Insurers as Asset Managers and Systemic Risk *

Andrew Ellul
Indiana University, CEPR, CESF and ECGI

Chotibhak Jotikasthira
Southern Methodist University

Anastasia Kartasheva
International Association of Insurance Supervisors,
Bank for International Settlements

Christian T. Lundblad
University of North Carolina, Chapel Hill

Wolf Wagner
Rotterdam School of Management

3 January 2018

Insurers as Asset Managers and Systemic Risk

Abstract

Asset fire sales arguably play a critical role in the propagation of systemic risk. We propose a new mechanism whereby financial institutions' business models engender correlated asset portfolios, increasing vulnerability to fire-sales. We use as our laboratory the U.S. life insurance industry, which has experienced a major transformation with the significant expansion of variable annuity (VA) investment products with guarantees, against which insurers have to post reserves and regulatory capital. We develop a theoretical model in which an insurer hedges its guarantee exposure, and, as a result, is incentivized to invest in illiquid assets. In the event of an asset shock or a shock to the value of the guarantee, insurers engage in fire sales to maintain their capital ratios. Using insurer-level data, we calibrate the model and confirm that insurers operating in the VA space invest in riskier portfolios, sharing common allocations to illiquid bonds. In a simulation exercise, we subject the insurers to various shocks and show that the system-wide fire-sale costs, directly attributable to VAs, can plausibly erase up to 30% of the insurers' total capital and surplus. Given the widespread nature of potentially underfunded guarantees (e.g., pension funds), the implications of our findings are not restricted to the insurance sector.

1 Introduction

This paper explores how systemic risk may arise from the inter-connectedness of the asset side of financial institutions' balance sheets. While much of the existing literature on systemic risk has concentrated on the interplay between leverage and banks' funding, attention has slowly shifted to another source of fragility that potentially exposes the financial system to contagion in the case of abrupt and sustained asset price declines: the herding of financial institutions into similar assets in search of higher returns (particularly over a decade characterized by historically low interest rates). Within the banking literature, Acharya and Yorulmazer (2007, 2008) show that the âtoo-many-to-fail' guarantees lead to banks herding in their lending behavior by, for example, investing in similar industries or exposing their balance sheet to a common risk factor. Greenwood, Landier and Thesmar (2015) show that fire sales, induced by regulatory requirements, can create contagion that spreads across banks holding the same assets.[1] So far, the literature has been limited to investigating generic dimensions of this broad issue: it has either examined macro-prudential regulation to address the emergence of banks' herding behavior or it has simply assumed an exogenously correlated investment structure and then investigated its potential repercussions for financial stability.

The paper proposes an innovative mechanism that engenders correlated investments and that arises from the financial institutions' business model, rather than macro prudential regulation per se. The endogenous *ex ante* herding can then generate *ex post* fire-sale externalities along the lines hypothesized by Greenwood et al. (2015). To study this mechanism, we focus on the transformation of the U.S. largest life insurers that has expanded significantly the supply of variable annuities (VAs) with various embedded investment guarantees (Koijen and Yogo (2017a,b)).[2] Importantly, the U.S. insurance business offers a remarkable level of measurement detail with respect to portfolio holdings, policy generation, and regulatory constraints (see Ellul, Jotikasthira, and Lundblad (2011),

---

[1]Domanski, Sushko and Shin (2015) examine portfolio adjustments by long-term investors to declining long-term interest rates and show that they can prompt further downward pressure on interest rates.

[2]A variable annuity is a life insurance policy which it sold to individuals approaching retirement. The policy consists of accumulation and decumulation phases, and combines insurance for life, longevity, and investment risks. We provide more institutional detail in Section 2.

for example) helping to shed light on other sectors of the financial industry besides insurance.

Given both their size and the nature of their return commitments, these VAs are attracting attention from policymakers as a potential source of systemic risk, as evidenced by the designation of some of the largest life insurers as systemically important (Drexler et al. (2017)). To place this development into perspective, annuity premia and deposits earned by the U.S. life insurance industry increased from $286 billion in 2010 to $353 billion in 2014, making them one of the fastest growing areas of policy generation, accounting for almost 35% of U.S. life insurers' liabilities in 2015. Figure 1 presents the history of the life insurance business over the last two decades as its major product lines have evolved from traditional life insurance to investment products, namely VAs.

The emerging concerns about the risks to which insurers with VA guarantees are exposing themselves, and the potential risk that they can cause if a negative market-wide event occurs, can be captured by the systemic risk measure proposed by Acharya et al. (2017) and Brownlees and Engle (2016).[3] There is a very striking difference between the post-crisis period evolution of the average systemic risk measure of banks versus that of insurance companies with VAs. While the banks' systemic risk measure spiked during the 2008-2009 financial crisis, it then decreased over time. However, the same measure for insurers selling VAs with guarantees increased during the crisis, and has not decreased in the same manner. Figure 2, which shows the average systemic risk measures for the aggregate banking and insurance sectors, makes this development very clearly.

The importance of such investment products is not restricted to the insurance sector; rather, it extends directly to other large intermediaries, such as banks and pension funds. For example, insurers and pensions both provide various guarantees and share a degree of under-fundedness. As the importance of traditional defined benefit plans wanes, VA products that offer similar returns and guarantee have gradually come to replace them.

For our purposes, the first critical feature of this evolution is the fact that most of these annuities carry guarantees, in terms of promised minimum returns to holders that have to be honored by

---

[3]A detailed description of the calculations behind the systemic risk measure used in the analysis is provided on NYU Stern's Systemic Risk website, http://vlab.stern.nyu.edu/welcome/risk.

the insurers. Given the put option-like nature of these contracts, regulations were introduced to safeguard annuity investors by forcing reserves that insurers have to set aside. Importantly, these reserves, now among the largest liabilities on the insurers' balance sheets, are necessarily dynamic; annuity balances (and minimum guarantees) are largely invested in (tied to) U.S. equity valuations, so that the link to stock market performance is very clear. If the expected value of future payouts increases in an equity market downturn (i.e., the guarantee is increasingly in-the-money), then insurers are required to increase their reserves. During a market stress period, financial distress, and potentially insolvency, can arise as the moneyness of guarantees explode.

Another significant concern is that the moneyness of the guarantees is itself correlated across insurers. As diversification is ineffective in the case of VAs with guarantees[4] because they are tightly linked with the performance of financial markets, guarantees go in-the-money at the same time for all insurers with VAs. It is exactly this type of shared risk that has raised significant concerns about financial stability across both the insurance sector and more broadly other parts of the interconnected financial system. This becomes very salient when considering the evidence in Billio et al. (2012), who show that the four core areas in the financial sector, namely hedge funds, banks, brokers, and insurance companies, have become highly linked over the past decade.

The recent financial crisis, with a stock market meltdown followed by a long period of low interest rates, is an example of how insurers with VA guarantees could end up with severe financial difficulties. As the increase in required reserves impairs the insurers' financial health, insurers may attempt to recover by either raising new capital or engaging in fire sales. Evidence shows that the latter course of action is more likely, thus shifting the attention to inter-connectedness between insurers' balance sheets. While not necessarily implying causality at this stage between VAs and systemic risk, it is important to highlight the role that the non-traditional life insurance sector may play in the event of a sustained market-wide stress event. The impact that such non-diversifiable

---

[4]The risks associated with these guaranteed investment products are very different from those that insurers faced when most of their products were traditional life insurance policies. Mortality risks, for example, are idiosyncratic and can be easily diversified away by issuing a large number of similar policies. This is not the case with VAs linked to the equity market, however.

risk poses to life insurers is borne out when we consider the experiences of individual companies.[5]

In this paper we show, both theoretically and through a calibration using U.S. insurance data, that guarantees induce herding on the part of insurers, thereby increasing the likelihood of fire sales that impose externalities on others holding the same assets. We provide a real-world setting in which the asset liquidation channel of systemic risk may become significant. A price shock to or a downgrade of many assets held to back the guarantees can trigger fire sales and set in motion contagion.

When the insurers hold similar assets, two potential triggers can set in motion contagion. First, the assets held by insurers to back the VA guarantees are downgraded or suffer a negative price shock. Second, an exogenous shock increases the value of the VA guarantees. In both scenarios, capital requirements become elevated forcing capital-constrained insurers to engage in fire sales, generating contagion to the wider industry and to other financial institutions. Making this issue of more immediate concern, the effect unconventional policy has had in creating an ultra-low yield environment has placed additional pressure on insurers to search for return among a limited set of available securities.

The most effective method by which insurers can manage the risks arising from VA guarantees is through appropriate offsets with equity put options. In this case, none of the concerns discussed so far apply. In reality, though, there are formidable challenges facing insurers on the path to a full, comprehensive hedge. First, the complexity of very different guarantee products translates into a reserve volatility structure that is hard to fully understand. Second, insurers face a triple challenge when engaging in hedging: first, there is the true economic vulnerability driving the hedging decision, and second, there is a complicated set of accounting implications associated with the reporting of reserves for VA guarantees that differ between GAAP and statutory (regulatory) accounting rules. This places an additional burden on insurers since these varied rules may yield rather different outcomes when reporting reserves net of some of these hedges. Third, the total

---

[5]AIG, Hartford Financial Services Group, and Lincoln National were among those that aggressively wrote investment-oriented life policies that had minimum guarantees attached to them. Besides the well-known case of AIG, Hartford Financial was also bailed out by the Troubled Asset Relief Program in 2009, and the reason was precisely the significant losses they faced arising from the VA business unit. Hartford eventually sold its VA business in 2013.

hedging amount that is deducted from the insurer's reported reserves is not made public, meaning that reserves for guaranteed VAs may fail to entirely reflect the exact funding needs associated with the guarantees. Finally, the sizable hedging in which insurers do engage introduces additional concerns, such as basis risk and counter-party.

To demonstrate how VA guarantees induce correlated investments, we present a theoretical model that captures the underlying economics and then calibrate the model to insurer-level data. The model considers a profit-maximizing insurer that (exogenously) sells VAs with guarantees linked to thestock market. The insurer optimally allocates its portfolio between (a) equity, (b) an illiquid, risky bond, and (c) a liquid, safe bond. An important input into the insurer's *ex ante* decision concerning which assets to purchase is the *ex post* price impact on these different assets in the event of a negative shock. In line with the existing literature, we assume that the liquid bond and stock can be sold at their expected values, but the riskier bond will be sold at a discount due to its illiquid nature. That said, the illiquid bond offers enough *ex-ante* risk compensation, even taking into consideration the fire sale price impact that may occur following a shock. The insurer is subject to risk-sensitive regulatory capital requirements.

Following practice, we assume that the insurer will hedge a proportion of the guarantees to manage the risk to which it is exposed. While part of the hedging may be facilitated by directly employing a portfolio of put options, we focus on delta hedging.[6] This involves selling short the equity and investing the proceeds in both the safe and risky bonds. Depending on how much hedging is employed, the insurer will have a lower risk exposure which, in turn, implies a commensurately lower overall portfolio expected return, prompting the question as to how the insurer can still generate sufficient returns to meet its investment objectives. As the insurer cannot scale down its aggregate bond positions because of the delta hedging constraint, any additional unit of risk that it wants to take will have to come from within the bond asset class, leading naturally to an over-weight in illiquid bonds.[7] Our model predicts that insurers that do not underwrite guaranteed VAs will

---

[6]From Schedule DB (derivatives), insurers hedge only about 5% of VAs by buying put options.

[7]A close empirical analogue is the reaching for yield behavior documented by Becker and Ivashina (2015) and Ellul, Jotikasthira, Lundblad, and Wang (2014).

invest a negligible amount in the illiquid bonds and, thus, are irrelevant for the propagation of systemic risk.

It is the portfolio over-weight on the riskier bonds chosen by the insurance companies with VAs that will become problematic during a market downturn. In such states, the guarantees become in-the-money, regulatory reserves spike, and thus insurers need to shore up their capital positions. While issuing equity is a possibility, it is precisely in these moments that such an avenue becomes impracticable. This calls for an alternative action: selling of the illiquid bonds, and possibly of the other assets on the balance sheet, in a regulatory-induced fire sale to regain financial health. This will cause contagion to other insurance companies and, because of the inter-sector interconnectedness, to other parts of the financial system.

To calibrate the model, we use National Association of Insurance Commissioners (NAIC) data, obtained through SNL Financial, on guaranteed VAs' account values, gross reserves, reinsurance credits (General Interrogatories), portfolio holdings (Schedules A, B, BA, and D), and derivatives positions (Schedule DB). To begin, we establish some important facts about the portfolio allocation of insurers with and without VA guarantees. We find that only few life insurers underwrite guaranteed VAs, and the ones that do tend to be very large and sophisticated. Further, we find that insurers that underwrite guaranteed VAs hedge their exposures by selling common stocks and buying bonds, tilting their portfolios towards higher yielding illiquid bonds. We find that those that underwrite guaranteed VAs have significantly smaller allocations to liquid bonds and significantly larger allocations to illiquid bonds than insurers with no VAs.

To examine this link more formally, we infer an insurer's guarantee-induced stock market exposure, or delta, which is the main driver of delta hedging in our model. We rely on the law of motion for the guaranteed VAs' account values and gross reserves, and operate under a set of simplifying assumptions about the requirements imposed on insurers and their hedging decisions.[8] We then calibrate the model by regressing an insurer's portfolio allocation to each asset group

---

[8]We divide derivatives earmarked for hedging VA into two groups. The first group includes mostly put options, which we assume are sufficiently "effective" to be used as credit to offset the gross reserve. We refer to this as comprehensive hedging. The second group includes linear derivatives, mostly stock market futures, which we assume are part of the delta hedging program highlighted in our model.

