# Longevity Shocks and Corporate Debt Markets[*]

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**Abstract**

This paper explores how longevity shocks transmit to corporate debt markets. We show that changes in life expectancy propagate to corporate debt via life insurers through their adjustment of the duration of their corporate bond holdings to match the duration of their liabilities. Life insurers demand more long-term bonds when longevity increases unexpectedly. Their demand of bonds of specific maturities affects corporate term spreads. Corporations exploit the predictable variation in term spreads by adjusting new debt maturities in response to longevity shocks. The debt response is concentrated among insurer-dependent firms and those with investment-grade ratings, which life insurers prefer.

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# 1 Introduction

Although human life expectancy is on an upward trend, it exhibits substantial year-to-year variation. Over the 1974-2018 period, for example, the U.S. life expectancy improved by an average of about 0.15 years annually, but there were many years in which it barely changed or even fell (the annual changes had a volatility of about 0.14 years).[1] The literature attributes these longevity shocks to a confluence of environmental, healthcare, lifestyle, biological, institutional, and socioeconomic factors (Fuchs, 2004; Shaw, Horrace, and Vogel, 2005; Cutler, Deaton, and Lleras-Muney, 2006; OECD, 2010; Moreno-Serra and Smith, 2015; Chiu and Pain, 2018; Woolf and Schoomaker, 2019).

We examine how these longevity shocks affect corporate debt markets. In particular, longevity shocks change the duration of liabilities from insurance policies and annuities that life insurers have sold to their customers, potentially exposing them to a mismatch with the duration of their assets. Insurance regulations require life insurers to adjust the duration of their assets to that of their liabilities (Section 2.1 provides more institutional details). Much of the duration adjustment occurs in life insurers' corporate bond portfolios, the most prominent asset class on their balance sheets (corporate bonds account for about 38% of their financial assets and 59% of transactions). Life insurers are also the largest holders of outstanding corporate bonds, and shifts in their demand for bonds of specific maturities affect bond yields and term structure. The paper asks the following questions: How much do longevity shocks matter for life insurers' trades of corporate bonds? Do they affect corporate term spreads? How do long-term debt financing costs and corporate debt maturity choices respond to longevity shocks?

We show that life insurers respond to longevity shocks by adjusting the duration of their corporate bond portfolios. This adjustment in duration is relatively large and rapid, ranging from approximately 0.7 to 0.8 years for a one-year change in life expectancy. Importantly,

[1] See Internet Appendix Figure A.1, which plots the weighted average period life expectancy in the US and its year-to-year variations over the 1950–2018 period.

insurance companies actively trade bonds of specific maturities. When life expectancy increases, they purchase more long-term bonds (predominantly investment grade) and sell shorter-term bonds. In contrast, when life expectancy decreases, life insurers strategically steer their investments away from long-term bonds.

We utilize the geographic dispersion in state-level longevity shocks to show that life insurers' trades of corporate bonds respond to changes in life expectancy rather than unobserved macroeconomic shocks affecting credit market conditions. The tests focus on "local" (state-level) insurers, mainly exposed to local longevity shocks (they generate at least 80% of their revenue from policies sold in their home state). We find that local life insurers in states with opposite state-level longevity shocks adjust the duration of their corporate bond portfolios in opposite directions. Furthermore, local life insurers tend to make opposite trades in *same bond* if they are located in states with negatively correlated local longevity shocks. Since local life insurers manage risks by holding corporate bonds issued by firms in other states, their trades are more aligned with their desire to hedge duration mismatches and less with their response to local macroeconomic or credit market conditions.

The remainder of our analysis focuses on how these shifts in life insurers' demand for bonds of specific maturities affect long-term bond yields and long-term debt supply. Preferred habitat models predict that changes in demand for bonds of specific maturities should result in bond yields that deviate significantly from the yields implied by the expectations hypothesis (Greenwood and Vayanos, 2010; Greenwood, Hanson, and Stein, 2010; Vayanos and Vila, 2021). Life insurers hold long-dated liabilities and adjust their portfolios of bonds primarily through trades in long-term bonds. So, when longevity increases unexpectedly, life insurers purchase more long-dated securities. Since arbitrage costs are high at the long end of the bond market (Badoer and James, 2016), an increase in the demand for long-term corporate bonds from life insurers lowers long-term bond yields, flattening the corporate term structure.

Corporate issuers have a comparative advantage in exploiting differences in the expected returns on short- and long-term debt. Although firms consider their preferred maturity profile, avoiding maturity concentration (Servaes and Tufano, 2006; Choi, Hackbarth, and Zechner, 2018; Chaderina, Weiss, and Zechner, 2022), they also weigh differences in financing costs in their decisions to issue debt with short or long maturities. There is considerable evidence that firms time bond markets and issue longer-dated bonds when long-term bond yields are low (Guedes and Opler, 1996; Barclay and Smith, 1995; Stohs and Mauer, 1996; Baker, Greenwood, and Wurgler, 2003). In situations where the cost of deviating from target maturity profiles is modest, lower long-term yields during periods of increasing life expectancy should induce a greater supply of long-term debt by corporations. In other words, firms should respond elastically by varying the maturity of their debt issues to absorb shocks resulting from life insurers' hedging needs.

We find that longevity shocks negatively affect corporate term spreads. And, as expected, the maturities of new corporate bond issues are significantly longer during periods of increasing life expectancy. Our results based on disaggregated firm-level data show a strong shift in the maturity of new debt issues between short- and long-term debt in response to longevity shocks. In particular, firms are significantly more likely to issue very long-term debt and less likely to issue short-term debt when life expectancy increases. One concern is that our finding could be driven by age-sensitive industries. For example, DellaVigna and Pollet (2007) show that changes in age cohorts could generate predictable consumption demand in certain industries, which could affect corporate debt issuances. We find robust results in a subsample of firms beyond the age-sensitive industries. Another potential objection to our interpretation is that some of the forces driving longevity shocks, which influence insurers' duration adjustments, may also determine the optimal debt maturities of firms. To address this concern, we conducted two cross-sectional tests to support the view that corporations' debt maturity choices respond to life insurers' demand for bonds of specific maturities rather than rational variations in optimal debt maturity.

