread across maturities in the case of sovereigns. Parameter estimates are based on Maximum-Likelihood and reported in Table 5. We do not allow bond yields to fall below risk-free rates and, thus, truncate them in the simulation such that $s^j(t) = \max(0, k^j(\bar{s}^j - s^j(t))dt + \sigma^j dW^j(t))$.

Name	# Observations	Mean	Sd	p25	p75	\bar{s}	k	σ
Sovereign (French)	2160	0.0001	0.0019	-0.0013	0.0014	0.0001	14.79	0.0095
Sovereign (Dutch)	2160	-0.0008	0.0024	-0.0024	0.0009	-0.0009	19.5	0.011
Sovereign (Italian)	2160	0.0005	0.0024	-0.001	0.0023	0.0005	12.09	0.0094
Sovereign (Spanish)	2160	-0.0006	0.0026	-0.0022	0.0012	-0.0007	11.75	0.0097
Corporate (AAA)	108	0.009186	0.0078	0.0015	0.0166	0.0047	0.3407	0.0059
Corporate (AA)	108	0.008801	0.0098	-0.00089	0.0169	0.0046	0.2517	0.0061
Corporate (A)	108	0.01293	0.0083	0.0062	0.01935	0.0099	0.312	0.0058
Corporate (BBB)	108	0.02042	0.0069	0.01695	0.0251	0.0185	0.5571	0.0068

Table 5: Descriptive statistics and calibration for bond spreads.

The table reports descriptive statistics (number of observations, mean, standard deviation, 25% and 75% percentiles) and Maximum-Likelihood estimators for the long-term mean (\bar{s}), speed of mean reversion (k), and volatility (σ) of the Ornstein-Uhlenbeck process $s^j(t) = k^j(\bar{s}^j - s^j(t))dt + \sigma^j dW^j(t)$ for monthly spreads between (a) sovereign bond yields and German sovereign bonds, and (b) corporate bond yields and the 10Y US treasury bond yield from January 1999 to December 2007. Sovereign bond yields include observations for 1-year to 20-year maturities and the calibration is based on the average spread across maturities. Corporate bond spreads are based on the effective yield of ICE BofAML US Corporate Indices and 10-year US treasury yields. *Source: Authors' calculations, Bloomberg (sovereigns), FRED St. Louis (corporates).*

Stocks and real-estate investments follow Geometric Brownian Motions (GBMs) that are calibrated to the main (market capitalization-weighted) national stock indices DAX (Germany), CAC 40 (France), FTSE-MIB (Netherlands), AEX (Italy), IBEX 35 (Spain), and real estate REIT indices (all obtained from *Bloomberg*). Table 6 reports the descriptive statistics for monthly log-returns. We calibrate the GBM drift and volatility with Maximum-Likelihood estimates for monthly log-returns, that are also reported in Table 6.

Finally, we correlate all stochastic processes via a Cholesky decomposition of their diffusion terms. Table 7 reports the correlation coefficients based on monthly residuals after fitting bond

Name	# Observations	Mean	Sd	p25	p75	GBM Drift	GBM Volatility
Stocks (German)	108	0.004196	0.06768	-0.02947	0.0423	0.07784	0.2345
Stocks (French)	108	0.003365	0.05175	-0.02903	0.03081	0.05645	0.1793
Stocks (Dutch)	108	-0.0005451	0.05705	-0.02173	0.03405	0.01298	0.1976
Stocks (Italian)	108	0.000884	0.05294	-0.02639	0.03213	0.02742	0.1834
Stocks (Spanish)	108	0.004364	0.05379	-0.02372	0.0332	0.06973	0.1863
Real Estate (German)	108	0.003055	0.07021	-0.02721	0.03902	0.06624	0.2432
Real Estate (French)	108	0.01126	0.04268	-0.006311	0.03777	0.146	0.1478
Real Estate (Dutch)	108	0.006153	0.03848	-0.01544	0.03137	0.08272	0.1333
Real Estate (Italian)	108	0.01018	0.06894	-0.01879	0.04678	0.1507	0.2388
Real Estate (Spanish)	108	0.008379	0.06365	-0.02957	0.05599	0.1249	0.2205

Table 6: Descriptive statistics and calibration for stocks and real estate.