(liquid and illiquid bonds, and common stocks) on the delta.

In the regression where the common stock allocation is the dependent variable, our model dictates that the coefficient on the dollar delta is exactly the delta hedge ratio. We find this coefficient (about 0.65) to be significantly negative, and economically plausible; insurers hedge a large, but incomplete fraction of their guarantee exposures. In the regression where the illiquid bond allocation is the dependent variable, the corresponding coefficient is the product of the hedge ratio and the relative capital requirements for common stocks versus illiquid bonds. We find this coefficient to be significantly positive, suggesting insurers with VA guarantees reach for yield. From here, we take the implied model parameters to determine three portfolios for each insurer: (i) an actual portfolio which reflects both delta (but incomplete) hedging and the associated reaching for yield behavior, (ii) a hypothetical portfolio that reflects only delta (but incomplete) hedging without reaching for yield behavior, and finally, (iii) a hypothetical portfolio which would obtain if the insurer had no guaranteed VAs at all (or completely and comprehensively hedged their exposures). The difference between portfolios (i) and (ii) uncovers the effect of reaching for yield behavior, while the difference between portfolios (ii) and (iii) comes from the guarantee exposure that is incompletely hedged. Reaching for yield and the guarantee exposure are the two main sources of systemic risk potentially induced by the incentives associated with guaranteed VAs.

In the final step, we perform a simulation exercise to quantify the asset pricing impacts of various market shocks that are attributable to the underwritten VAs. To do so, we follow a framework similar in spirit to that of Greenwood et al. (2015); facing a negative shock to their statutory capital, insurers must sell risky assets to maintain a healthy risk-based capital ratio and their collective asset sales engender price impacts. We focus on three types of shocks, all of which have magnitudes comparable to what we observed during the 2008-9 financial crisis: first, a categorical shock (prices decline across the board); second, a shock to the illiquid bond (prices of illiquid bonds decline in a similar manner to those of mortgage-backed securities during the crisis); and finally, a shock to the value of the guarantee. In each scenario, we examine in detail the differences in price impact across the different actual and hypothetical portfolios mentioned above to gauge the relative importance

of the drivers of systemic risk. For example, we demonstrate that categorical asset value shocks of between 10-40% would result in insurers selling \$134-\$537 billion of illiquid bonds, with the corresponding system-wide fire-sale costs representing up to 30% of insurers' total capital and surplus. Further, our model facilitates a decomposition of the fire sale effect, and we find that the largest culprit, by far, of *ex post* systemic risk is *ex ante* reaching for yield behavior.

This paper makes a contribution to the systemic risk literature along several dimensions. First, the existing literature has identified correlated investments as a potential source of systemic risk. Wagner (2010) and Allen et al. (2012) have theoretically shown that elevated asset similarity across institutions is one channel through which systemic risk may arise. Greenwood et al. (2015) show empirically how regulatory fire-sales can translate correlated investments into systemic risk. However, with the exception of Acharya and Yorulmazer (2007) and Acharya (2009), existing studies have not investigated how such inter-connectedness first arises in equilibrium. In this paper, we propose theoretically and investigate empirically one mechanism, different from regulation, that gives rise to asset inter-connectedness. While capital regulation is a part of our analysis, asset similarity across insurers instead arises from the business decisions to provide investment products. While there is an emerging literature investigating the similarity across portfolios of financial institutions (e.g., Getmansky et al. (2016)), we are among the first to link this elevated portfolio correlation to the transformation of the insurance sector and the emergence of VAs with guarantees. To the best of our knowledge, our paper is the first to explicitly link VAs to interconnectedness and systemic risk.

Second, another strand of the literature addresses the issue of liquidity provision in times of market stress, proposing that some intermediaries, by virtue of their long horizons and balance sheet structure, can take on that vital role. Indeed, the spillover effects of fire sales will be attenuated, or perhaps even halted, if enough buying capital comes in, thus highlighting the importance of the stability of such intermediaries. Chodorow-Reich et al. (2016) propose that insurance companies behave like asset insulators during normal conditions, they do not during market meltdowns. Aside from providing a micro-founded explanation for this result, our paper also shows that life insurers

may not only stop insulating assets in market meltdown but rather may themselves become a source of significant selling activity. More importantly, by virtue of the asset inter-connectedness, they are now more likely to contribute to the contagion through regulatory fire-sales. This has far reaching implications for the stability of the entire financial system.

The rest of the paper is organized as follows. Section 2 provides the salient institutional features of the VA market and how the associated guarantees impact insurers' regulatory capital. Section 3 introduces the first part of the model to demonstrate how policy generation in the VA space leads to a riskier portfolio allocation and engenders inter-connectedness. Section 4 introduces the insurance-level data and calibrates the model's predictions. Section 5 provides several simulations exercises, based on the model's fire sale mechanism, to quantify the impact of various negative shocks. Section 6 concludes.

2 Institutional Framework

A guaranteed VA is a savings product in the U.S. sold by life insurers to individuals for retirement purposes. The VA market has been growing rapidly in the last two decades for several reasons. In late 1990s insurers started to offer various guarantees that protect policyholders from poor investment returns, effectively offering insurance against a downturn in the stock market. More broadly, during this period the U.S. retirement system has been shifting from defined benefit to defined contribution schemes, which increased demand for pension-like investment products elsewhere. Tax reform in mid-1980s reduced the

2.1 Basic Description of VAs with Guarantees

The VA product is a long-term contract between an insurer and a policyholder and consists of accumulation and decumulation phases. During the accumulation phase, the policyholder contributes funds to the annuity account, and the balance is invested in stock and bond market instruments such as mutual funds, ETFs, etc. The policyholder has some discretion to reallocate

9

investments among different asset classes offered by an insurer. She can also terminate the contract and withdraw the cash value of the policy, subject to termination fees. Once a policyholder reaches retirement age, she has an option to convert the account balance into an annuity or take out the cash value of the policy (terminating the contract). If she decides to annuitize, the policyholder is entitled to receive regular payments from the insurer either during a fixed number of years or for life, depending upon the terms. While there are many different types of guarantees associated with VAs, we focus on those that are linked to the equity market.

VAs expose a policyholder to market risk as the amount that she can eventually annuitize is uncertain and depends on stock market performance. To reduce this risk, insurers offer a host of guarantees. Guarantees come in various forms, effectively providing an assurance for a policyholder that her savings and annuity payments are protected from adverse market conditions.[9] For example, a âGuaranteed Minimum Accumulation Benefitâ ensures that the account value does not fall below a contractually determined minimum value. Alternatively, a âGuaranteed Minimum Income Benefitâ guarantees that a policyholder receives a minimum income stream when the policy is annuitized, even though the remaining account value fluctuates with stock market performance. These, and other, guarantees are sold as separate riders. For reference, more than 80% of variable annuity contracts in the U.S. have some form of guarantee. Similar such provisions are pervasive in insurance markets around the world.

2.2   Impact of VAs on Insurers' Capital

From the perspective of an insurer, a VA policy is a combination of business components related to asset management and life insurance. An insurer allocates policyholder savings to a separate account and acts as a delegated asset manager of policyholder's funds. It offers a policyholder a menu of investments and charges fees based on assets under management. Absent any guarantees, the separate account is a pass-through account in which a policyholder bears all investment risk.

---

[9]One example of a VA with guarantees is the so-called Guaranteed Lifetime Withdrawal Benefit (GLWB) and this product is the most common type of guaranteed living benefit. There are other types of guarantees, such as the Guaranteed Minimum Withdrawal Benefit (GMWB), Guaranteed Minimum Income Benefit (GMIB), and Guaranteed Minimum Accumulation Benefit (GMAB).

The life insurance component of the VA is the option held by the policyholder to convert the funds to an annuity at retirement. If a policyholder annuitizes, an insurer then faces easily diversifiable longevity risk.

Most importantly for this paper, guarantees attached to the VA products create important implications for insurers' reserves and, as a consequence, on the insurers' financial health as measured by the Risk-Based Capital (RBC) ratio. In general, insurers are required to hold reserves, now a major liability, that are used to make promised payments to policyholders. For traditional insurance risks, insurers' reserves are set to match (a profit margin adjusted) expected periodic payment to policyholders. Based upon standard asset-liability matching, reserves are usually invested in fixed-income securities. As an insurer may face insufficient reserves if it underestimates, say, the average longevity risk of its clients. However, this risk would be largely idiosyncratic to the insurer.

In sharp contrast to longevity risk, which is the usual type of risk associated with traditional insurance products, the size of the reserves associated with guarantees fluctuates with stock market performance. During a stock market decline, the moneyness of guarantees and associated required reserves increases. To mitigate the fluctuation of reserves associated with guarantees, insurers need to raise more capital. However, the demand for capital is now synchronized among insurers offering guarantees, and capital can be costly during a sharp market downturn. As an alternative, insurers partially hedge their stock market exposure with derivatives and/or invest in riskier, less liquid assets.

The VA liabilities have a direct impact on the RBC ratio as they affect both the reserves and also the required capital.[10] In order to measure these liabilities and reserves, insurers first rely on inputs supplied by insurance regulators and then their own simulations (Koijen and Yogo (2017a)). The first input comes from insurance regulators who supply various scenarios for the joint path of several asset classes, namely treasury bonds, corporate bonds, and equity prices. Within this

---

[10]Specifically, Actuarial Guideline 43 (or Actuarial Guideline 39, prior to December 2009) determines the reserve value of variable annuities, and, since December 2005, the C-Phase II regulatory standard determines the contribution of variable annuities to required capital (Junus and Motiwalla (2009)).

framework, insurers gauge any possible equity deficiency by simulating the values of their VA business under each supplied scenario (keeping the highest present value of equity deficiency in each path). Reserves that have to be kept by the insurers are computed as the conditional mean over the upper 30 percentile of the equity deficiencies. It should be kept in mind, though, that there is no presumption that this value will be identical to the market value. The same methodology is used by insurers when computing required capital, with the difference that the conditional mean is calculated over 10 percent of equity deficiencies.

The two most important factors that influence reserves are equity prices and interest rates. From their own nature, reserves will suffer when equity prices decline and interest rates either decline or are kept at a low level for a long period of time. In Figure 4 we plot the evolution of reserves for the VA guarantees as a ratio of various insurance characteristics that directly measure different aspects of financial health: the evolution of insurers' gross reserves to capital (Panel A), their stock returns (Panel B), and their return on equity (Panel C) for the period from 2004 to 2013. Each year, life insurers with guaranteed VAs are divided into two groups by the ratio of gross reserve to capital. The "high" ("low") group includes life insurers with a ratio of gross reserve to capital larger than (less than or equal to) the median. For comparison, the annual averages for life insurers without guaranteed VAs are also plotted.

As expected, reserve additions (and, as a consequence, capital reductions) spike when two conditions emerge: declining stock markets and interest rates, which are the conditions that feature in most recessions. Panel A also highlights the devastating effects on the reserves associated with the rapid deterioration of equity markets, such as the 2008-2009 financial crisis and the 2011-2012 price decline due to the Euro crisis. This is central for the understanding of how the VAs business can create contagion during such a shock. As insurers' RBC ratios rapidly deteriorate, they will be under pressure to improve their financial health and this can be obtained through two ways: issuing new equity or reducing risk from their balance sheet by engaging in fire sales, akin to a deleveraging process. Given that issuing equity may be very difficult during stress periods, engaging in regulatory-induced fire sales become more likely.

VAs with embedded guarantees introduce several new features and risks to an insurer's overall business model. Like any delegated portfolio manager, the size of assets under management becomes a significant driver of profitability. To attract funds in a highly competitive market, insurers are incentivized to offer generous guarantees that may prove costly in certain states of the world. Guarantees also prompt more complex hedging strategies, and induce more aggressive investments. In the following sections, we provide a model and associated empirical evidence to support these observations.

3 A Model of Guarantees, Hedging, and Portfolio Choice

In this section, we develop a simple model that facilitates an understanding of the links between, on the one hand, an insurer's guarantee activities and its respective hedging and, on the other, its portfolio choice. An central focus of the analysis will be an examination of the sensitivity of portfolio allocations to (effective) guarantee-exposures, which will then be estimated using U.S. life insurance data in Section 4.

In our model, we consider an insurer whose risk-taking is constrained by its (regulatory) capital position. The consequence is that whenever the insurer's risk in one part of the portfolio is, say, reduced (for example because of hedging), it has the capacity (and the will) to increase risk in other parts of its portfolio. This is what will drive portfolio adjustments following the writing of guarantees (and any associated hedging activity). Whether these adjustments increase or decrease risk for the entire financial system will crucially depend on the regulatory risk-weights of the various assets in which the insurer can invest. We will assume that these risk-weights are fair, insofar as they fully reflect the fundamental risk posed by an activity. However, we do critically assume that regulation under-prices illiquidity risk (which is endogenous in our model, arising from fire-sales in the bond market). This under-pricing can result in risk-shifting by the insurer, and ultimately create systemic risk. The systemic consequences will be analyzed in more detail in Section 5.

In the subsequent analysis, we will take both the guarantees as well as any associated hedging as

given. We can think of these characteristics as being determined exogenously by the business model of the insurer. As discussed in Section 2, insurance companies employ several forms of hedging, the most prominent of which being delta-hedging, where insurers take (short) positions in the stock market to offset the market exposure arising from the guarantee. We will focus the theoretical analysis on this type of hedging – but will incorporate direct hedging (e.g., buying put-options) in our estimations.