First, as Barbosa and Ozdagli (2023) show, life insurers exhibit a great deal of persistence in their bond purchases; they tend to favor bonds from firms already in their portfolio. If life insurers prefer a particular group of issuers, then longevity shocks would increase demand for their bonds, prompting these firms to fill the gap by issuing more long-term bonds. In other words, we expect firms with larger bond ownership by life insurers ("insurer dependent") to be exceptionally responsive to longevity shocks. Consistent with this prediction, we find that insurer-dependent firms react more strongly to longevity shocks. They issue significantly more long-term bonds during periods of high longevity shocks. In contrast, long-term debt issuances by other ("noninsurer-dependent") firms are insensitive to longevity shocks.

Second, since life insurers invest primarily in safe securities, much of the response should be concentrated among issuers that are rated investment grade. In other words, if shocks to life expectancy drive firms' debt issues, supply elasticities should be more significant for long-term debt issued by highly rated firms. Consistently, we find that longevity shocks induce a more pronounced long-term issue response among issuers with investment-grade ratings. Non-investment grade firms show little responsiveness to longevity shocks.

Overall, we demonstrate that changes in life expectancy affect credit availability for firms that can readily provide macro liquidity to the long-term corporate debt market, primarily investment-grade firms and those whose bonds are already in the portfolios of life insurers. Our results are important because they show that longevity improvements have consequences for corporations' financing policies, with the insurance sector, traditionally a substantial buyer of corporate bonds, as the primary transmission channel.

This paper contributes to several strands of research. First, we contribute to the literature on the effect of demographics on the real economy and financial markets. Much of this line of existing research is about understanding how changes in life expectancy affect aggregate consumption, savings, labor supply, incentives to obtain schooling, human capital stock, and productivity.[2] The literature is also interested in understanding the effect of demographic changes on asset demand, with consequences for interest rates, asset prices, and portfolio choices of households.[3] For example, some economists examine how cohort size fluctuations result in predictable shifts in consumer demand, with consequences for cross-sectional stock returns, corporate investment, and cash accumulation in age-sensitive industries (DellaVigna and Pollet, 2007, 2013; Cunha and Pollet, 2020), that is, the consumption channel. We contribute to this literature by examining whether longevity shocks affect firms' financing decisions by shifting the demand for corporate debt with specific maturities. We focus on the effects of longevity shocks on debt financing costs, which allows us to identify the aggregate impacts of longevity shocks on the corporate bond market without tracing back to specific age cohorts and industries. In doing so, we highlight that longevity shocks broadly affect the economy beyond the age-sensitive industries previously studied.

Second, we contribute to the preferred habitat theory of the term structure of interest rates, recently formalized by Vayanos and Vila (2021). The preferred habitat theory posits that investor clienteles have preferences for specific maturity segments and that interest rates for a given maturity are driven by shocks affecting the demand of the corresponding clientele. This theory is used to interpret several episodes, such as the 2004 U.K. pension reform, which increased the demand for long-term bonds from pension funds, leading to a downward-sloping term structure (Greenwood and Vayanos, 2010). Greenwood and Vissing-Jorgensen (2018) show that pension and insurance demand drives the long end of the yield curve globally. Jansen (2023) finds that regulatory reforms in the Netherlands increased pension funds and insurance demand for 20-year bonds, causing their yields to drop below those of 30-year bonds. Even changes in the supply of Treasury securities affect corporate borrowing costs, as shown by Krishnamurthy and Vissing-Jorgensen (2011).

[2] Examples include Bloom and Canning (2000), Murphy and Topel (2006), Acemoglu and Johnson (2007), Cervellati and Sunde (2005), Cervellati and Sunde (2013), Jayachandran and Lleras-Muney (2009), Oster, Shoulson, and Dorsey (2013), and Scott (2021).

[3] Examples include Bakshi and Chen (1994), Poterba (2001), Goyal (2004), Ang and Maddaloni (2005), Geanakoplos, Magill, and Quinzii (2004), Favero, Gozluklu, and Tamoni (2011), Carvalho, Ferrero, and Nechio (2016), and Chen and Yang (2019).

Our results regarding the impact of aggregate demand shifts in long-term bond holdings on corporate term spreads align with the habitat theory and are consistent with previous findings.

Moreover, we provide direct evidence that life insurers actively trade bonds of specific maturities, thereby driving corporate term spreads. In doing so, we also contribute to the literature that examines corporate debt maturity choices when bond market returns have some predictability in partially segmented bond markets. Greenwood, Hanson, and Stein (2010) articulate the "gap-filling" theory of corporate debt maturity choice and show that firms act as macro liquidity providers by absorbing the supply shocks resulting from changes in the maturity structure of government debt. Similarly, Badoer and James (2016) show that changes in long-term government debt supply affect long-term corporate issuances. Although the mechanism of our paper resonates with that of Greenwood, Hanson, and Stein (2010), our focus is distinct as we emphasize a demand shock that arises from regulatory mandates that require life insurers to hedge their duration risks. Given the substantial role of life insurers as the largest investors in corporate bond markets and significant providers of long-term capital for firms, this focus allows us to demonstrate the importance of insurance firms in transmitting exogenous shifts in life expectancy to the financing of the corporate sector. We show that longevity shocks distinctly affect the maturity choices of corporate debt for firms that depend on long-term debt.