The table reports descriptive statistics (number of observations, mean, standard deviation, 25% and 75% percentiles) and Maximum-Likelihood estimators for Geometric Brownian Motions for monthly stock and real estate log-returns from January 1999 to December 2007. Stock returns are based on national stock indices (DAX, CAC 40, FTSE-MIB, AEX, and IBEX 35 for Germany, France, Netherlands, Italy, and Spain, respectively), and real estate returns are based on national REIT indices. *Source: Authors' calculations, Bloomberg.*

spreads, stock and real estate returns.⁷⁵

⁷⁵Since our short-rate model is not designed to fit with short rates between 1999 to 2007, we use residuals from fitting EONIA to an ordinary Ornstein-Uhlenbeck process during this period.

	Short rate	SP (FR)	SP (NL)	SP (IT)	SP (ES)	SP (AAA)	SP (AA)	SP (A)	SP (BBB)	ST (DE)	ST (FR)	ST (NL)	ST (IT)	ST (ES)	RE (DE)	RE (FR)	RE (NL)	RE (IT)	RE (ES)
Short rate	1	0.005	0.107	0.105	0.056	0.009	0.003	-0.036	0.003	0.138	0.234	0.205	0.222	0.109	0.036	0.133	0.014	-0.065	-0.002
SP (FR)	0.005	1	0.935	0.92	0.925	-0.163	-0.134	0.001	0.014	-0.038	0.095	0.095	0.051	-0.04	-0.014	-0.066	-0.033	0.001	-0.031
SP (NL)	0.107	0.935	1	0.956	0.949	-0.19	-0.172	-0.158	0.016	0.032	-0.022	0.119	0.051	-0.036	0.039	-0.021	0.005	0.01	0.038
SP (IT)	0.105	0.92	0.956	1	0.974	-0.233	-0.195	-0.175	-0.01	0.032	-0.027	0.122	0.031	-0.07	0.008	-0.086	-0.075	-0.029	-0.068
SP (ES)	0.056	0.925	0.949	0.974	1	-0.198	-0.164	-0.153	0.024	0.026	-0.026	0.105	0.018	-0.085	0.016	-0.091	-0.084	0.004	-0.045
SP (AAA)	0.009	-0.163	-0.19	-0.233	-0.198	1	0.946	0.909	0.723	0.181	0.197	0.155	0.112	0.119	0.117	0.107	0.068	0.198	0.124
SP (AA)	0.003	-0.138	-0.172	-0.195	-0.164	0.946	1	0.951	0.758	0.182	0.197	0.148	0.107	0.106	0.119	0.058	0.05	0.192	0.079
SP (A)	-0.036	-0.134	-0.158	-0.175	-0.153	0.909	0.951	1	0.849	0.069	0.081	0.055	0.022	0.027	0.03	-0.023	-0.024	0.168	0.023
SP (BBB)	0.003	0.001	0.016	-0.01	0.024	0.723	0.758	0.849	1	-0.042	-0.052	-0.049	-0.088	-0.103	-0.129	-0.138	-0.11	0.06	-0.051
ST (DE)	0.138	0.014	0.032	0.032	0.026	0.181	0.182	0.069	-0.042	1	0.937	0.912	0.823	0.8	0.433	0.257	0.397	0.441	0.191
ST (FR)	0.234	-0.038	-0.022	-0.027	-0.026	0.197	0.197	0.081	-0.052	0.937	1	0.912	0.847	0.801	0.493	0.301	0.395	0.474	0.244
ST (NL)	0.205	0.095	0.119	0.122	0.105	0.155	0.148	0.055	-0.049	0.912	0.912	1	0.815	0.776	0.495	0.308	0.417	0.432	0.263
ST (IT)	0.222	0.051	0.051	0.031	0.018	0.112	0.107	0.022	-0.088	0.823	0.847	0.815	1	0.769	0.366	0.275	0.435	0.504	0.184
ST (ES)	0.109	-0.04	-0.036	-0.07	-0.085	0.119	0.106	0.027	-0.103	0.8	0.801	0.776	0.769	1	0.408	0.331	0.417	0.433	0.332
RE (DE)	0.036	-0.014	0.039	0.008	0.016	0.117	0.119	0.03	-0.129	0.433	0.493	0.495	0.366	0.408	1	0.475	0.42	0.516	0.357
RE (FR)	0.133	-0.066	-0.021	-0.086	-0.091	0.107	0.058	-0.023	-0.138	0.257	0.301	0.308	0.275	0.331	0.475	1	0.677	0.449	0.527
RE (NL)	0.014	-0.033	0.005	-0.075	-0.084	0.068	0.05	-0.024	-0.11	0.397	0.395	0.417	0.435	0.417	0.42	0.677	1	0.465	0.395
RE (IT)	-0.065	0.001	0.01	-0.029	0.004	0.198	0.192	0.168	0.06	0.441	0.474	0.432	0.504	0.433	0.516	0.449	0.465	1	0.326
RE (ES)	-0.002	-0.031	0.038	-0.068	-0.045	0.124	0.079	0.023	-0.051	0.191	0.244	0.263	0.184	0.332	0.357	0.527	0.395	0.326	1