3.1 Setup

Consider one insurer and three dates $(0, 1, 2)$. The insurer has total funds A, of which E is capital and $A - E$ are liabilities. The insurer can use the funds to invest in three assets: stocks, an illiquid, risky bond, and a liquid, safe bond. The expected date-2 returns on stocks and the illiquid bond are r_S and r_I ($r_S > r_I$), respectively; the return on the liquid bond is normalized to zero: $r_L = 0$.

At date 0 the insurer decides upon the fraction of funds to invest in stocks, the illiquid, and the liquid bond. We denote the respective portfolio weights as α_S, α_I, and α_L ($\alpha_i \in [0, 1]$). The portfolio choice has to obey two constraints.

First, there is a constraint arising from the guarantee and any associated hedging. We consider an insurer who has sold (guaranteed) variable annuities using the stock market as an underlying. Specifically, the insurer has written guarantees of size $g > 0$ expressed as a fraction of its balance sheet (so the total guarantee is gA). We denote the (absolute value) of the option delta of a unit of the guarantee with $|\delta|$. Thus, when the stock market falls by one unit, the total value of the guarantee written increases by $|\delta| g$. We refer to $|\delta| g$ as the *effective* guarantee exposure. The option delta will reflect the characteristics of the guarantee written, for example, the degree to which it is out-of-the-money. We assume that the insurer hedges a proportion h ($h \in [0, 1]$) of the guarantee using delta hedging.[11] For this, the insurer sells short $h \cdot |\delta| g$ units of the stock market at date 0 and invests the proceeds into the remaining part of its portfolio. The guarantee thus amounts to the

---

[11]As discussed previously, an alternative (although expensive) means of hedging is to buy outright puts. Such hedging has the effect of simply neutralizing (a part of) the guarantee. That is, the effective guarantee exposure when a proportion h_D is directly hedged becomes $(1 - h_D) |\delta| g$. By replacing the effective guarantee exposure with this expression in our estimations, we will hence take into account direct hedging.

restriction that at least $h \cdot |\delta| \, g$ has be invested in the two bonds:

$$\alpha_L + \alpha_I \geq h \cdot |\delta| \, g. \tag{1}$$

Note that the guarantee does not impose a similar constraint on the stock market position, as we allow for short-selling of stocks.

Second, the insurer is subject to risk-sensitive capital requirements. We assume that the regulatory risk-weights on the three assets, denoted γ_i ($i \in \{S, I, L\}$), are proportional to their date-2 returns (reflecting that assets that are priced to have higher returns posses commensurately higher risk levels):

$$\frac{\gamma_S}{r_S} = \frac{\gamma_I}{r_I} \text{ and } \gamma_L = 0. \tag{2}$$

The insurer's total risk-weighted assets are then $(\alpha_S \gamma_S + \alpha_I \gamma_I) A$. Given a required capital-adequacy-ratio of ρ, the insurer's portfolio thus has to fulfill the following risk-weighted capital constraint:

$$\frac{E}{(\alpha_S \gamma_S + \alpha_I \gamma_I) A} \geq \rho. \tag{3}$$

This equation presumes that the guarantee itself do not affect regulatory constraints.[12] However, hedging – even though not directly apparent in equation (3) – does affect the regulatory constraint. For example, an insurer who invests the proceeds from hedging exclusively into liquid bonds will see its risk-weighted assets decline by $\triangle \alpha_S \gamma_S = h \cdot |\delta| \, g \gamma_S$. Note that an alternative interpretation of equation (3), aside from a regulatory constraint, is that of the insurer's target ratio of risk.

At date 1 with probability π ($\in (0, 1)$), we assume that a shock arrives which forces the insurer to sell a part of its portfolio. In Section 5, we model this explicitly as being the result of a capital shortfall. For now, we assume that the shock forces the insurer to sell a proportion s ($\in (0, 1)$) of its portfolio. While we assume that the liquid bond and stocks can be sold at their expected value, we

---

[12]The regulatory treatment of guarantees is complex. As a first approximation it is plausible to assume that the fee the insurer receives for offering the guarantee (which adds to capital and hence relaxes the regulatory constraint) offsets the capital required for the guarantee (this would be the case for a fairly-priced guarantee).

also assume that this is not the case for the illiquid bond (see Ellul, Jotikasthira and Lundblad (2011) for an analysis of why bonds held by insurance companies are subject to illiquidity). Specifically, the illiquid bond can only be sold at a discount $c > 0$ to its date-0 value. We can think of c as the bond's fire-sale discount, which is determined by the **total** amount of selling in the economy and hence will be taken as given by an individual insurer. Note further that the regulatory risk-weights do not reflect the potential fire-sale discount; that is, we assume that regulation does not (fully) price illiquidity risk. This is the imperfection that will allow for the creation of systemic risk.

Finally, we assume that all assets pay out their respective returns at date 2.

3.2 Portfolio Choice

At date 0, the insurer chooses portfolio weights to maximize its expected profits. When the shock does not arrive at date 1, the insurer will earn the respective return r_i (in expectation) on each asset. However, when the shock does arrive, the insurer's overall portfolio return will be reduced by $\alpha_I(r_I + sc)$. The insurer's expected date-2 return is hence given by $\alpha_S r_S + \alpha_I(r_I - \pi(r_I + sc))$.[13]

We make the following three assumptions:

Assumptions: (i) $r_I > \frac{\pi}{1-\pi}sc$, (ii) $\gamma_I > \frac{E}{A\rho}$, and (iii) $h \cdot |\delta| g > 1 - \gamma_S \frac{E}{A\rho}$.

The first assumption ensures that the illiquid bond, taking into account the probability that it has to be liquidated at date 1, has a positive expected return to the insurer.[14] The second assumption states that the capital constraint is sufficiently tight so that the insurer cannot invest everything into the illiquid bond (and hence also not stocks). The third assumption says that effective guarantee exposure (after hedging) has to be sufficiently large. If guarantees are very small, the bond holdings required to hedge the guarantee will be small as well, and will not affect the optimization problem (that is, the constraint (1) will not bind).

---

[13]We can ignore the pay-outs to guarantee holders and holders of other liabilities here since, as long as the insurer remains solvent, they are a given cost to the insurer.

[14]This has the consequence that expectations of fire-sales at date 1 do not (directly) affect portfolio allocations at date 0. See Wagner (2011) for an analysis of optimal portfolio strategies in the presence of fire-sale risk.

The insurer's maximization problem can be written as

$$\max_{\alpha_S, \alpha_L, \alpha_I} \alpha_S r_S + \alpha_I (r_I - \pi(r_I + sc)), \text{ subject to} \tag{4}$$

$$\alpha_L + \alpha_I \geq h \cdot |\delta| g, \ \alpha_S \gamma_S + \alpha_I \gamma_I \leq \frac{E}{A\rho}, \ \alpha_S + \alpha_L + \alpha_I = 1, \ \alpha_L, \alpha_I \geq 0.$$

The insurer's resulting optimal portfolio is given by

$$\alpha_S^* = 1 - h \cdot |\delta| g, \tag{5}$$

$$\alpha_I^* = \left(\frac{E}{A\rho} - (1 - h \cdot |\delta| g)\gamma_S\right)\frac{1}{\gamma_I}, \tag{6}$$

$$\alpha_L^* = h \cdot |\delta| g - \left(\frac{E}{A\rho} - (1 - h \cdot |\delta| g)\gamma_S\right)\frac{1}{\gamma_I}. \tag{7}$$

Proof. To build intuition, let us first consider the insurer's problem when there is no guarantee constraint (that is, we drop condition (1)). The insurer's objective is to maximize expected returns, subject to the condition that it has sufficient regulatory capital. The question thus becomes one of which asset gives the highest return per unit of risk-weight. Since risk-weights are proportional to date-2 returns, in the absence of fire-sales, the insurer is indifferent between investing in stocks and the illiquid bonds. However, due to the fire-sale cost, it strictly prefers stocks. The insurer will thus not hold any illiquid bonds ($\alpha_I = 0$), and invest up to the regulatory constraint (3) in stocks. From solving equation (3) for $\alpha_I = 0$, we obtain $\alpha_S = \frac{1}{\gamma_S}\frac{E}{A\rho}$. The remaining funds will be invested into the liquid bond. The holdings of the liquid bond can hence be obtained from the budget constraint ($\alpha_S + \alpha_L = 1$): $\alpha_L = 1 - \frac{1}{\gamma_S}\frac{E}{A\rho}$. Note that $\alpha_I + \alpha_L = 1 - \frac{1}{\gamma_S}\frac{E}{A\rho}$ fulfills the guarantee constraint (1) only when $h \cdot |\delta| g \leq 1 - \frac{1}{\gamma_S}\frac{E}{A\rho}$, that is, precisely when assumption (iii) is not fulfilled. It follows that insurers are constrained by the guarantee whenever assumption (iii) holds.

Let us now solve for the optimal portfolio when the guarantee constraint binds (assumption (iii) holds). Since the insurer strictly prefers stocks to bonds, it will only invest into bonds up to the guarantee constraint ($\alpha_L + \alpha_I = h \cdot |\delta| g$) and invest the remaining funds into stocks: $\alpha_S^* = 1 - h \cdot |\delta| g$. The division between illiquid and liquid bonds in the bond portfolio (of size $h \cdot |\delta| g$)

will be determined by the regulatory constraint: the insurer will invest into illiquid bonds until its capital adequacy ratio becomes binding: $(1 - h \cdot |\delta| \, g)\gamma_S + \alpha_I \gamma_I = \frac{E}{A\rho}$. *Rearranging gives* $\alpha_I^* = (\frac{E}{A\rho} - (1 - h \cdot |\delta| \, g)\gamma_S)\frac{1}{\gamma_I}$. *The rest is held in liquid bonds:* $\alpha_L^* = h \cdot |\delta| \, g - (\frac{E}{A\rho} - (1 - h \cdot |\delta| \, g)\gamma_S)\frac{1}{\gamma_I}$.

From (6) we can derive the following result:

Result 1 *Larger guarantee amounts will increase holdings of the illiquid bond* $(\frac{\partial \alpha_I^*}{\partial g} > 0)$.

The intuition is the following. A higher amount of guarantees means that, because of delta hedging, an insurer will necessarily have lower stock market exposure (α_S is lower) and will hold more bonds ($\alpha_I + \alpha_L$ is higher). The insurer's regulatory risk thus declines, and it has room to pursue returns. As it cannot scale down on its overall bond holdings (because of the hedging constraint), it has to take the risk *within* the bond portfolio, that is, invest more in higher yielding illiquid bonds.

In the next section, we will calculate effective guarantee exposures $|\delta| \, g$ using U.S. life insurers' balance sheet data. We then use two of the model's implications on equilibrium portfolio holdings, (5) and (6), to estimate the hedging ratio, h, and the relative risk-weight of stocks, $\frac{\gamma_S}{\gamma_I}$, from insurers' actual holdings of stocks and illiquid bonds. The next result highlights the relationship between portfolio holdings and effective guarantees:

Result 2 *The sensitivities of stock and illiquid bond holdings to effective guarantees are given by*

$$\frac{\partial \alpha_S^*}{\partial |\delta| \, g} = -h \text{ and } \frac{\partial \alpha_I^*}{\partial |\delta| \, g} = h \frac{\gamma_S}{\gamma_I}. \tag{8}$$

The sensitivity of an insurer's stock market position to guarantee activity is simply the (negative of the) hedging ratio $-h$ because the associated hedging requires one-to-one short-selling in the stock market. The sensitivity of an insurer's holdings of illiquid bonds to guarantee activity is given by $h\frac{\gamma_S}{\gamma_I}$. This is because each unit of stocks sold relaxes the capital constraint by $\frac{\gamma_S}{\gamma_I}$ (since $\gamma_S > \gamma_I$, the effect is always larger than one). Since the insurer sells h units in total, it can increase its holdings of illiquid bonds by $h\frac{\gamma_S}{\gamma_I}$.[15]

---

[15]Our model implies that the insurer offsets reduced risk-taking in the equity market with higher risk in the bond universe. However, it should be noted that hedging still provides diversification benefits as it reduces overall exposure

18

4   Data and Model Calibration

To calibrate the model, we use the National Association of Insurance Commissioners (NAIC) data, obtained through SNL Financial, on guaranteed VAs' account values, gross reserves, and reinsurance credits (from the General Interrogatories), portfolio holdings (from Schedules A, B, BA, and D), and derivatives positions (from Schedule DB). The data frequency is annual and the unit of observation is firm-year, where each firm refers to an independent life insurer or all life insurers in the same group (e.g., AIG). The sample period is from 2004 to 2013, although we have the data on guaranteed VAs spanning 2003-2015.

Figure 3 plots the aggregated VAs' account value, summed across all insurers, and its associated gross reserve over time. The account value significantly increased from about $840 billion in 2003 to almost $1.5 trillion in 2007, due in part to the rise in the stock market. Over the same period, the associated gross reserve (part of insurers' liabilities) remained relatively low, potentially because the guarantees were deep out-of-the-money. In 2008, as the stock market collapsed, the account value dipped and the gross reserve spiked from about $10 billion to almost $60 billion. Since then, account values recovered and eventually surpassed the previous peak in 2007. Despite the recovery, the gross reserves remained relatively high and volatile, reaching a new high at over $70 billion during the 2011-12 European financial crisis.