Third, our paper relates to the literature investigating how regulatory constraints affect insurers' asset holdings and products. The literature shows that rating-based capital requirements affect insurer investment demand, and thus corporate bond prices (Murray and Nikolova, 2022). Regulatory frictions also result in fire sales of downgraded bonds by constrained life insurers (Ellul, Jotikasthira, and Lundblad, 2011), incentivize insurers to increase investments in safe bonds after losses (Ge and Weisbach, 2021) and influence the demand for bonds of specific maturities (Jansen, 2023). Insurance regulations also shape insurers' risk management decisions (Sen, 2023), affect their holdings of asset-backed and mortgage-backed securities (Ellul et al., 2015; Becker, Opp, and Saidi, 2022), and impact the pricing of insurance products (Koijen and Yogo, 2015). We contribute to this literature by examining the effect of regulatory constraints that require insurers to minimize asset-liability duration mismatches in response to shocks in life expectancy on demand for long-term debt. We provide novel evidence that changes in life expectancy drive insurance companies to trade bonds of specific maturities, affecting corporate term spreads and, in turn, influencing firms' debt issuance decisions.

Fourth, we contribute to the demand-based asset pricing literature that examines the effect of investor demand on asset prices (Koijen and Yogo, 2019; Koijen, Richmond, and Yogo, 2023; Bretscher et al., 2023). Sen and Sharma (2020) and Bretscher et al. (2023) show that investors prefer illiquid bonds. Becker and Ivashina (2015) find evidence of excess yields in insurance companies' bond portfolios, as insurance firms select more credit-risky bonds while controlling for regulatory risk weights. On the other hand, Ozdagli and Wang (2020) attribute this documented excess yield mainly to a duration tilt rather than a credit risk tilt. Ellul et al. (2022) document "reach-for-yield" behavior through investments in illiquid assets among life insurers that offer variable annuities. Other studies show that low-interest rates lead to a tendency toward longer-dated bonds (Domanski, Shin, and Sushko, 2017; Yu, 2020). In contrast to these papers, which primarily focus on low-interest rates, we highlight the importance of longevity shocks in driving life insurance companies' adjustment to the duration of their corporate bond portfolios. Specifically, life insurers trade corporate bonds of specific maturities to close duration mismatches caused by changes in life expectancy. The paper documents that these duration adjustments have significant effects on corporate debt markets and debt maturity decisions of firms.

# 2 Background

## 2.1 Regulatory constraints on life insurers

The National Association of Insurance Commissioners (NAIC), the primary regulatory body for U.S. life insurers, provides a regulatory framework for their asset-liability management. This framework requires life insurers to match their assets' and liabilities' projected cash flows periodically. In particular, the Actuarial Opinion and Memorandum Regulation (AOMR) requires life insurers to test asset adequacy and submit statements of actuarial opinions affirming that they hold sufficient assets to meet both current and future financial obligations to policyholders. Actuarial Standards of Practice No. 7 and No. 22 discuss regulations requiring life insurers to cover their longevity liabilities at the 99% confidence level and submit these statements to the regulators annually.

Life insurers must perform cash flow tests for assets and liabilities in various economic scenarios. Section 11.D.4.b of the Standard Valuation Law requires life insurers to establish reserves at a level that "quantifies the benefits and guarantees, and the funding associated with contracts and their risk at a level of conservatism that reflects conditions that include unfavorable events that have a reasonable probability of occurring." The mortality rate is an essential component of the asset adequacy analysis, and it is ranked as the second most frequent input for sensitivity tests, according to the practice note of the American Academy of Actuaries.

Risk-based capital (RBC) regulations require insurance companies to hold a minimum statutory level of capital in proportion to their risk, further imposing obligations on insurance companies to match their cash flows of liabilities and assets annually. Regulators use RBC to determine when to intervene, with legal authority to take preventive and corrective measures. All insurers must file reports on their RBC levels annually. Within the RBC framework, life insurers follow Cash Flow Modeling for C-3 RBC, where the risk depends on how closely assets and liabilities are matched. An insurer is classified as "Low-Risk" (i.e., it has a well-matched portfolio) if the assumed asset-liability *duration mismatch* is smaller than or equal to 0.125 years. Conversely, the medium- and high-risk categories have an assumed asset-liability duration mismatch greater than 0.125 years. Life insurers in the medium and high-risk categories receive a higher risk factor, resulting in a higher RBC ratio. Therefore, life insurers that do not manage duration mismatches are compelled to add more capital.[4]

Regulations imply that the passive approach of "waiting" for longevity shocks to revert to their long-term trend eventually is costly for life insurers. The NAIC Standard Valuation Law mandates life insurers to conduct asset adequacy tests for in-force businesses using current assumptions to support the sufficiency of assets under various scenarios. The law requires establishing adequate reserves if there are gaps between life insurers' assets and liabilities. Reserves constitute a significant financial cost to insurers. To ensure regulatory compliance, insurers must actively match the duration of their assets and liabilities and file solvency reports. According to the NAIC Risk Management and Own Risk and Solvency Assessment Model Act (RMORSA Model Act # 505), insurers are required to provide their "Own Risk and Solvency Assessment (ORSA)" reports that describe the insurer's risk management framework, risk exposure assessment and projections of future economic capital and solvency. In particular, the ORSA report should explain the risks modeled and the time horizon of risk exposure. In addition, the commissioner may request additional information, such as insurer underwriting, investment, claims, duration, or asset-liability management. Since regulatory filings, including asset adequacy analysis and statements of actuarial opinions on reserve adequacy, are submitted annually, life insurers actively manage asset-liability duration mismatches. Because duration gaps impose large reserve requirements and lead to greater regulatory scrutiny, life insurers are likely to proactively respond to year-to-year variations in life expectancy, even when such variation is transitory.

[4] Recently, a longevity risk factor was included in the RBC framework. The Capital Adequacy (E) Task Force adopted factors for the longevity risk charge (Proposal 2021-13-L). The longevity risk charge affects the reserves associated with life insurers' liabilities.