Table 7: Correlation matrix for financial market processes.

The table reports the correlation coefficients for increments of standard Brownian motions that drive the short-rate (represented by EONIA), sovereign bond spreads (SP) for France (FR), Netherlands (NL), Italy (IT), Spain (ES), corporate bond spreads (SP) for AAA, AA, A, and BBB-rated bonds, stocks (ST) and real estate (RE) returns. The correlation coefficients are calculated from monthly residuals from January 1999 to December 2007 after fitting the short rate and spread evolution to Ornstein-Uhlenbeck processes, and stocks and real estate returns to Geometric Brownian Motions, respectively. *Source: Authors' calculations, ECB Statistical Data Warehouse (EONIA), Bloomberg (sovereigns, stocks, real estate), FRED St. Louis (corporates).*

B.3 Calibration of the insurer’s investment portfolio and financial market securities’ processes

We calibrate the insurer’s asset portfolio weights based on [German Insurance Association \(GDV\) \(2016\)](#), according to which German life insurers held 6.7% in stocks (shares and participating interests) and 3.9% in real estate in 2015. For the corporate bond portfolio weight, we aggregate German life insurers’ investments in 2015 in mortgages (5.8%), loans to credit institutions (9.8%), loans to companies (1%), policy and other loans (0.5%), corporate bonds (10.3%), and subordinated loans and profit participation rights, call money, time and fixed deposits and other bonds and debentures (6.7%), which results in 34.1% and coincides with the fraction of corporate bonds reported by [European Insurance and Occupational Pensions Authority \(EIOPA\) \(2014a\)](#) for German insurers. We allocate the remaining fraction of fixed income instruments to sovereign bonds (55.3%).

The weights within sub-portfolios are based on [Berdin et al. \(2017\)](#) and [European Insurance and Occupational Pensions Authority \(EIOPA\) \(2014a\)](#) and reported in Table 8. The weights in the sovereign bond portfolio exhibit a larger home bias towards German bonds than those of [Berdin et al. \(2017\)](#) to match a modified duration of 8 years as reported by the German Insurance Association (GDV) for 2015.