Only a handful of life insurers underwrite guaranteed VAs, and even a smaller number do so in a significant amount. These insurers tend to be very large and sophisticated, compared to an average life insurer. To create a relevant sample, we therefore start with the sample of insurers that underwrite guaranteed VAs and add to it other insurers with average assets greater than or equal to the fifth percentile of the average assets of VA insurers. Our sample includes a total of 176 unique insurers, of which 82 underwrite guaranteed VAs at some point. To observe firm characteristics and asset allocations that are associated with VAs, we divide the insurers each year into three groups: [1] those with a greater than median VA exposure, as measured by the ratio of gross reserve to

---

to the stock market (coming through both direct holdings of stocks and the guarantee).

capital, [2] those with a lower than median VA exposure, and [3] those with no VA exposure. It is important to note that the VA exposures of insurers in groups [1] and [2] are vastly different; the average ratio of gross reserve to capital is 0.241 for the former and just 0.003 for the latter.

Table 1 presents summary statistics on several relevant firm characteristics as well as investment portfolio asset allocations across the three groups of insurers. The statistics are pooled across firm-year observations in each group. Panel A shows that insurers with high VA exposures are generally larger than others both in terms of assets (in the general account or on balance sheet) as well as capital and surplus. Their average assets and capital are $54,452 million and $4,959 million, respectively, larger than the corresponding averages for insurers with low VA exposures by $22,353 million (significant at 10%) and $1,363 million (not significant). Insurers with no VAs are the smallest. Insurers with high VA exposures also have slightly lower RBC ratios, returns on equity, and stock returns than the other two groups; the differences, however, are not statistically or economically significant.

In Panel B of Table 1, we present the portfolio asset allocations across the three groups of insurers. To simplify our analysis and map the data to the model, we divide assets into four broad groups: (i) liquid bonds (L in the model), (ii) illiquid bonds (I in the model), (iii) common stock exposures (S in the model), and (iv) other assets (not in the model). The composition of each group is listed underneath the group's heading; for example, the liquid bonds comprise cash, synthetic cash (from selling futures), bonds in NAIC classes 1 and 2, and agency asset/mortgage backed securities (ABS) in NAIC classes 1 and 2. Note that NAIC classes 1 and 2 include assets rated A- and above, and BBB- to BBB+, respectively (see Ellul, Jotikasthira, Lundblad, and Wang (2015)). Both groups of insurers that underwrite guaranteed VAs have significantly lower liquid bond allocations (about 8%) than insurers with no VAs. The differences are driven by cash and agency ABS in NAIC class 1 but are partially offset by synthetic cash from selling stock futures.

Insurers with high VA exposures have a significantly higher allocation to illiquid bonds than do both insurers with low or no VA exposures. The differences are in the same direction for all types of assets that we classify as illiquid bonds, although the magnitudes are most economically significant

among private-label ABS, mortgages, and loans. For common stock exposures, we consider both cash stocks and stock futures, and find that insurers with high VA exposures, relative to the other two groups, both have smaller allocations to cash stocks and sell disproportionately more stock futures. Together, the summary statistics for the asset allocations are generally consistent with our model's predictions. Insurers that underwrite guaranteed VAs hedge their exposures by selling common stocks and buying bonds, and tilt their portfolio towards illiquid bonds to utilize the reduction in risk-based capital and maximize their portfolio expected return. Insurers' allocations to other assets are relatively small and uninteresting.

To formally isolate the effects of VAs on insurers' asset allocations and evaluate their contribution to systemic risk, we calibrate the parameters of our model. We focus on two parameters, the delta hedge ratio (h) and the ratio of RBC requirements for common stocks and illiquid bonds (γ_S/γ_I), which together determine the tilt towards illiquid bonds. As shown in equations (5) and (8), h is the negative of the sensitivity of the common stock allocation to an insurer's guarantee-induced stock market exposure, or equivalently the delta normalized by total assets ($|\delta|\, g$). Equations (6) and (8) indicate that $h \cdot (\gamma_S/\gamma_I)$ is the sensitivity of the illiquid bond allocation to the normalized delta. We therefore calibrate our model by simply regressing asset allocations on the normalized delta.

To start, we need to uncover the normalized delta for each insurer. The insurer-level data on guaranteed VAs only tell us the account value and the gross reserve. Considering the gross reserve as a proxy for the value of the guarantee (which is admittedly imprecise), we can calculate the delta as the change in gross reserve per a one unit change in the account value, given the existing VAs. Since we cannot separate the account value and gross reserve into the components associated with the existing VAs and new business, we rely on the law of motion for the account value and gross reserve under a set of simplifying assumptions. Ignoring non-linearities, the law of motion states that

$$\frac{reserve_t}{value_t} = \frac{reserve_{t-1} + \delta_{t-1} \cdot value_{t-1} \cdot ret_{stock,t-1,t} + newreserve_t}{value_{t-1} * (1 + ret_{t-1,t}) + newvalue_t}$$

We infer $newvalue_t$ as the $value_t - value_{t-1} * (1 + ret_{t-1,t})$, using a combination of stock returns (CRSP value-weighted index including dividends) and three-month interest rates as an estimate

of $ret_{t-1,t}$. Based on the aggregate statistic from SNL Financial, we assume that 77% of account value is associated with VAs with common stocks as underlying assets are common stocks and the remaining is associated with money-market VAs.

We then calculate $newreserve_t$ by assuming that the guarantee remains at the same level as before, and therefore $newreserve_t = newvalue_t \cdot \left(\frac{reserve_t}{value_t}\right)$. Finally, we assume that the reserve on the money-market VAs remains constant, such that the change in reserve on existing VAs is driven primarily by the stock market return, $ret_{stock,t-1,t}$, implying $\delta_{t-1} \cdot value_{t-1} = [reserve_t - reserve_{t-1} - newreserve_t]/ret_{stock,t-1,t}$. Finally, the normalized delta, $\delta_{t-1} \cdot \left(\frac{value_{t-1}}{assets_{t-1}}\right)$, corresponds to $|\delta|g$ in the model.

In practice, hedging complicates our calculation of the normalized delta since some hedge coverage can be used as a credit, under the regulation, to offset the gross reserve. We divide derivatives earmarked for hedging VAs into two groups. The first group includes mostly (long) put options, which we assume are sufficiently 'effective' to be used as credit to offset the gross reserve. We refer to the use of these derivatives as direct, comprehensive hedging, which insurers report as either effective or other hedging. We assume that 70% (50%) of effective (other) hedging offsets the calculation of gross reserve so that the change in gross reserve for existing VAs is induced by the unhedged assets plus 30% of assets covered by effective comprehensive hedging plus 50% of assets covered by other comprehensive hedging. Because comprehensive hedging is sufficiently effective regardless of the regulatory treatment, our calculated delta is biased upward as a measure of the sensitivity of the guarantees to the stock market. We therefore further adjust the normalized delta above by a factor equal to the ratio of unhedged assets to the sum of unhedged assets and uncredited comprehensive hedges.

The second group of derivatives includes linear derivatives, mostly stock market futures, which we assume are part of the delta hedge program highlighted in our model. We do not allow these derivatives to offset the gross reserve and layer them directly as synthetic cash and common stocks on top of insurers' asset allocations. To hedge the guarantee, insurers sell stock market futures, resulting in positive synthetic cash and negative synthetic common stocks, as observed in Table 1.

Having obtained the inputs, we then perform our main calibration by regressing each insurer's allocation to each asset group, liquid bonds, illiquid bonds, common stocks, and others, on the normalized delta (normalized by total assets). Table 2 reports the results. We include year fixed effects and control for insurers' capitalizations by also including RBC ratio. In Panel A, we obtain the coefficient estimates by OLS with robust standard errors clustered by insurer. In Panel B, we use seemingly unrelated regressions (SUR) and impose a natural cross-equation constraint that the sum of coefficients on the normalized delta and the sum of coefficients on the RBC ratio equal zero (i.e., the sum of asset allocations is fixed at one). We calculate standard errors by boot strapping, using 500 repetitions. The results in both panels are almost the same, and the cross-equation constraints in Panel B are not rejected. Nevertheless, we will use the SUR estimates in our subsequent analysis.

Many insurers in our sample have no or very low exposures to guaranteed VAs and therefore zero or very low normalized deltas. For this reason, the sample standard deviation of normalized delta is just 0.050. The coefficient estimates show that a one standard deviation increase in normalized delta is associated with an increase in illiquid bond allocation of about 0.090 (or 9 percentage points), where 0.056 comes from liquid bonds (i.e., decrease in liquid bond allocation of 0.056) and 0.033 comes from common stock exposures. These re-allocations are both statistically and economically significant. The decrease in other assets is insignificant and negligible in magnitude.

The coefficients on the RBC ratio show insurers that have high RBC ratio tend to allocate more of their assets to liquid bonds and less to the three other asset groups. This implies that the RBC ratio may reflect insurer-specific risk aversion and/or risk bearing capacity, and each insurer may strive to maintain its RBC ratio target over time.

Table 3 reports statistics on hedge coverage and the capital requirement for illiquid bonds, calculated from the data and from the estimates in Table 2 Panel B. We focus only insurers with high exposures to guaranteed VAs, as these insurers together account for over 90% of all underwritten VAs in our sample. Moreover, our model predicts that the portfolio tilt towards illiquid bonds only occurs among insurers with exposures to guaranteed VAs above a certain level. The first two rows of Panel A report the statistics for effective and other comprehensive hedge coverage. Through the

23

lens of regulation, insurers' use of options for hedging the guarantee is not considered effective, and thus the effective comprehensive hedge coverage is zero for all firms. However, insurers do use options extensively, covering on average about 0.052 (or 5.2%) of the guarantee. The median insurer does not use options, possibly to avoid paying the option premia.

Insurers delta-hedge much of the remaining guarantee exposure. As discussed, our model interprets the negative of the coefficient on the normalized delta in the regression of common stock allocation as the delta hedge coverage, i.e., $h = 0.655$. We multiply h by the proportion of guaranteed exposure that remains after comprehensive hedging to obtain the delta hedge coverage for each insurer. The average delta hedge coverage is 0.690, with the 90% confidence interval (calculated by bootstrapping) between 0.658 and 0.721. Thus, all together, insurers that underwrite most of guaranteed VAs hedge about three quarters of their guarantee exposure.

Our model also interprets the corresponding coefficient in the regression on the allocation to illiquid bond as the product of the delta hedge ratio and the relative capital requirements for common stocks vs. illiquid bonds (in excess of the capital requirement of liquid bonds). From this interpretation, and the fact that the capital requirement for common stocks is 0.30 (assuming beta of one), our coefficient of 1.809 implies that the capital requirement for illiquid bonds equal to 0.113, with the 90% confidence interval (calculated by bootstrapping) between 0.049 and 0.177. Our back-of-the-envelope calculation from each asset type that make up the illiquid bond grouping suggests the capital requirement of about 0.060, which is slightly lower than our regression estimate but lies within the 90% confidence interval. Both the delta hedge coverage and the capital requirement for illiquid bonds implied by our estimation are reasonable and consistent with the data and anecdotes from conversations with practitioners. Below, we use our estimates to infer counter-factual portfolios.

Our model indicates that the portfolio we observe reflects the insurer's desire to both hedge a certain portion of its guarantee exposures as well as to maximize the expected return. The former leads to over-weighting bonds and under-weighting common stocks in general, while the latter tilts the bond allocation towards illiquid (and riskier) ones. The literature often refers to such

tilt as "reaching for yield." To examine the contribution of guaranteed VAs to systemic risk and to isolate the effect of reaching for yield, we create the following two counter-factual portfolios. Portfolio 1 captures the desired delta hedge coverage (same as reported above) but eliminates the reaching-for-yield tilt. We construct Portfolio 1 by keeping the sum of allocations to liquid and illiquid bonds the same as the actual portfolio, but re-allocate between them such that the ratio of liquid and illiquid bond allocations is the same as what we would observe should the insurer have no guaranteed VAs. Reaching for yield thus explains the difference between the actual portfolio and Portfolio 1, as well as their associated systemic risk.

In contrast, Portfolio 2 explores the implication of completely eliminating the guarantee exposure. We construct it by unwinding the products of coefficients from Panel B of Table 2 and the normalized delta for each insurer, i.e., setting the normalized delta to zero. The guarantee exposure and its incomplete hedging account for the difference between Portfolios 1 and 2. Together, the guarantee exposure and the reaching for yield incentives that stem from delta hedging the exposure comprise the two main sources of systemic risk coming from guaranteed VAs.

Panel B of Table 3 reports allocations of Portfolios 1 and 2, and their bootstrapped standard errors. Compared to the actual portfolio, Portfolio 1, on average, allocates 0.109 less to illiquid bonds and 0.109 more to liquid bonds. These are the effects of reaching for yield. Compared to the actual portfolio of insurers with no guaranteed VAs, Portfolio 1 allocates 0.045 less to common stocks, reshuffling that amount to liquid and illiquid bonds. Portfolio 1's allocations make sense given that it maintains the same levels of guarantee exposure and hedge coverage as the actual portfolio of insurers with high exposures to guaranteed VAs.

By construction, Portfolio 2 has significantly less illiquid bonds and significantly more liquid bonds and common stocks than the actual portfolio. Portfolio 2 looks quite similar to the actual portfolio of insurers that do not underwrite VAs, though we do not directly use these insurers' portfolios in our construction. This provides comfort that our calibration is realistic and internally consistent.

5 Fire Sales and Systemic Risk

Having calibrated our model to U.S. insurance data, we now analyze how a shock at date 1 can lead to fire sales. We expand the model introduced in Section 3 by assuming that there is a continuum of insurers, each of size A, with effective guarantee exposures of $|\delta| g$ and hedging ratios h. We first consider a shock that reduces the value of all assets proportional to their risk weights (so in this case there are no diversification benefits between stocks and bonds). The shock is expressed in terms of a ε (percentage) decline in the value of stocks. The value of illiquid bonds will thus decline by a $\frac{\gamma_I}{\gamma_S}\varepsilon$ percentage (the value of the liquid bond remains unchanged, as its risk-weight is zero). The increase in the value of the guarantee will be $|\delta| \varepsilon$, given that its stock market dependence is given by $|\delta|$.