## 2.2 Life insurer holdings of corporate bonds

Insurance firms hold many different assets and could feasibly change the duration of their portfolio of assets through adjustments across various asset classes. Given our focus on corporate bonds, the pertinent question is how significant corporate bond holdings are relative to other assets on life insurers' balance sheets. To address this, we obtain information on the composition of life insurers' financial assets using Table L.116 of the U.S. national accounts over the 1990-2019 period (the March 2023 release of Z.1 Financial Accounts of the United States).

Panel A of Table 1 presents the life insurance holdings of different classes of financial assets, estimated as a fraction of the total financial assets and then averaged over the available years in each five-year period. Corporate bonds are the largest category, accounting for about 38% of their financial assets over 1990-2019. Other debt, including open market paper, Treasury securities, agency and GSE-backed securities, and municipal securities, represents only about 14%. Equities constitute even less, at about 8%, on average.[5] Panel B of Table 1 reports transactions estimated as a fraction of the net acquisition of financial assets by the life insurance sector (from Table F.116 of the U.S. national accounts). Most financial asset acquisitions by life insurers consist of purchases of corporate bonds. Thus, while life insurers technically could respond to longevity shocks by adjusting the duration of their other financial assets, such as their holdings of Treasury securities or corporate equities, we expect much of their duration adjustment to go through their corporate bond portfolio, the largest financial asset class on their balance sheets.

The data also show that life insurance companies are the largest holders of corporate bonds in the economy. Panel A of Figure 1 shows the fraction of outstanding corporate and foreign bonds held by life insurance companies, private pension funds, and mutual funds from Table L.213 of the March 2023 release of Z.1 Financial Accounts of the United States.

[5] Life insurers have high capital requirements on equities, which potentially explains why they hold so little of this asset class.

Life insurance companies hold, on average, about 24.1% of outstanding corporate and foreign bonds issued by non-financial corporate businesses, domestic financial corporations, and the rest of the world (line 27 over line 12).[6] Internet Appendix Table IB shows that their share of outstanding corporate bonds decreased from about 30.5% in the early 1990s to about 22.3% in the late 2020s. However, excluding holdings from the rest of the world, the life insurance sector remains the largest holder of corporate bonds. Corporate bond holdings by mutual funds have increased from 1990 to 2019 but are smaller than life insurer holdings. The holdings of other sectors do not show any discernible trends.

Panel B of Figure 1 shows the share of the corporate bond trading volume contributed by life insurers across different rating classes. To construct this series, we use NAIC "Schedule D" filings to estimate the annual dollar volume of trades of corporate bonds by life insurers. We then aggregate the dollar trading volume of corporate bonds for the entire market from the Trade Reporting and Compliance Engine (TRACE) and plot the ratio of the dollar trading volume of life insurers to that of the entire market. The figure highlights an important fact about life insurers' corporate bond portfolios – they are significantly more active in the investment-grade segment of the bond market. From 2002 to 2018, life insurers contributed approximately 14% of the dollar trading volume of investment-grade corporate bonds. In contrast, their trades of noninvestment-grade bonds contributed only about 6% of the total bond trading during the same period.

In summary, our analyses rely on three important institutional features of U.S. life insurers. First, life insurers are subject to regulatory restrictions that require them to minimize the duration gap between their assets and liabilities. Consequently, when longevity shocks affect the duration of their liabilities, we expect life insurers to adjust the duration of their assets to minimize the capital charge. Second, life insurers allocate a large portion of their portfolio to corporate bonds, primarily investment grade. Therefore, we expect most of the duration adjustment to be in their portfolios of corporate bonds. Third, the

[6]These numbers are similar to those in Koijen and Yogo (2023), which documents that insurers owned 38% of U.S. corporate bonds in 2017.

U.S. corporate bond market is segmented with institutions holding much of the outstanding corporate bonds. Among these institutions, U.S. life insurers are the largest holders of corporate bonds and have owned around 24% of the corporate bonds outstanding over the years. Based on the structure of their liabilities and the regulatory constraints in place, life insurers have a natural demand for long-term assets, primarily higher-quality corporate bonds, and they adjust the mix of bonds to manage the asset duration. Taken together, the institutional background discussed in this section implies that longevity shocks affect life insurers' demand for bonds of specific maturities, which influences corporate term spreads, leaving behind residual predictability in bond returns. As suggested in Greenwood, Hanson, and Stein (2010), arbitrageurs (such as broker-dealers and hedge funds) often are constrained by their risk-bearing capacity and costs associated with arbitrage across bonds with different maturities. Therefore, we expect corporate issuers to have a greater capacity than arbitrageurs in absorbing demand shocks, as they can elastically adjust the maturity of the debt they issue.

# 3 Data and variables

The longevity shocks of the U.S. population are estimated from the mortality and population information provided by the Human Mortality Database during the 1974–2018 period.[7] We begin by computing the average period life expectancy ($E_t$) of a population in year $t$, weighted by the corresponding exposure, as follows:

$$E_t = \frac{\sum_{x=0}^{99}(x + e_{x,t})E_{x,t}}{\sum_{x=0}^{99} E_{x,t}}, \tag{1}$$

where $e_{x,t}$ is the remaining period life expectancy for a person aged $x$ in year $t$, and $E_{x,t}$ is the corresponding exposure of cohort $x$.[8] We then estimate longevity shocks (*LongevityShocks*)

[7] The Human Mortality Database is available at `mortality.org`.