Entire Investment Portfolio	Weight	Duration
Sovereigns w_{sov}	55.3%	9.4
Corporate w_{corp}	34.1%	5.5
Stocks w_{stocks}	6.7%	-
Real Estate $w_{\text{real estate}}$	3.9%	-
Sovereign Bond Portfolio	Weight	Modified Duration
German Sovereigns/All Sovereigns w_{DE}	90.4%	9.5
French Sovereigns/All Sovereigns w_{FR}	2.4%	9.2
Dutch Sovereigns/All Sovereigns w_{NL}	2.4%	9.5
Italian Sovereigns/All Sovereigns w_{IT}	2.4%	7.3
Spanish Sovereigns/All Sovereigns w_{ES}	2.4%	9.5
Corporate Bond Portfolio	Weight	Duration
AAA/All Corporates w_{AAA}	23.6%	5.7
AA/All Corporates w_{AA}	16.85%	5.9
A/All Corporates w_{A}	33.71%	5.5
BBB/All Corporates w_{BBB}	25.84%	5.2
Stocks and Real Estate Portfolios	Weight	
German/Portfolio $w_{\text{s/re DE}}$	60%	-
French/Portfolio $w_{\text{s/re FR}}$	10%	-
Dutch/Portfolio $w_{\text{s/re NL}}$	10%	-
Italian/Portfolio $w_{\text{s/re IT}}$	10%	-
Spanish/Portfolio $w_{\text{s/re ES}}$	10%	-

Table 8: Investment portfolio allocation.

The table depicts the weights and average modified duration of each asset class in the insurer’s investment portfolio.

The duration of individual bond types is taken from [European Insurance and Occupational Pensions Authority \(EIOPA\) \(2014a\)](#)’s Tables 13 and 14.

C Additional Figures

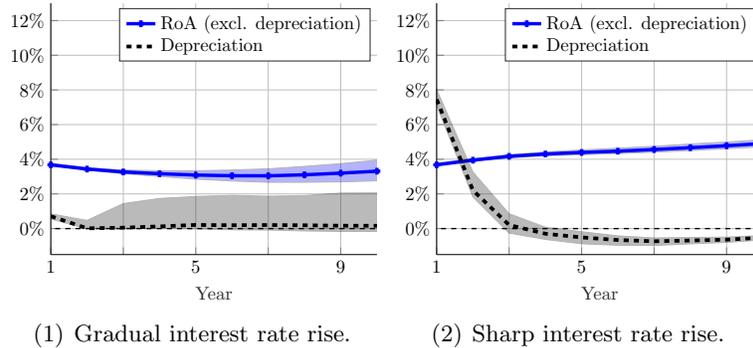


Figure 11: Return on assets and depreciations of HCA book values. The insurer's return on assets (RoA) is calculated by comparing the HCA book value of assets at time t with that at time $t - 1$. Depreciations of book values (upon a decline of at least 10% of market values compared to face values) are the negative change in book values from $t - 1$ to t . We show the median and 90% confidence at each point in time.

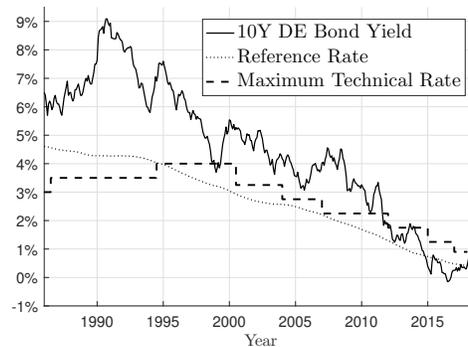


Figure 12: Historical German interest rates.

The figure depicts (1) the 10-year German sovereign bond yield (straight line), (2) the reference rate used to determine the maximum technical rate in our model (dotted line), which corresponds to 60% of the 10-year moving average of the 10-year German sovereign bond yield, and (3) the maximum discount rate for life insurance reserves under German GAAP accounting (dashed line), which typically corresponds to the level of guaranteed rates offered for new life insurance savings policies. *Source: FRED St. Louis, German Insurance Association (GDV), own calculations.*