The shock will negatively affect capital by, first, lowering asset values (the value of stocks and illiquid bonds) and, second, by increasing the guarantee liability. Insurers will thus be in violation of their required capital adequacy ratios. We assume that insurers restore their capital by deleveraging.[16] As in Greenwood et. al (2015), we assume that insurers do this by selling assets proportionally to pay down debt. Illiquid bonds potentially suffer from fire-sale discounts, as outlined in Section 3. Specifically, we assume that when an amount, S, of illiquid bonds in the economy is sold, the bonds are traded at a discount of $c_0 S$ ($c_0 > 0$) to their date-0 value. The asset discount will lead to an additional deterioration in insurers' capital positions, which in turn will require even more liquidations (and so on...). Note that the asset discount leads to a fire-sale externality (e.g., Stein 2012): selling by some insurers will depress prices and hence worsen the capital positions of all insurers in the economy, thus forcing additional liquidations throughout the system.

We first derive the change in the capital position of an insurer between date 0 and 1. The latter is given by:

$$\triangle E = -(\alpha_S + \frac{\gamma_I}{\gamma_S}\alpha_I)\varepsilon A - |\delta| g\varepsilon A - \alpha_I A \cdot c_0 S, \tag{9}$$

---

[16]Equivalently, one can also assume that insurers hold the size of their balance sheet constant and sell risk assets (stocks and illiquid bonds) in return for liquid bonds ("flight to quality").

where the portfolio allocations α_S and α_I are given by equation (5) and (6).[17] The first term, $-(\alpha_S + \frac{\gamma_I}{\gamma_S}\alpha_I)\varepsilon A$, is the direct effect on the portfolio associated with the negative shock. The second effect, $-|\delta| g\varepsilon A$, is the effect associated with the moneyness of the guarantee. The third effect, $-\alpha_I A \cdot c_0 S$, reflects the losses due to fire-sales (these losses are permanent for the illiquid bonds that are sold but temporary for the ones remaining on balance sheet).[18] Dividing by E, we obtain the relative change in capital

$$\%E = (-(\alpha_S + \frac{\gamma_I}{\gamma_S}\alpha_I)\varepsilon - |\delta| g\varepsilon - \alpha_I \cdot c_0 S)\frac{A}{E}, \tag{10}$$

showing the amplification emanating from the equity multiplier, $\frac{A}{E}$.

The evolution of assets is identical to the evolution of capital, except that assets are also reduced by asset sales s, expressed as a proportion of the balance sheet:

$$\triangle A = -(\alpha_S + \frac{\gamma_I}{\gamma_S}\alpha_I)\varepsilon A - |\delta| g\varepsilon A - \alpha_I A \cdot c_0 S - sA. \tag{11}$$

In relative terms, this becomes

$$\%A = -(\alpha_S + \frac{\gamma_I}{\gamma_S}\alpha_I)\varepsilon - |\delta| g\varepsilon - \alpha_I \cdot c_0 S - s. \tag{12}$$

As a final condition, we have that, after asset sales, the insurer is again in fulfillment of its capital requirements:

$$\frac{E + \triangle E}{(\alpha_S\gamma_S + \alpha_I\gamma_I)(A + \triangle A)} = \rho \tag{13}$$

From equation (13) follows that the equity multiplier, A/E, does not change between date 0 and date 1 (effectively, because the proportion of assets does not change, the capital requirement becomes a

---

[17]Note that hedging enters equation (9) indirectly by lowering the stocky market exposure α_S.

[18]We assume that assets on the balance-sheet are marked-to-market, that is, the asset discount on illiquid bond also reduces date-1 capital through the illiquid bonds that are not sold. The regulatory accounting treatment of assets during crisis is nuanced in practice (see Ellul, Jotikasthira, Lundblad, and Wang (2014)); if assets on balance sheet are not marked-to-market, fire-sale spirals will be less pronounced.

leverage constraint). It follows that capital and asset growth mirror each other:

$$\%E = \%A. \tag{14}$$

Using this to combine the equations that determine $\%E$ and $\%A$ (equations (10) and (12)), we can solve for an insurer's asset sales:

$$s = ((\alpha_S + \frac{\gamma_I}{\gamma_S}\alpha_I)\varepsilon + |\delta|\, g\varepsilon + \alpha_I \cdot c_0 S)\frac{A - E}{E}. \tag{15}$$

This expression illustrates the three channels through which capital, and hence asset sales, are affected. The first term, $(\alpha_S + \frac{\gamma_I}{\gamma_S}\alpha_I)\varepsilon\frac{A-E}{E}$, is the direct effect of asset values, depending on the size of the shock and leverage. The second term, $|\delta|\, g\varepsilon\frac{A-E}{E}$, is the effect coming through the guarantee. Besides the size of the shock and leverage, its magnitude depends also on the effective guarantee exposure, $|\delta|\, g$. The effect of fire-sales on deleveraging is represented by the last term. Aggregate liquidations of the illiquid bond reduce capital by $\alpha_I c_0 S\frac{A-E}{E}$, thus causing more asset sales at a specific insurer than in the absence of fire-sales. The equation also clearly highlights the fire-sale externality: liquidations by some institutions ($S \uparrow$) will increase that at others ($s \uparrow$).

We now solve for the general equilibrium level of asset fire sales. We have that in equilibrium total sales are given by $S = s\alpha_I A$. Inserting into equation (15) and solving for S gives:

$$S = \frac{((\alpha_S + \frac{\gamma_I}{\gamma_S}\alpha_I)\varepsilon + |\delta|\, g\varepsilon)\frac{A-E}{E}}{\frac{1}{\alpha_I A} - \alpha_I \cdot c_0\frac{A-E}{E}}, \tag{16}$$

Result 3 *Fire sales in the illiquid bond are increasing in the effective guarantee exposure $|\delta|\, g$.*

Note that guarantees affect fire-sales in two ways. First, higher guarantee exposure means that shocks to stocks have a larger impact on capital, and hence following a negative shock, a greater quantity of assets need to be sold to restore the capital position. Second, more guarantees mean that insurers hold a larger proportion of their portfolio in illiquid bonds (because of hedging, α_I is higher, as shown in Section 3). Thus, a given amount of liquidations leads to more illiquid bonds

being sold, further increasing system-wide fire-sales.

From equation (16), we can derive an expression for the total fire-sale cost. This is a measure of *systemic risk* in our economy. Using that total costs are given by $C = S \cdot c_0 S$, we obtain:

$$C = c_0 \left(\frac{((\alpha_S + \frac{\gamma_I}{\gamma_S}\alpha_I)\varepsilon + |\delta| \, g\varepsilon)\frac{A-E}{E}}{\frac{1}{\alpha_I A} - \alpha_I \cdot c_0 \frac{A-E}{E}} \right)^2. \tag{17}$$

It can be seen that higher guarantee exposures lead to larger systemic risk.[19]

Shock to illiquid bonds Instead of the categorical asset shock, we can alternatively consider a shock that reduces the value of illiquid bonds by ε_I percent, but leaves all other assets in the economy unchanged (including the value of the guarantee). The evolution of capital and assets is now given by

$$\triangle E = -\alpha_I \varepsilon_I A - \alpha_I A \cdot c_0 S, \tag{18}$$

$$\triangle A = -\alpha_I \varepsilon_I A - \alpha_I A \cdot c_0 S - sA. \tag{19}$$

Similar to the case of the categorical shock, individual selling s and total fire-sales S can be derived as follows:

$$s = (\alpha_I \varepsilon_I + \alpha_I c_0 S)\frac{A-E}{E}, \tag{20}$$

$$S = \frac{\alpha_I \varepsilon_I \frac{A-E}{E}}{\frac{1}{\alpha_I A} - \alpha_I \cdot c_0 \frac{A-E}{E}}. \tag{21}$$

Shock to the guarantee Next, imagine an alternative scenario where the shock directly increases the value of the guarantee by ε_G percent. This may for example be the result of an increase in the

---

[19]Systemic risk may lead to welfare losses as it can cause instability in the financial system, for example, due to a failure of insurers (potentially spreading to other financial institutions). In the absence of any instability issues, fire-sales are a pure zero-sum event, benefitting the buyers of illiquid bonds (e..g, focused distressed hedge funds) at the cost of the sellers.

volatility in the stock market. The resulting equations for changes in capital and asset are

$$\triangle E = -g\varepsilon_G A - \alpha_I A \cdot c_0 S, \tag{22}$$

$$\triangle A = -g\varepsilon_G A - \alpha_I A \cdot c_0 S - sA. \tag{23}$$

Note that there is no longer the δ, as we consider a shock to the value of the guarantee directly (and not to the underlying stock market, as in the case of the categorical shock). The expressions for s and S become

$$s = (g\varepsilon_I + \alpha_I c_0 S)\frac{A-E}{E}, \tag{24}$$

$$S = \frac{g\varepsilon_I \frac{A-E}{E}}{\frac{1}{\alpha_I A} - \alpha_I \cdot c_0 \frac{A-E}{E}}. \tag{25}$$

Shock to stock market   Finally, we consider a shock that hits the equity market (and thus also the guarantee) but not the illiquid bond. This shock is similar to the categorical shock considered first, but shuts down the impact through the illiquid bond. For a shock to stocks ε_S the equations for equity and assets are

$$\triangle E = -\alpha_S \varepsilon_S A - |\delta| \, g\varepsilon_S A - \alpha_I A \cdot c_0 S, \tag{26}$$

$$\triangle A = -\alpha_S \varepsilon_S A - |\delta| \, g\varepsilon_S A - \alpha_I A \cdot c_0 S - sA. \tag{27}$$

We can derive the two types of selling to be

$$s = (\alpha_S \varepsilon_S + |\delta| \, g\varepsilon_S + \alpha_I c_0 S)\frac{A-E}{E}, \tag{28}$$

$$S = \frac{(\alpha_S \varepsilon_S + |\delta| \, g\varepsilon_S)\frac{A-E}{E}}{\frac{1}{\alpha_I A} - \alpha_I \cdot c_0 \frac{A-E}{E}}. \tag{29}$$

The latter equations directly show the benefit from hedging in our model: hedging reduces the equity market exposure (α_S declines) and hence leads to less fire-sales.

In the final step, we perform a simulation exercise to quantify the amount and costs of asset

fire sales when insurers are hit by a market shock. We focus on insurers with high exposures to guaranteed VAs, and parametrize equations (16), (17), (21), and (25) as follows. We use the price impact (c_0) of 18.6 basis points per \$10 billion of sale, which is the Net Stable Funding Ratio (NSFR) estimate for non-agency MBS by Duarte and Eisenbach (2015). Under the NSFR framework, assets are assumed to be slowly liquidated over one year. Therefore, our estimates of fire-sale amounts and costs may be on the conservative side, as insurers are more likely to take less than a year to adjust their portfolios and maintain their target RBC ratios.[20] We set the capital requirement for common stocks (α_S) at 0.3 and the total invested assets, capital and surplus, RBC ratio, and normalized delta of the guarantee at their averages during the period from 2010 to 2013 (after the crisis).

Clearly, sufficiently large shocks can induce fire sales by insurers, even if the insurers have no exposures to guaranteed VAs. To distinguish between the fire sales that would have occurred anyway and those that are induced by guaranteed VAs, we use the counter-factual portfolios in Panel B of Table 3 along with the actual portfolios from Table 1. As discussed, Portfolio 2 is the portfolio that would have prevailed had the insurers not underwritten VAs, and thus the differences in fire-sale amount and costs between the actual portfolio and Portfolio 2 are attributable to VAs. Portfolio 1 lies between the actual portfolio and Portfolio 2, allowing us to decompose the total fire-sale effects into those that are induced by the mere exposure to guarantees (Portfolio 1 - Portfolio 2) and those that are induced by reaching for yield behavior (actual portfolio - Portfolio 1). We consider three types of shocks following our theoretical discussion above: a categorical shock to all assets, a shock only to the illiquid bonds, and a shock to the guarantee. In each analysis, we assume that the price impacts are negligible for liquid bonds and common stocks, and focus on the fire sales of illiquid bonds.

Table 4 reports the results for negative categorical shocks, ranging in magnitude from 10% to 40%. Hit by a categorical shock, asset prices drop across the board, and the drops are proportional to their expected returns. For example, a shock of -10% would decrease the common stock price

---

[20]Greenwood et al. (2015) use the price impact of 10 basis points per \$10 billion of sale for all assets.

by 10% and the illiquid bond price by 3.8% (0.113/0.100*10%). Panel A considers the fire-sale externality, in which the amount of selling fully anticipates the aggregate price impact due to selling by other insurers. The results show that the categorical shocks of 10-40% would result in actual insurers selling $134-$537 billion of illiquid bonds, of which the majority ($120-$482 billion) is an amount attributable to the VAs (through the lens of our model). The corresponding fire-sale costs (value losses) are $3-$54 billion, representing 2-30% of insurers' total capital and surplus. Almost all of the fire sale costs are due to the VAs.

Further, our decomposition shows that the fire sales are largely associated with *ex ante* reaching for yield. Without the tilt towards illiquid assets in the first place, the fire-sale amount would be 84% smaller, and the fire-sale costs would have been 95% smaller. These results imply that the exposure to VAs alone, sufficiently hedged, is not the main culprit behind the generation of systemic risk; in contrast, the associated reaching for yield behavior is. Insurers, delta hedging their guarantee exposures, tilt towards illiquid bonds to take advantage of the reduction in RBC from under-weighting common stocks, and in the process, make themselves vulnerable to fire sales and illiquidity costs.