[8] As data for cohorts over 100 years old are unreliable, the age is restricted to 99 years. Young cohorts are included because some life insurance products target young people (and are sold to their parents or

as the change in the weighted average of period life expectancy, that is, $E_t$ - $E_{t-1}$. We similarly constructed state-level longevity shocks (*LocalLongevityShocks*) using state-level mortality data from the U.S. Mortality Database from 1989 to 2018.[9] Both *LongevityShocks* and *LocalLongevityShocks* are easily interpretable model-free measures of longevity shocks over time.[10]

Panel A of Table 2 shows that changes in life expectancy ($LongevityShock$) during 1974–2018 average about 0.15 years with an annual standard deviation of 0.14 years. In the Internet Appendix Figure A.1, we plot the weighted-average period life expectancy together with time series changes in life expectancy over a much longer period. The plot confirms the increasing trend of longevity over the past several decades. However, as shown in the right panel, there are significant year-to-year variations in changes in life expectancy. These longevity shocks drive year-to-year variations in the duration of liabilities on insurers' balance sheets, generating duration mismatches with their asset holdings. State-level longevity shocks average approximately 0.10 years per year but are relatively more volatile (with an annual standard deviation of 0.21 years).

Panel B shows the summary statistics of the aggregated bond market variables from 1990 to 2019. Data on credit market conditions and macroeconomic variables come from the Federal Reserve Economic Data (FRED). The credit spread (*CreditSpread*) is the spread between the percentage yields of Moody's Seasoned Baa Corporate Bond Index and 20-year Treasury securities (mean = 2.07%). Changes in 1-year Treasury yields ($\Delta$*Treasury-1Y*) average -0.21%, reflecting the overall low-interest rate environment during this period. The term spread (*TermSpread*) is the spread between the percentage yields of 10- and 1-year Treasury securities (mean = 1.42%). Orthogonalized term spread (*Term spread*$^{\perp}$) is estimated as the residuals of a regression of term spread on longevity shocks (mean =

guardians). Restricting the sample to the working-age population aged 20–65 does not materially change our results.

[9] The U.S. Mortality Database is available at `usa.mortality.org`. See Mila (2019) for more details.

[10] The latent mortality index in Lee and Carter (1992) is an alternative measure of longevity shocks. The Lee-Carter measure is strongly correlated with our measure (with a correlation coefficient of -0.99) and yields qualitatively identical results.

0.57%). The excess bond premium (*EBP*), which captures bond market sentiment, has a mean of 0.11%.[11]

We obtain new corporate bond issues by U.S. nonfinancial firms from the Mergent Fixed Income Securities Database (FISD). The annual changes in the spread between long- and short-term corporate bond yields ($\Delta$*CorpTermSpread*) average approximately 0.03%. We define long-term bonds as those with maturities of more than ten years and short-term bonds as those with less than or equal to 3 years. Long-term bond issues are, on average, approximately 5.2 times higher than short-term bond issues (*LTtoSTDebt*). The mean change in the weighted average duration of new bond issues ($\Delta$*NewBondDuration*), weighted by issue size, is approximately 0.04 years.[12]

Panel C focuses on the characteristics of life insurers obtained from NAIC filings. Insurers' bond holdings, including the issuer's name, bond characteristics, and holding size, are from NAIC "Schedule D" filings available from 1995 to 2019. Schedule D transaction data provide date-stamped trades, including trading prices, transaction size, and trade direction. Life insurers are large (mean assets = \$6.66 billion; median = \$338 million), highly leveraged (average total liabilities-to-assets ratio, *InsLeverage*, of 0.73) and profitable (return on assets, *InsROA*, of 2%). The average risk-based capital ratio (*InsRBC*) for life insurers in our sample is 17.57. *InsRBC* is estimated following the NAIC's Risk-Based Capital Guidelines as the ratio of total available regulatory capital (i.e., assets - liabilities) to total required capital, where needed capital is obtained by multiplying the book value of a bond holding by the appropriate risk weight, depending on the bond's credit rating. The NAIC Securities Valuation Office designates bonds into six categories (on a scale from 1 to 6) based on credit ratings by approved agencies, where NAIC 1 corresponds to the lowest risk and NAIC 6 corresponds to the highest risk (see Appendix IC). Higher NAIC designation bonds are of lower credit quality, and an insurer must hold more capital to

[11] For more details on *EBP*, see Gilchrist and Zakrajšek (2012) and López-Salido, Stein, and Zakrajšek (2017). Data are available at `www.federalreserve.gov/econresdata/notes/feds-notes/2016/files/ebp_csv.csv`.

[12] These Macaulay duration estimates do not consider other features of bonds, such as callability and convertibility. This introduces noise in our duration estimates but also biases the results toward zero.

cover the expected losses on that security to satisfy risk-based capital requirements. To maintain capital adequacy, insurers invest primarily in investment-grade bonds (i.e., bonds designated NAIC 1 or 2). Almost 55% of corporate bonds held by life insurers in our sample have the NAIC 1 designation (the highest quality), 27% are NAIC 2, and the rest are NAIC 3 or higher. The average change in bond portfolio duration (Δ*InsDuration*) is 0.04 years.

We obtain financial data on bond issuers for the 1975–2019 period from Compustat. Panel D shows that the issuers have been listed on Compustat for an average of 17 years. They are large, with a mean *Assets* of $6.67 billion (median of $906 million). Issuers have an average ROA of 16%, Tobin's $q$ of 1.63, a cash-to-asset ratio of 8%, and tangibility of 46%.

# 4 Life insurers' corporate bond portfolio adjustments

## 4.1 Duration of corporate bond portfolios

Figure 2 documents a remarkable comovement between changes in the average duration of holdings of life insurers' corporate bonds and lagged longevity shocks ($\rho = 0.32$, $p < 0.01$). To examine the duration response to changes in life expectancy, we estimate the following regression:

$$\Delta InsDuration_{i,t} = \beta \cdot LongevityShocks_{t-1} + \mathbf{X}^{'}_{i,t} \cdot \lambda + \mathbf{Z}^{'}_{t} \cdot \gamma + \zeta_i + \epsilon_{i,t}, \qquad (2)$$

where the dependent variable Δ*InsDuration* measures the change in the duration of the corporate bond portfolio of life insurer $i$ in year $t$. The key variable of interest is lagged longevity shocks (*LongevityShocks*$_{t-1}$). The tests include a vector of insurer characteristics $\mathbf{X}_{i,t}$ to control the size of the insurer (the natural logarithm of insurer assets, *ln(InsAssets)*), insurer leverage (*InsLeverage*), the insurer risk-based capital ratio (*InsRBC*), insurer profitability (*InsROA*), and the growth of net premium written (*InsNPWGrowth*).