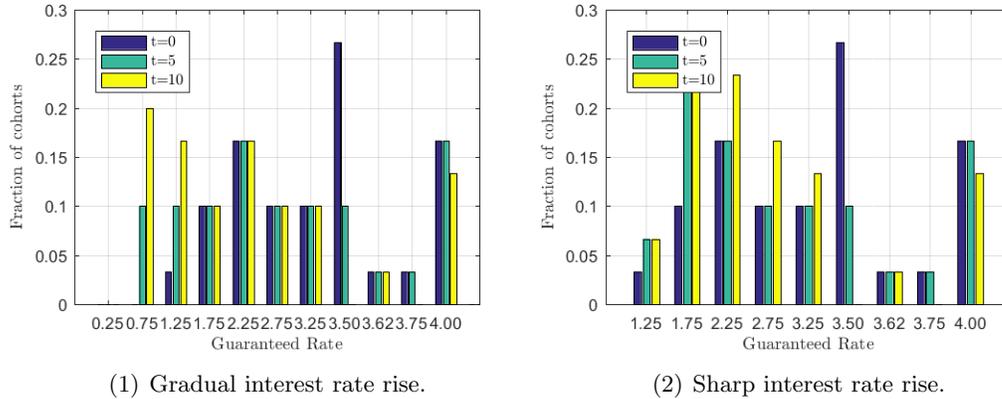


Figure 13: Distribution of guaranteed rates across cohorts.

The figures depict the fraction of cohorts in the insurer's active policy portfolio with a given guaranteed rate at different points in time for the median simulation path.

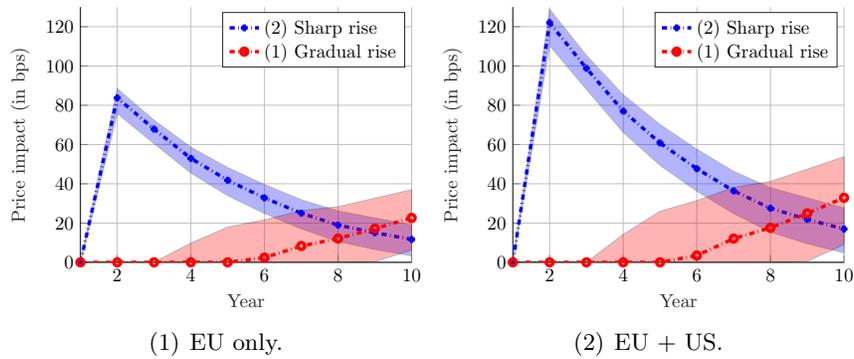


Figure 14: Amplification effect of fire sales.

The figures illustrate how much average asset prices decline (in bps) due to life insurers' fire sales. We calculate the amplification effect by $\delta \times s_t$, where δ is the price impact per EUR 1bn asset sales and s_t is the asset sale volume in year t . We show the median and 90% confidence level at each point in time.

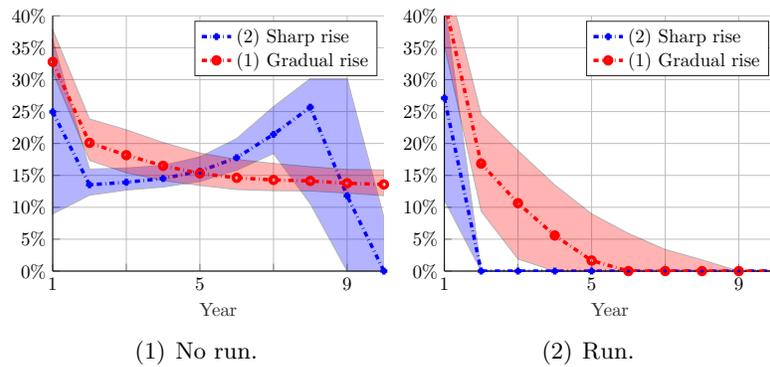


Figure 15: Dividend payments.

The figures illustrate dividend payments relative to previous year's MtM value of equity capital. We show dividend payments based on our baseline calibration ("Run") as well as based on a counterfactual calibration with surrender rates fixed to 2.86% ("No run"). If the free cash flow is positive, the insurer pays out part of (or the full) free cash flow in form of dividends up to the maximum amount to maintain a solvency ratio of 100%. We show the median and 90% confidence level at each point in time.