Panel B of Table 4 does not consider the fire-sale externality, shutting down the c_0 term in equation (15). The results show that for a given magnitude of shock, the amount of fire sales decreases by almost half, compared to the counterpart in Panel A. Further, the costs fall by over 70%, suggesting that it is not the fire sales, per se, but rather the fire-sale externality that is the most important driver behind the systemic risk among financial institutions.

In Table 5, we examine the separate effects of negative shocks to illiquid bonds (Panel A) and positive shocks to the value of the guarantee (Panel B). The results show that the shocks to illiquid bonds of 10-40% would result in actual insurers selling $81-$323 billion of illiquid bonds, of which $55-$220 billion are attributable to the VAs. Since the shock to illiquid bonds does not affect value of the guarantee, the fraction of effects attributed to the VAs is smaller than in the case of categorical shocks. The fire-sale costs are $1-$19 billion, representing 1-10% of insurers' total capital and surplus. About 90% of the fire-sale costs are due to the VAs, and virtually all of the effects are again

32

a result of reaching for yield.

Finally, the positive shocks to the value of guarantee of 10-40% would induce actual insurers to sell $64-$254 billion of illiquid assets. These effects are exclusively due to the VAs, by construction. The costs associated with these fire sales are $1-$12 billion, of which about 90% are attributed to reaching for yield. It is important to note that we hold the magnitudes of the shocks constant across the scenarios in Tables 4 and 5. However, for categorical shocks, these magnitudes are stressful and comparable to what we observe during the financial crisis while for shocks to value of the guarantee, these magnitudes are in the normal range. For example, the gross reserve jumped four-fold from 2007 to 2008. Therefore, our results pertaining to the shocks to value of the guarantee should be thought of as being on the small side from the perspective of systemic risk.

6   Conclusion

We explore how systemic risk may arise from the inter-connectedness of the asset side of financial institutions' balance sheets. Specifically, we propose an innovative mechanism, namely, an incentive that arises from the financial institutions' business model rather than regulation per se, that can induce correlated investments across financial institutions. While capital regulation is an essential part of our analysis, asset similarity across insurers instead arises from insurers' business decisions to provide (and hedge) investment products. This endogenous *ex ante* herding can then generate *ex post* fire sale externalities that will propagate systemic risk. To study this, we employ the U.S. life insurance sector as a laboratory and focus on the recent transformation of the largest life insurers from institutions offering traditional insurance products to ones that offer investments products in the form of variable annuities.

To investigate how variable annuity guarantees induce correlated investments by insurance companies operating in this space, we present a theoretical model that captures the underlying economics and then calibrate the model by using insurer-level data. We propose a theoretical model that shows that, as a result of the fact that hedging the risks associated with these variable annuities

lowers expected profitability, individual insurers have an incentive to aggressively reach for yield in the limited riskier asset space. We calibrate the model using insurance-level data and confirm that insurers operating in the VA space allocate their portfolios to riskier, illiquid bonds. Herding in illiquid assets emerges in equilibrium, increasing the likelihood of fire sales in the event of common shocks and in turn imposing externalities among insurers.

Our paper shows that the transformation of the life insurance industry has made these institutions less likely to behave as asset insulators, able to absorb temporary market dislocations. More importantly, by virtue of the asset inter-connectedness, they are now *more* likely to contribute to systemic risk through correlated regulatory-induced fire-sales. This has far reaching implications for the stability of the financial system.

Finally, it is worth reminding that the importance of the particular guarantees embedded in the VA market are not necessarily unique. The correlated risk-taking that these types of guarantees incentivized may not be restricted to the insurance sector. Dangerously underfunded private and U.S. state pension funds may too be induced to reach for yield. As various forms of guarantees pervade the global finance system, made perhaps only more problematic in the ultra-low interest rate environment after the finance crisis, regulators should perhaps be wary of the implications of asset side vulnerability to the broader financial sector associated with the mechanism that we identify.

7 References

Acharya V., L.H. Pedersen, T. Philippon, and M. Richardson, 2017, Measuring systemic risk, *Review of Financial Studies* 30, 2-47.

Acharya V., and T. Yorulmazer, 2007, Too many to fail: An analysis of time-inconsistency in bank closure policies, *Journal of Financial Intermediation* 16 (1), 1-31.

Acharya, V., and T. Yorulmazer, 2008, Information contagion and bank herding, *Journal of Money, Credit and Banking* 40 (1), 215-231.

Allen, F. A. Babus, and E. Carletti, 2012, Asset commonality, debt maturity and systemic risk, *Journal of Financial Economics* 104, 519-534.

Becker, B., and V. Ivashina, 2015, Reaching for Yield in the Corporate Bond Market, *Journal of Finance* 70, 1863-1902.

Billio, M., M. Getmansky, A.W. Lo, and L. Pelizzon, 2012, Econometric measures of connectedness and systemic risk in the finance and insurance sectors, *Journal of Financial Economics* 104 (3), 535-559.

Brownlees, C., and R. Engle, 2016, SRISK: A conditional capital shortfall index for systemic risk assessment, *Review of Financial Studies*, forthcoming.

Chodorow-Reich, G., A. Ghent, and V. Haddad, 2016, Asset insulators, Working Paper.

Drexler A.H., T. Plestis, and R.J. Rosen, 2017, How much risk do variable annuity guarantees pose to life insurers?, *Chicago Fed Letter*, No. 384.

Duarte, F., and T.M. Eisenbach, 2015, Fire-sale spillovers and systemic risk, Working Paper, FRB of New York.

Ellul, A. C. Jotikasthira, and C. T. Lundblad, 2011, Regulatory pressure and fire sales in the corporate bond market, *Journal of Financial Economics* 101, 596-620.

Ellul, A., C. Jotikasthira, C. Lundblad, and Y. Wang, 2014, Mark-to-Market Accounting and Systemic Risk in the Financial Sector, *Economic Policy* 29, 299-341.

Ellul, A., C. Jotikasthira, C. Lundblad, and Y. Wang, 2015, Is historical cost accounting a panacea?

Market stress, incentive distortions, and gains trading, *Journal of Finance* 70, 2489-2538.

Getmansky, M., G. Girardi, K.W. Hanley, S. Nikolova, and L. Pelizzon, 2016, Portfolio similarity and asset liquidation in the insurance sector, Working Paper.

Greenwood, R., A. Landier, and D. Thesmar, 2015, Vulnerable banks, *Journal of Financial Economics* 115, 471-485.

Haldane, A. and R.M. May, 2011, Systemic risk in banking ecosystems, *Nature* 469, 351-355.

Koijen R.S.J., and M. Yogo, 2017a, The fragility of market risk insurance, Working Paper.

Koijen R.S.J., and M. Yogo, 2017b, Risk of life insurers: Recent trends and transmission mechanisms, Working Paper.

Stein, J., 2012, Monetary Policy as Financial-Stability Regulation, *Quarterly Journal of Economics* 127, 57-95

Wagner, W., 2010, Diversification at financial Institutions and Systemic Crises, *Journal of Financial Intermediation* 19, 373-386.

Wagner, W., 2011, Systemic Liquidation Risk and the Diversity–Diversification Trade-Off, *Journal of Finance* 66(4), 1141-1175.
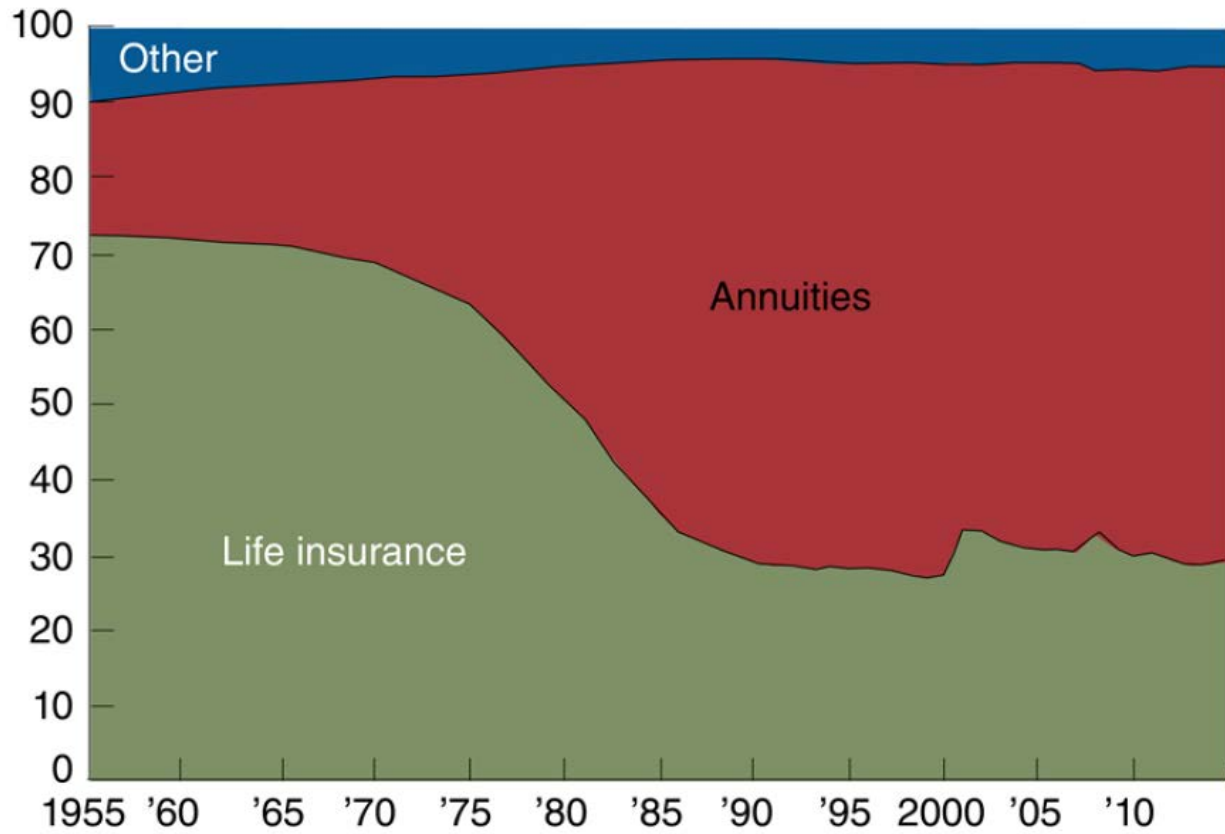
Figure 1: Life insurance product shares over the period 1955-2014