We include macroeconomic variables in $\mathbf{Z}_t$ to control for the growth of the Consumer Price Index (*CPIGrowth*), growth of U.S. gross domestic product (GDP) (*GDPGrowth*), and state GDP growth (*StateGDPGrowth*) and state population growth (*StatePopGrowth*) in the insurer's state. We include these variables to address concerns that they may affect insurers' duration adjustments and may also be correlated with longevity shocks. However, we note that the literature offers no conclusive evidence of a relationship between U.S. longevity shocks and observed macroeconomic factors. For example, Acemoglu and Johnson (2007) find that increases in life expectancy have not led to faster growth in income per capita. Similarly, Cutler, Deaton, and Lleras-Muney (2006) argue that income differences have little to do with changes in life expectancy in the U.S. in recent decades. Instead, they emphasize that improvements in medicine and health-related behaviors are the primary drivers of improvements in life expectancy. Ehrlich and Lui (1991) show that increases in old age longevity have an ambiguous effect on the steady-state growth rate of the economy.

In addition to macroeconomic controls, we also include controls for expected interest rate changes to address concerns that longevity shocks change interest rate expectations, thereby influencing duration mismatch and duration adjustments that life insurers make to their corporate bond portfolio. For example, increases in life expectancy could lead to higher savings rate (Bloom, Canning, and Graham, 2003), which in turn may affect interest rates. Changes in credit market conditions could also affect life insurers' duration adjustments. For example, Domanski, Shin, and Sushko (2017) and Yu (2020) argue that lower interest rates lead to a faster increase in the duration of insurers' liabilities compared to the increase in their assets, thus widening the duration gap during periods of lower interest rates. Ozdagli and Wang (2020) argue that lower interest rates weaken policyholders' incentives to surrender their policies, increasing the duration of life insurers' liabilities.[13] In both cases, life insurers will increase the duration of their assets to reduce the duration gap. Furthermore, reaching-for-yield incentives may also result in insurers tilting toward longer-duration bonds when term spreads and credit spreads are large. Thus,

[13]We find that the surrender rates over the 1996-2018 period are relatively small, averaging about 1.6%.

vector $\mathbf{Z}_t$ additionally includes controls for credit market conditions such as changes in the 1-year Treasury yield ($\Delta$*Treasury1Y*), the term spread (*TermSpread*), and the credit spread (*CreditSpread*). Finally, $\zeta_i$ are fixed effects of insurers, and $\epsilon_{i,t}$ is an idiosyncratic error term.

Column (1) of Table 3 shows that the coefficient on *LongevityShocks* is positive and statistically significant at the 1% level of significance. This result suggests that life insurers increase the duration of their bond portfolio by approximately 0.69 years for every one-year increase in nationwide longevity. Interest rate variables have the predicted signs.[14] Overall, the observed significant and relatively quick duration response is consistent with life insurers' demand to hedge longevity-induced shocks to the duration of their liabilities.[15]

Column (2) specification controls for incentives to tilt portfolios toward bonds with higher yields. Changes in life expectancy can affect insurance customers' decisions to purchase and surrender insurance policies. If insurance liabilities change as a result, then it may affect insurers' risk-taking incentives. Insurers may also adjust their holdings of bonds purely to chase higher yields. If these adjustments show up in duration adjustments, then one may be concerned that some of the effects we document are due to reaching-for-yield incentives rather than duration hedging. We follow Choi and Kronlund (2018) to measure the extent to which insurance firms engage in "reaching for yield (*ReachForYield*)" and estimate *ReachForYield* as the value-weighted average (across all corporate bonds held by an insurer) of the deviation of each bond's yield from the yield of a benchmark index consisting

[14]Longevity shocks also affect term spreads, a result we present later, which may also drive duration adjustment. Thus, we control for term spreads in all of our specifications. Unreported tests that include orthogonalized term spreads yield qualitatively similar findings. In other tests, we reexamine the response of life insurers to longevity shocks after controlling for changes in term spreads to address concerns that life expectancy changes may correlate with interest rate expectations. We do not report these results for the sake of brevity. However, they show that longevity shocks remain positive and significant, with coefficient estimates that have magnitudes similar to those reported in column (1) of Table 3. Term spread changes themselves are not significant.

[15]Life insurers appear to adjust the duration mismatches caused by longevity shocks relatively quickly, likely due to relatively large benefits from duration adjustments and the low cost of adjusting bond portfolios. By contrast, Ozdagli and Wang (2020) show that life insurers make slow duration adjustments to interest rate shocks. However, accurately estimating adjustment speed is challenging as we do not observe the target duration to which life insurers are adjusting, nor can we estimate it with any precision. The reason is that there is limited disclosure of liabilities, and thus, estimating any measure of the duration of liabilities is noisy. If the target duration is mismeasured, the estimates of the adjustment speed will be biased towards zero.

of bonds in the same rating notch and having the same maturity. Column (2) shows that although *ReachForYield* positively affects duration changes as predicted by reaching-for-yield incentives, its inclusion does not affect our $\beta$ estimates. The coefficient on *LongevityShocks* continues to be strongly significant, with an economic magnitude similar to that in column (1).