D Additional sensitivity analysis

D.1 Strict vs moderate OTTI

An insurer’s discretion about the recognition of asset market value declines varies across different jurisdictions. For example, [Ellul et al. \(2015\)](#) find high variation across US states in the degree to which life insurers recognize asset values. In Germany, before 2003 insurers needed to immediately recognize any reduction in asset market values below (historical cost) accounting values (*strict OTTI*). Since a change in legislation in 2003, insurers have more flexibility in recognizing whether a market value drop is temporary or not (*moderate OTTI*).⁷⁶

In our baseline model, we assume that any annual drop in market value below 90% of the accounting value is immediately recognized on the balance sheet. Based on interviews with German industry and regulatory representatives, it is, however, likely that German insurers have flexibility (a) in determining whether a market value decline is other-than-temporary and (b) in recognizing market values over a period of roughly 1.5 years. This flexibility (we refer to it as moderate OTTI) might affect the insurers’ historical cost accounting balance sheet. We implement a sensitivity check with additional flexibility in OTTI accounting by assuming that insurers recognize 75% of a drop in market values below 90% of the book value during the last 2 year. Thus, the book value of an asset is given by

$$BV_t = \begin{cases} BV_{t-1} - 0.75(BV_{t-1} - MV_t), & \text{if } MV_t < 0.9BV_{t-1} \text{ and } MV_{t-1} \leq 0.9BV_{t-1}, \\ \min(MV_t, HC), & \text{if } MV_t > BV_{t-1}, \\ BV_{t-1}, & \text{else,} \end{cases} \quad (34)$$

where BV_t and MV_t are the book and market value at time t , and HC the historical cost value.

As [Figure 16](#) shows, moderate OTTI notably changes the insurer’s HCA capital position only by delaying the impact of a sharp interest rate rise. Intuitively from [\(34\)](#), the insurer recognizes the substantially larger interest rates (thus smaller market value of fixed income assets) at $t = 1$ only at $t = 2$. However, its HCA capital position at $t = 2$ with moderate OTTI is negligibly larger

⁷⁶Before 2002, German insurers’ assets were accounted as current assets (*Umlaufvermögen*) that underly strict OTTI in German local accounting rules. Since 2002, assets that are deemed to be held at a long-term horizon can be accounted as fixed assets (*Anlagevermögen*) that underly moderate OTTI.

than with strict OTTI. The effect of surrender rates is also the same. We conclude that discretion over OTTI does not qualitatively alter our main baseline results.

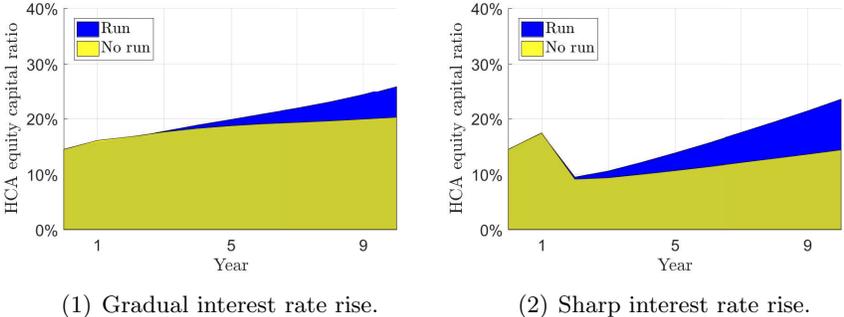


Figure 16: Moderate OTTI: Historical cost accounting equity capital ratio.

Figures depict the HCA equity capital ratio with moderate OTTI as described in (34), i.e., the value of equity capital relative to total assets on the HCA balance sheet. We show the median equity capital ratio based on our baseline calibration ("Run") as well as based on a counterfactual calibration with surrender rates fixed to 2.86% ("No run").