Source: American Council of Life Insurers, 2015 Life Insurers Fact Book, and Alejandro H. Drexler , Zain Mohey-Deen, Richard J. Rosen.
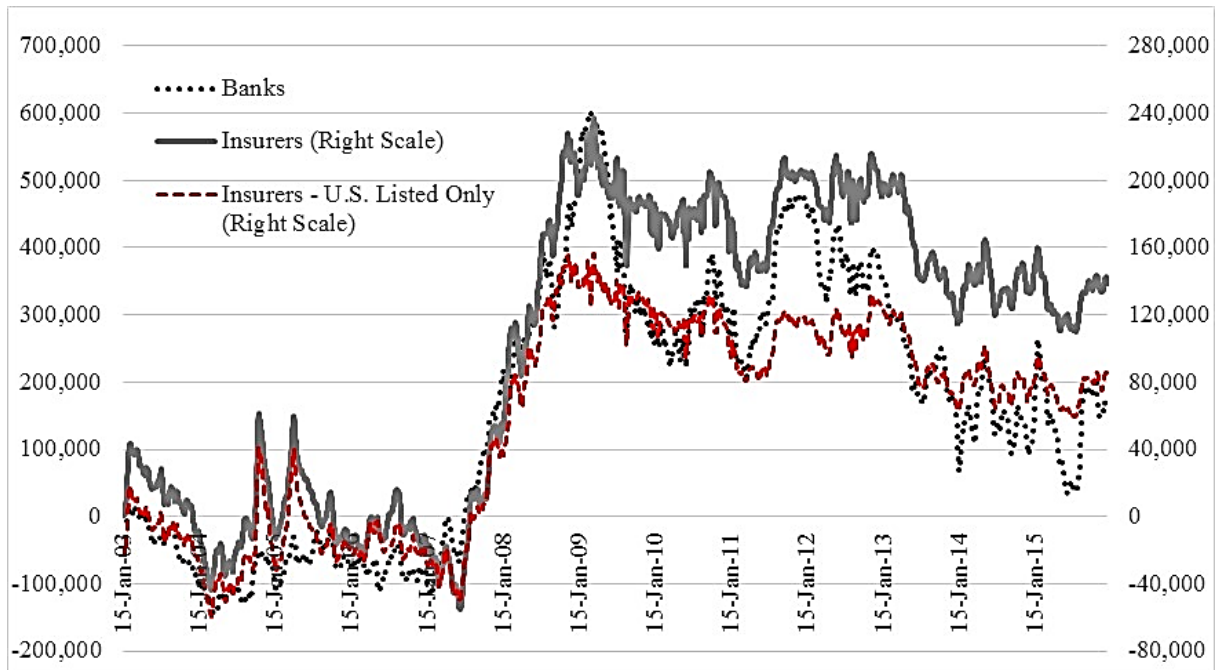
Figure 2: SRISK of Largest Banks and Insurers over Time. This figure plots the time series of (sum of) SRISK ($ million) for (i) ten largest publicly traded banks in the U.S. (dotted line), (ii) ten publicly traded insurers with the largest outstanding guaranteed variable annuities in the U.S. (solid line), and (iii) a subset of insurers in (ii) whose stocks are publicly traded in the U.S. (dashed line). The SRISK data are from NYU Stern Volatility Lab (vlab.stern.nyu.edu/welcome/risk) from January 1, 2003 until end of December 2015.
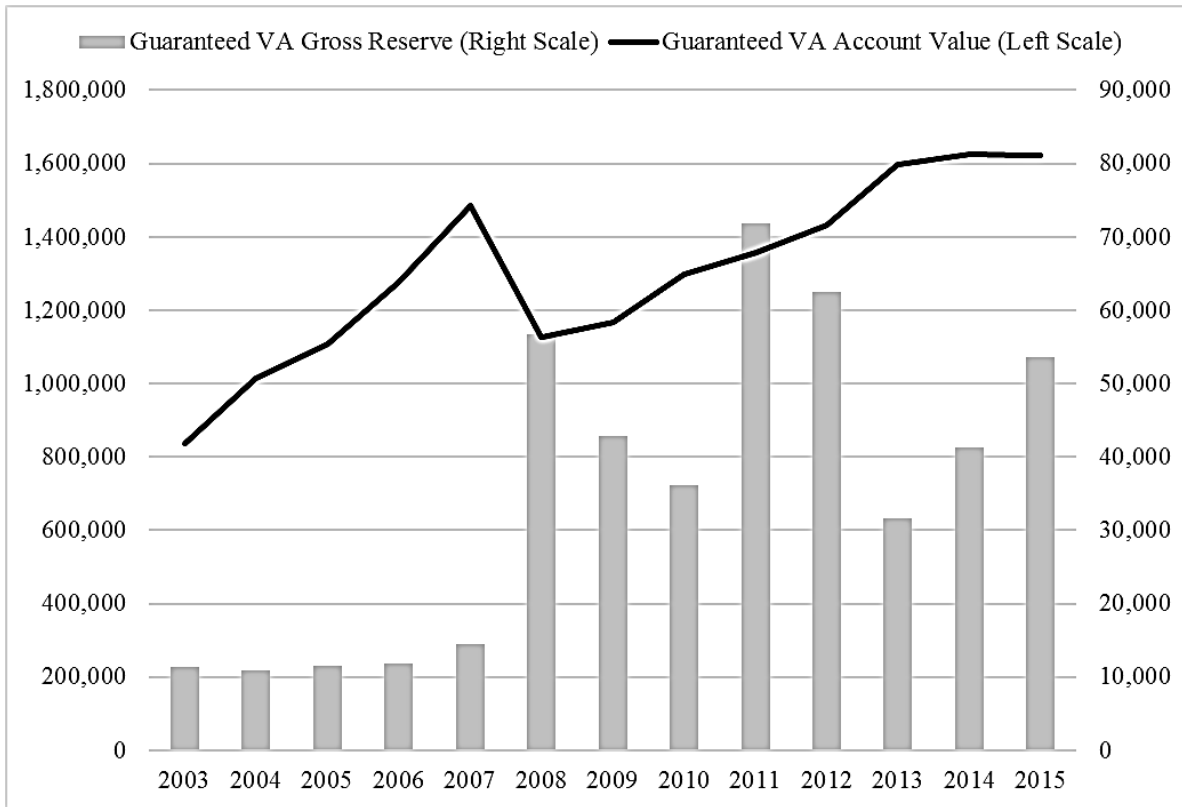
Figure 3: Guaranteed Variable Annuities (VA) Account Value and Gross Reserve over Time. This figure plots the time series of account value (line) and gross reserve (bar) ($ million) for guaranteed VA, as reported annually by life insurers to the NAIC in the general interrogatories form. The sample period is from 2003 to 2015. The account value and gross reserve are summed over individual life insurers with outstanding guaranteed VA.

Panel A: Ratio of Gross Reserve to Capital
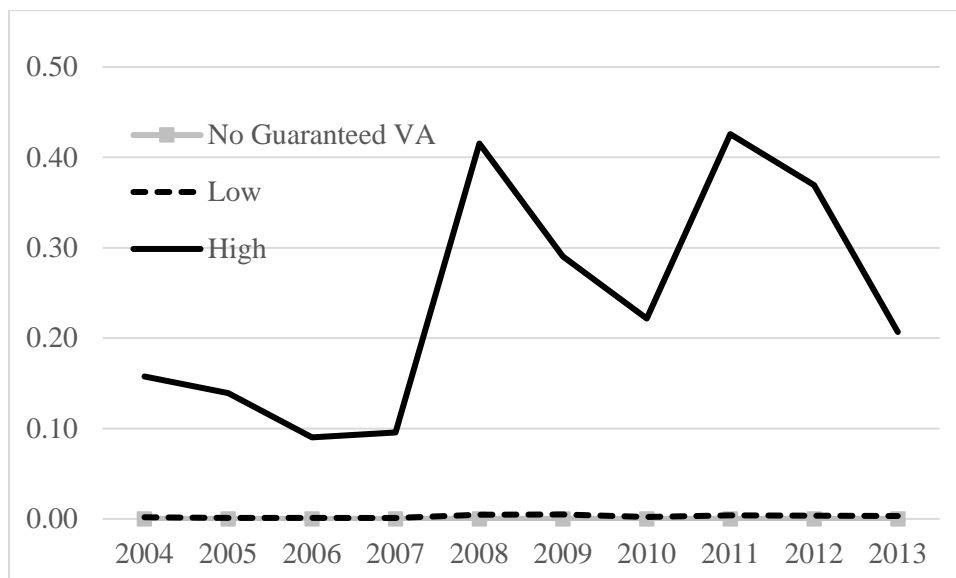
Figure 4: Exposure to Guaranteed Variable Annuities (VA) and Firm Performance. This figure plots the time series of ratio of gross reserve to capital (Panel A), stock return (Panel B), and return on equity (Panel C) for the period from 2004 to 2013. Each year, life insurers with guaranteed VA are divided into two groups by the ratio of gross reserve to capital. The "high" ("low") group includes life insurers with ratio of gross reserve to capital higher than (less than or equal to) the median. For each variable, the annual averages across life insurers in each group are plotted— the solid line representing the high group and the dashed line representing the low group. For comparison, the annual averages for life insurers without guaranteed VA are also plotted (solid line with square markers). Only life insurers that have averaged total assets greater than the fifth percentile of the sample of life insurers with guaranteed VA are included.

Panel B: Stock Return
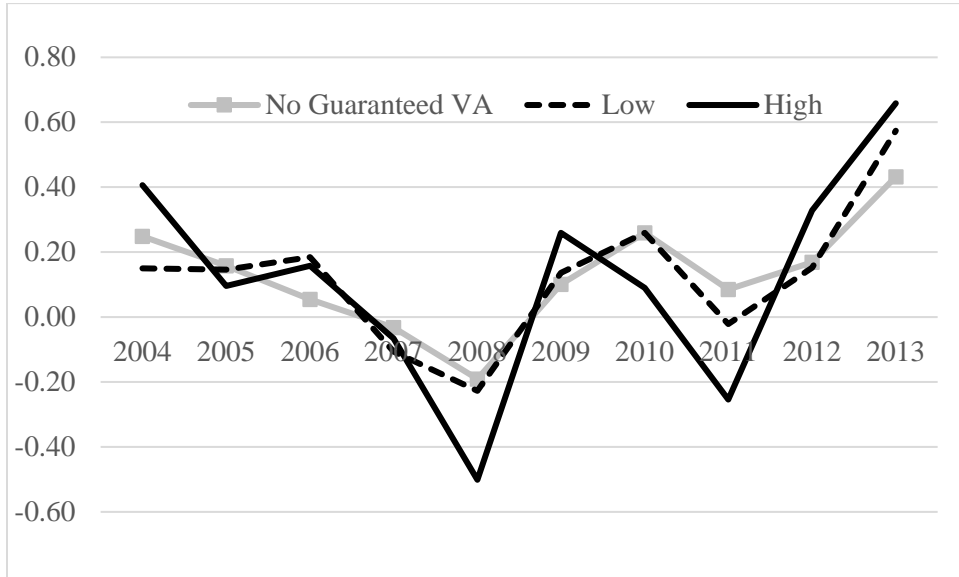
Panel C: Return on Equity

Figure 4, cont'd: Exposure to Guaranteed Variable Annuities (VA) and Firm Performance.

Table 1: Summary Statistics of Life Insurers' Characteristics and Asset Allocations

This table presents summary statistics of general firm characteristics (Panel A) and asset allocations (Panel B). The data are from the NAIC, obtained through SNL Financial. The sample period is from 2004 to 2013, 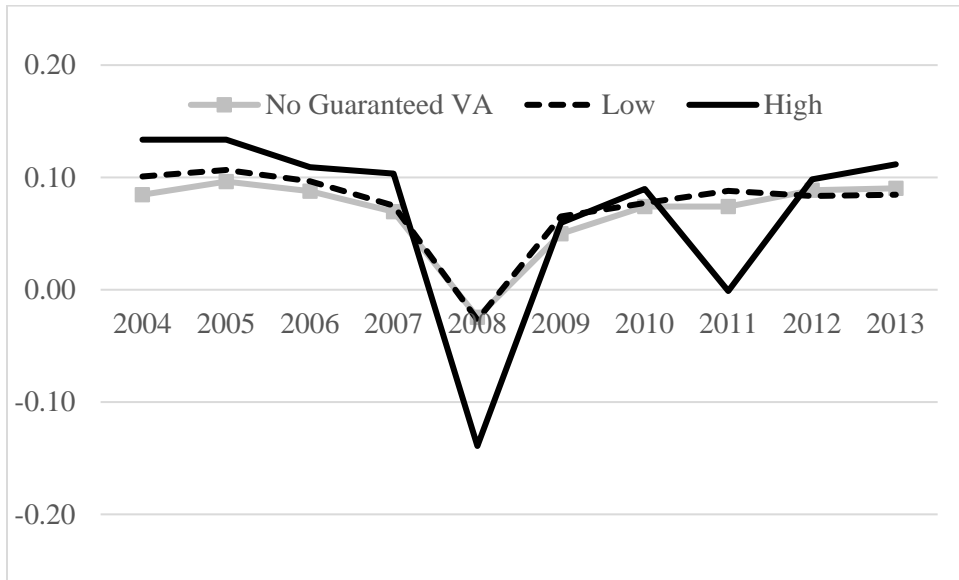and the observation frequencies are firm-year. The sample includes only (group-level) insurers whose average assets in the general account are greater than or equal to the fifth percentile of average assets of insurers that underwrite guaranteed variable annuities (VA). A total of 176 unique insurers are included, of which 82 have guaranteed VA at some point during the sample period. Each year, insurers are divided into three groups by the ratio of guaranteed VA gross reserve to capital. Insurers in groups 1 (2) have the ratios of guaranteed VA gross reserve to capital that are at or higher (lower) than the median. Insurers in group 3 have no guaranteed VA, and are used as a benchmark. For each insurer, assets include all invested assets reported at statutory accounting values, and capital and surplus are assets minus liabilities. Risk-based capital ratio (RBC ratio) is the (adjusted) statutory capital divided by the required risk-based capital. Return on equity is net income divided by common equity, as reported under GAAP. Stock return includes both percentage price change and dividend, and is available only for public insurer groups. Assets are divided into NAIC-defined categories, which are then grouped into liquid bonds, illiquid bonds, common stocks, and others. Asset allocation is the value of assets in each category or broad group divided the value of all invested assets. Tests of difference in mean are conducted using pooled panel regressions with standard errors clustered by calendar year-month. $*$, $**$, and $***$ refer to statistical significance at 10%, 5%, and 1% levels.

	[1] High			[2] Low			[3] No Guarantee			[1] - [2]	[1] - [3]
	Mean	Std. Dev.	Median	Mean	Std. Dev.	Median	Mean	Std. Dev.	Median	Mean	Mean
Panel A: Firm Characteristics											
Assets ($ Million)	54,452	66,070	32,894	32,099	50,509	11,027	5,404	11,198	1,702	22,353*	49,047***
Capital and surplus ($ Million)	4,959	5,827	3,048	3,596	5,721	1,225	712	1,208	244	1,363	4,247***
RBC ratio	9.395	4.945	8.760	10.335	4.605	9.142	10.944	11.248	8.691	-0.940	-1.549
Return on equity	0.065	0.167	0.087	0.074	0.082	0.078	0.069	0.171	0.070	-0.008	-0.003
Stock return	0.116	0.372	0.125	0.127	0.283	0.109	0.120	0.304	0.114	-0.011	-0.003