Next, we address the possibility that life insurers could hedge the effects of duration mismatches through derivative contracts. If so, then the duration adjustments to their corporate bond portfolio will be less responsive to changes in life expectancy. Following Sen (2023), we calculate an insurer's total net interest risk exposure by aggregating such exposures across all derivative positions (*DerivativeHedging*). Aggregation accounts for significant heterogeneity in contract characteristics, including maturity and direction of exposure. Data on life insurer derivative holdings are obtained from NAIC "Schedule DB" filings, available from 2006 to 2019. The interest rate data (forward swap rates) used to calculate the interest risk exposure are from Bloomberg. In column (3), which controls for *DerivativeHedging*, we find coefficient estimates that are qualitatively similar to those in column (1), suggesting a limited role of derivatives in hedging interest rate risks from duration mismatches.[16]

The remaining columns of Table 3 examine two sources of cross-sectional heterogeneity in the strength of response to longevity shocks. The first dimension in which life insurers differ is in their financial strength. Although more constrained insurers may have greater incentives to manage risks, they also have less flexibility to adjust their asset portfolios. The existing literature consistently finds that financial constraints reduce the ability to manage risks (e.g., Nance, Smith, and Smithson, 1993; Stulz, 1996; Rampini, Sufi, and Viswanathan, 2014). Therefore, we expect small, more constrained insurers to be less responsive to longevity shocks, as they lack the flexibility to adjust their bond portfolios at a lower cost. Ge and Weisbach (2021) argue that the size of an insurer is a better

[16]Berends and King (2015) note that many life insurers have limited derivative capacity because regulations require them to maintain a strict "derivatives use plan."

measure of its financial strength than its leverage or the RBC ratio. Consequently, we sort life insurers as large and small annually according to their assets and report the estimates of Equation (2) for the two groups of insurers in columns (4) and (5). As expected, we find that large insurers are considerably more responsive to longevity shocks than small insurers, increasing their bond portfolio duration by almost 0.91 years for a 1-year increase in life expectancy. In contrast, the corresponding response for smaller insurers is a much smaller 0.47-year increase.

Second, we construct a measure of exposure to longevity shocks based on the mix of life insurance and annuity liabilities on insurers' balance sheets. An increase in life expectancy leads to larger annuity liabilities since annuity benefits have to be paid for longer than expected. However, the same increase in life expectancy leads to smaller life insurance liabilities because death benefits under life insurance policies are paid later or less than expected. Therefore, insurers with a mixture of life insurance and annuity products are naturally hedged to some extent, attenuating the effects of longevity shocks on their balance sheets (Cox and Lin, 2007). In Appendix ID, we estimate natural hedge ratios through a simulation that minimizes the variance of portfolio liabilities to longevity shocks by varying the premiums collected from annuity and life insurance products. Simulations suggest that the variance of insurer liabilities with longevity shocks is minimized when premiums from life insurance policies are approximately 81.9% of total premiums. A typical life insurer is far from being naturally hedged; the average premium share of life insurance is only 31.6%. We use the absolute difference between an insurer's life insurance premium share and its natural hedge share estimated from the simulation (*deviation*) as exposure to longevity shocks and define insurers with *deviation* above the sample median as more exposed to longevity shocks. Columns (6) and (7) show that more exposed insurers adjust more aggressively, increasing the duration of their bond portfolio by 0.88 years for an increase in life expectancy of one year. In contrast, life insurers with lines of business that act as natural hedges (thus reducing their exposure longevity shocks) adjust the bond portfolio's duration by only 0.47 years, a statistically significant difference at the 1% level.

**Changes in bond market liquidity** Bao, Pan, and Wang (2011) show that changes in market-wide liquidity explain a large part of the time variation in yield spreads of highly rated bonds. Other research shows that bond illiquidity drives corporate yield spreads (Longstaff, Mithal, and Neis, 2005; Chen, Lesmond, and Wei, 2007). If the liquidity of the bond market coincides with the factors that drive the longevity shocks, adjustment of the bond duration can reflect movements in aggregate bond liquidity rather than longevity shocks. We follow Lin, Wang, and Wu (2011) to estimate Amihud illiquidity for individual bonds each year using TRACE data (available from 2002 to 2019) and then aggregate individual illiquidity measures across all bonds each year to obtain market-wide illiquidity ($Amihud$). We include $Amihud$ as an additional variable in our baseline specification and examine whether our results are robust to controlling for market illiquidity. Column (1) of Appendix Table IE shows that market illiquidity ($Amihud$) has a negative coefficient, suggesting that life insurers reduce the duration of the bond portfolio during periods of high market-wide bond illiquidity. Importantly, however, the coefficient on $LongevityRisk$ in this augmented specification continues to be significantly positive and has roughly the same economic magnitude as our main results. We conclude that our key findings are not sensitive to controls for time variation in market illiquidity.

**Business cycles** Could unmeasured macroeconomic variables correlated with longevity shocks explain our results? Our baseline specification includes controls for aggregate and state-level economic indicators, including CPI, GDP, and population growth rates. Although income is an important driver of early mortality, much less is known about the relationship between other macroeconomic conditions and life expectancy. For example, Acemoglu and Johnson (2007) do not find much evidence that life expectancy affects GDP growth or income per capita. Despite theoretical ambiguity about the effect of macroeconomic conditions and longevity shocks, we additionally test the robustness of our results by focusing on longevity shocks that are orthogonal to business cycles (LongevityShocks$^{\perp}$), estimated as the residuals of longevity shock regressions on the cyclical component of industrial production growth. Column (2) of the Appendix Table IE yields similar conclusions regarding the importance of orthogonalized longevity shocks for bond duration adjustments by life insurers.

**A placebo test** We do a last test to address concerns that insurers are responding to other factors that are correlated to longevity shocks. The tests focuses on property and casualty (P&C) insurers. We do not expect longevity shocks to affect the duration of P&C insurers' liabilities since the insurance products they sell are not life-related. If so, then changes in life expectancy should not drive duration adjustment of P&C corporate bond portfolios. We estimate Equation (2) but with the dependent variable replaced by the change in the duration of the corporate bond portfolio of P&C insurers. The key variable of interest is the coefficient on lagged longevity shocks. Column (5) of Appendix Table IE shows that P&C insurers do not adjust the duration of their bond holdings in response to longevity shocks. The coefficient on *LongevityShocks* is virtually indistinguishable from zero. Taken together, we conclude that life insurers adjust the duration of their corporate bond portfolios in response to longevity shocks. The duration adjustments are significant and relatively quick, attributable to the regulatory constraints they face in minimizing duration mismatches.