Continued next page

	[1] High			[2] Low			[3] No Guarantee			[1] - [2]	[1] - [3]
	Mean	Std. Dev.	Median	Mean	Std. Dev.	Median	Mean	Std. Dev.	Median	Mean	Mean
Panel B: Asset Allocation											
Liquid bonds	0.653	0.115	0.634	0.657	0.135	0.655	0.737	0.138	0.753	-0.004	-0.084***
Cash	0.035	0.036	0.025	0.024	0.025	0.018	0.050	0.081	0.028	0.010***	-0.015**
Synthetic cash	0.032	0.048	0.003	0.006	0.027	0.000	0.000	0.000	0.000	0.025***	0.032***
Bonds in NAIC 1	0.297	0.127	0.274	0.282	0.204	0.279	0.350	0.261	0.378	0.015	-0.053*
Bonds in NAIC 2	0.208	0.064	0.212	0.228	0.111	0.207	0.205	0.139	0.193	-0.020	0.003
Agency ABS in NAIC 1	0.081	0.066	0.066	0.116	0.086	0.106	0.131	0.129	0.104	-0.035**	-0.050***
Agency ABS in NAIC 2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Illiquid bonds	0.326	0.113	0.347	0.288	0.120	0.289	0.195	0.126	0.178	0.038*	0.131***
Long-term assets	0.024	0.021	0.020	0.021	0.022	0.012	0.012	0.018	0.004	0.003	0.013***
Bonds in NAIC 3-6	0.034	0.018	0.032	0.032	0.020	0.032	0.028	0.032	0.019	0.002	0.006
Agency ABS in NAIC 3-6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Private ABS in NAIC 1	0.108	0.060	0.106	0.104	0.083	0.096	0.078	0.090	0.045	0.004	0.031***
Private ABS in NAIC 2	0.011	0.011	0.009	0.008	0.012	0.004	0.007	0.012	0.002	0.002	0.004***
Private ABS in NAIC 3-6	0.008	0.008	0.006	0.005	0.006	0.003	0.004	0.008	0.001	0.003***	0.004***
Mortgages	0.087	0.062	0.097	0.077	0.059	0.087	0.041	0.065	0.005	0.010	0.046***
Loans	0.045	0.047	0.030	0.036	0.031	0.024	0.025	0.031	0.014	0.009	0.021**
Derivatives for income gen.	0.008	0.013	0.003	0.005	0.010	0.000	0.001	0.003	0.000	0.004*	0.008***
Common stock exposures	0.000	0.051	0.010	0.041	0.058	0.026	0.046	0.063	0.021	-0.040***	-0.045***
Common stocks	0.032	0.033	0.022	0.047	0.051	0.027	0.046	0.063	0.021	-0.015*	-0.013*
Synthetic common stocks	-0.032	0.048	-0.003	-0.006	0.027	0.000	0.000	0.000	0.000	-0.025***	-0.032***
Other assets	0.017	0.019	0.010	0.013	0.016	0.010	0.021	0.027	0.012	0.003	-0.004
Preferred stocks	0.008	0.014	0.003	0.008	0.015	0.003	0.013	0.024	0.003	0.000	-0.005**
Real estates	0.006	0.013	0.002	0.004	0.006	0.002	0.006	0.011	0.002	0.002	0.000
Securities lending/borrowing	0.003	0.006	0.001	0.002	0.004	0.000	0.002	0.006	0.000	0.001*	0.001

Table 2: Guaranteed Variable Annuities (VA) and Asset Allocations

This table reports estimates of equation-by-equation OLS regressions (Panel A) and seemingly unrelated regressions (SUR, Panel B) of asset allocations on guaranteed variable annuities' delta with respect to the stock market. The sample period is 2004-2013, excluding 2008-2009. Both the asset allocations and the delta are normalized by total invested assets. All models include risk-based capital ratio (RBC ratio) and year fixed effects. Columns (1) - (4) are for liquid bonds, illiquid bonds, common stock exposures, and other assets, as defined in Table 1. In Panel A, standard errors in parentheses are clustered by insurer. In Panels B, the coefficients of both Delta/Assets and RBC ratio are constrained to sum to zero to keep the sum of asset allocations to 100%, and standard errors in parentheses are calculated by bootstrapping, using 500 repetitions. *, **, and *** refer to statistical significance at 10%, 5%, and 1% levels.

Panel A: Equation by Equation OLS

| | Asset Allocations | | | |
| | Liquid Bonds | Illiquid Bonds | Common Stocks | Others |
	(1)	(2)	(3)	(4)
Delta/Assets	-1.194***	1.857***	-0.667***	-0.034
	(0.349)	(0.340)	(0.221)	(0.045)
RBC ratio	0.003***	-0.002***	-0.000	-0.000**
	(0.001)	(0.001)	(0.000)	(0.000)
Year fixed effects	YES	YES	YES	YES
Observations	1,071	1,071	1,071	1,071
R-squared	0.038	0.043	0.018	0.057

Panel A: Seemingly Unrelated Regressions

| | Asset Allocation | | | |
| | Liquid Bonds | Illiquid Bonds | Common Stocks | Others |
	(1)	(2)	(3)	(4)
Delta/Assets	-1.119***	1.809***	-0.655***	-0.035
	(0.357)	(0.311)	(0.216)	(0.042)
RBC ratio	0.003***	-0.002***	-0.000	-0.000**
	(0.001)	(0.001)	(0.000)	(0.000)
Year fixed effects	YES	YES	YES	YES
Cross-equation restrictions	Sums of coefficients of Delta/Assets and RBC ratio across equations (1) - (4) are zero.			
Observations	1,071	1,071	1,071	1,071
R-squared	0.038	0.043	0.018	0.057

Table 3: Calibration Results and Counterfactual Portfolios

This table reports summary statistics on actual and calibrated hedge coverage and risk-based capital (RBC) requirement for illiquid bonds (Panel A) and counterfactual asset allocations (Panel B) for the sample of insurers with guaranteed variable annuities (VA) greater than the median. In Panel A, total hedge coverage is divided into comprehensive (effective plus others) and delta hedge coverages. Comprehensive hedging includes hedging using options with negative delta, e.g. buying put options. Effective and other hedging are categorized based on hedging effectiveness and separately reported by insurers. Only derivatives that have common stocks underlying, and are earmarked for hedging guarantees associated with variable annuities are included. Delta hedging is estimated using the coefficient of Delta/Assets in column (3) of Table 2 Panel B, scaled by the fraction of exposure that remains after taking into account comprehensive hedging. RBC requirements for illiquid bonds are calculated in two ways-- (a) from the data as the weighted average of RBC requirement for each asset category that comprises illiquid bonds, and (b) from the model estimates in Table 2 Panel B as the coefficient of Delta/Assets in column (3) divided by the coefficient of Delta/Assets in column (2) and then multiplied by the RBC requirement of 0.30 for common stocks. In Panel B, the allocations for Portfolio 1 are calculated by keeping the estimated delta hedge coverage the same as actual but without tilting the allocation towards illiquid bonds, i.e. keeping the mix between liquid and illiquid bonds as if the insurers had not underwritten the guaranteed VA. The allocations for Portfolio 2 are calculated by adjusting the actual allocations by negative of the products of the coefficients in Table 2 Panel B and Delta/Assets. The pooled averages of Portfolios 1's and 2's allocations and their differences from the averages of actual allocations as well as the average allocations of insurers without guaranteed VA are reported. Bootstrapped standard errors, calculated using 500 repetitions, are in parentheses. *, **, and *** refer to statistical significance at 10%, 5%, and 1% levels.

Panel A: Hedge Coverages and Implied Capital Constraint

	Data			Estimation		
	Mean	Std. Dev.	Median	Mean	PCT5	PCT95
Comprehensive hedging - effective	0.000	0.000	0.000	-	-	-
Comprehensive hedging - others	0.052	0.121	0.000	-	-	-
Delta hedging	-	-	-	0.690	0.658	0.721
RBC requirement for illiquid bonds	0.060	0.020	0.058	0.113	0.049	0.177

Panel B: Counterfactual Portfolios

	Portfolio 1: Same Level of Guaranteed VA and Hedge Ratio; No Reaching for Yields			Portfolio 2: No Guaranteed VA		
	Mean	Mean - Actual	Mean - Actual of No VA Insurers	Mean	Mean - Actual	Mean - Actual of No VA Insurers
Liquid bonds	0.762***	0.109***	0.025*	0.718***	0.065***	-0.019
	(0.014)	(0.015)	(0.015)	(0.021)	(0.022)	(0.021)
Illiquid bonds	0.217***	-0.109***	0.021	0.221***	-0.105***	0.025
	(0.036)	(0.037)	(0.037)	(0.018)	(0.019)	(0.019)
Common stock exposures	0.000	0.000	-0.045***	0.039***	0.038***	-0.007***
	(0.001)	(0.003)	(0.002)	(0.001)	(0.003)	(0.002)
Other assets	0.017***	0.000	-0.004	0.019***	0.002	-0.002
	(0.002)	(0.003)	(0.003)	(0.002)	(0.003)	(0.003)

Table 4: Fire-Sale Amount and Costs under Categorical Shock

This table presents estimates of fire-sale amount and fire-sale costs incurred by insurers with guaranteed variable annuities (VA) greater than the median, given a negative categorical shock. Panel A considers the fire-sale externality in which the amount of selling fully anticipates the aggregate price impact due to selling by other insurers. Panel B does not consider the fire-sale externality. The price impact (c_0) of 18.6 basis points per $10 billion of sale is assumed, following the NSFR estimate for non-agency MBS by Duarte and Eisenbach (2015). The allocations of actual portfolio, Portfolio 1, and Portfolio 2 are as reported in Tables 1 and 3. The risk-based capital (RBC) requirement for common stocks is 0.3. The total invested assets, capital and surplus, RBC ratio, and (percentage) delta exposure of the guarantee are the averages from 2010 to 2013 (after the crisis). The decomposition attributes the difference between the effects on actual portfolio and Portfolio 1 to "reaching for yield" and the difference between the effects on Portfolios 1 and 2 to the guarantee exposure net of comprehensive and delta hedging.

Panel A: Fire Sales with Full Externality

Magnitude of Shock	Fire-Sale Amount ($ Million)			Decomposition of Fire-Sale Amount ($ Million)	
	Actual	Portfolio 1	Portfolio 2	Reaching for Yield	Net Guarantee Exposure
10%	134,360	33,555	13,821	100,805	19,734
20%	268,720	67,110	27,642	201,610	39,468
30%	403,080	100,665	41,462	302,415	59,203
40%	537,440	134,220	55,283	403,220	78,937

Magnitude of Shock	Fire-Sale Costs ($ Million)			Decomposition of Fire-Sale Costs ($ Million)	
	Actual	Portfolio 1	Portfolio 2	Reaching for Yield	Net Guarantee Exposure
10%	3,358	209	36	3,148	174
20%	13,431	838	142	12,593	696
30%	30,220	1,885	320	28,335	1,565
40%	53,725	3,351	568	50,374	2,782

Table 4, cont'd: Fire-Sale Amount and Costs under Categorical Shock

Panel B: Fire Sales without Full Externality

Magnitude of Shock	Fire-Sale Amount ($ Million)			Decomposition of Fire-Sale Amount ($ Million)	
	Actual	Portfolio 1	Portfolio 2	Reaching for Yield	Net Guarantee Exposure
10%	71,809	29,820	12,061	41,989	17,758
20%	143,618	59,639	24,123	83,979	35,517
30%	215,427	89,459	36,184	125,968	53,275
40%	287,237	119,279	48,245	167,958	71,033

Magnitude of Shock	Fire-Sale Costs ($ Million)			Decomposition of Fire-Sale Costs ($ Million)	
	Actual	Portfolio 1	Portfolio 2	Reaching for Yield	Net Guarantee Exposure
10%	959	165	27	794	138
20%	3,836	662	108	3,175	553
30%	8,632	1,489	244	7,144	1,245
40%	15,346	2,646	433	12,700	2,213

Table 5: Fire-Sale Amount and Costs under Other Shocks

This table presents estimates of fire-sale amount and fire-sale costs incurred by insurers with guaranteed variable annuities (VA) greater than the median, given a negative shock to illiquid bonds (Panel A) or a positive shock to value of the guarantee (Panel B). Both panels fully consider the fire-sale externality. The price impact (c_0) of 18.6 basis points per $10 billion of sale is assumed, following the NSFR estimate for non-agency MBS by Duarte and Eisenbach (2015). The allocations of actual portfolio, Portfolio 1, and Portfolio 2 are as reported in Tables 1 and 3. The total invested assets and capital and surplus are the averages from 2010 to 2013 (after the crisis). In Panel B, the value of guarantee is assumed to equal the gross reserve. The decomposition attributes the difference between the effects on actual portfolio and Portfolio 1 to "reaching for yield" and the difference between the effects on Portfolios 1 and 2 to the guarantee exposure net of comprehensive and delta hedging.

Panel A: Shock to Illiquid Bonds

Magnitude of Shock	Fire-Sale Amount ($ Million)			Decomposition of Fire-Sale Amount ($ Million)	
	Actual	Portfolio 1	Portfolio 2	Reaching for Yield	Net Guarantee Exposure
10%	80,835	23,772	25,887	57,063	-2,115
20%	161,671	47,545	51,775	114,126	-4,230
30%	242,506	71,317	77,662	171,189	-6,345
40%	323,342	95,089	103,549	228,252	-8,460

Magnitude of Shock	Fire-Sale Costs ($ Million)			Decomposition of Fire-Sale Costs ($ Million)	
	Actual	Portfolio 1	Portfolio 2	Reaching for Yield	Net Guarantee Exposure
10%	1,215	105	125	1,110	-20
20%	4,862	420	499	4,441	-78
30%	10,939	946	1,122	9,993	-176
40%	19,446	1,682	1,994	17,764	-313

Table 5, cont'd: Fire-Sale Amount and Costs under Other Shocks

Panel B: Shock to Value of Guarantee

Magnitude of Shock	Fire-Sale Amount ($ Million)			Decomposition of Fire-Sale Amount ($ Million)	
	Actual	Portfolio 1	Portfolio 2	Reaching for Yield	Net Guarantee Exposure
10%	63,543	18,687	0	44,856	18,687
20%	127,085	37,374	0	89,711	37,374
30%	190,628	56,060	0	134,567	56,060
40%	254,170	74,747	0	179,423	74,747

Magnitude of Shock	Fire-Sale Costs ($ Million)			Decomposition of Fire-Sale Costs ($ Million)	
	Actual	Portfolio 1	Portfolio 2	Reaching for Yield	Net Guarantee Exposure
10%	751	65	0	686	65
20%	3,004	260	0	2,744	260
30%	6,759	585	0	6,174	585
40%	12,016	1,039	0	10,977	1,039