## 4.2 Corporate bond trades

As life insurers adjust the duration of their bond portfolios, they must do so through trades of bonds of specific maturities. Seeking to reduce the duration mismatch induced by longevity shocks, life insurers will purchase longer-term bonds when life expectancy increases and do the opposite when life expectancy declines. Table 4 examines changes in net purchases of long- and short-term bonds in response to lagged longevity shocks, controlling for insurer characteristics, macroeconomic variables, and credit market conditions.

The dependent variable in Panel A is *NetBuyLTBonds*, measured as purchases (net of sales) of long-term bonds (10 years or more) scaled by the market value of the insurer's bond portfolio. Column (1) shows that a 1-year increase in life expectancy increases net purchases of long-term bonds by 8.8% ($p<0.01$). The dependent variable in Panel B is *NetBuySTBonds*, measured as purchases (net of sales) of short-term bonds (3 years or less). Life insurers reduce net purchases of short-term bonds by 1.8% ($p<0.10$) for a one-year increase in life expectancy. Evidence suggests that longevity shocks drive life insurers to trade bonds of specific maturities, purchasing more long-term bonds, and selling short-term bonds when life expectancy increases.

We expect much of the duration adjustment to be accomplished through trades of highly rated corporate bonds since almost 82% of their corporate bond holdings consist of investment grade bonds, designated NAIC 1 and 2 (see Table 2). Therefore, we analyze the net purchases of long- and short-term bonds disaggregated by NAIC rating and present the results for each NAIC designation in columns (2) to (7). Panel A, which presents results for net purchases of long-term bonds, shows that much of the active duration adjustment is concentrated in investment-grade bonds. Specifically, a one-year improvement in longevity increases net purchases of long-term bonds rated NAIC 1 and 2 by 2.0% and 1.7%, respectively. In contrast, the same improvement in longevity increases the net purchases of NAIC 6-rated long-term bonds by only 0.2%.

Panel B presents results for net purchases of short-term bonds and shows that insurers sell their highest-quality short-term bonds in response to increases in life expectancy. Short-term bonds in other rating categories have minimum responsiveness to longevity shocks. Overall, the evidence from corporate bond trades confirms that when longevity increases, insurers actively hedge duration risk by purchasing long-term, primarily investment-grade bonds.

## 4.3 Trades of local life insurers

Longevity shocks vary at the state level, meaning that life expectancy could be increasing in one state while simultaneously declining in another. These geographic disparities arise primarily due to regional variations in health and environmental factors, such as the smoking rate, the obesity rate, the number of physicians per capita, the concentrations of fine particulate matter ($PM_{2.5}$), as well as differences in socioeconomic variables, such as median house values, income per capita, poverty rate, upward income mobility, urban population, and crime rates.[17] Using the U.S. Mortality Database, we measure state-level longevity shocks and present snapshots in four years corresponding to the end of each decade in Figure 3. Each map shows how life expectancy rose or fell in a state in that year. Darker shading represents more significant increases in life expectancy, whereas lighter shading represents more significant decreases. As seen in the graphs, changes in life expectancy are positively correlated in some states while negatively correlated in others. For example, longevity shocks in Florida and Georgia are positively correlated ($\rho$ = 0.88), while longevity shocks in Massachusetts and Alaska are negatively correlated ($\rho$ = -0.27).

We leverage these state-level disparities in longevity shocks to address concerns that life insurers' purchases of long-term bonds during periods of increasing longevity may be a response to changes in credit market conditions or aggregate economy, which may be correlated with longevity shocks. Our tests focus on corporate bond trades of "local" life insurers, defined as insurers obtaining at least 80% of their revenues from insurance products sold to customers in one state. This criterion implies that their liabilities respond to state-level longevity shocks.[18] Furthermore, local life insurers manage risks by holding and trading corporate bonds in the national markets. They heavily invest in bonds issued by firms in other states, not their home state (Liu and Xiong, 2023). Given the minimal degree of home bias observed in portfolios of local life insurers, it is unlikely that local credit market conditions drive their trades. Therefore, if we find that their duration adjustments are in the direction of local longevity shocks, we could infer that insurers adjust the duration

[17] See, for example, Chetty et al. (2016), Dwyer-Lindgren et al. (2017), Couillard et al. (2021), Deryugina and Molitor (2020), and Deryugina and Molitor (2021).

[18] We show this by regressing changes in bond portfolio duration of local life insurers on local longevity shocks using a specification similar to Equation (2). The results in column (3) of the Internet Appendix Table IE show a strong response of local life insurers to local longevity shocks.

of their corporate bond portfolios to hedge against duration mismatches caused by local longevity shocks.

Relying on cross-state variations in longevity shocks, we examine whether two local life insurers in different states with negatively correlated longevity shocks adjust their portfolio duration in opposite directions. The dependent variable in Table 5 is an indicator variable equal to one if, for a pair of local life insurers ($i$ and $j$), the two insurers adjust the duration of their bond portfolios in the *opposite* direction and zero otherwise. The key variable of interest in columns (1) and (3) is the correlation coefficient of local longevity shocks in the states where the two life insurers are located ($LongevityCorr_{i,j}$). The key variable of interest in columns (2) and (4) is a dummy variable ($SimilarLongevityShocks_{i,j}$) that equals one if the pair of states in which two local life insurers operate have longevity shocks either above or below the sample median simultaneously in a year and zero otherwise. The tests control for state characteristics (state GDP growth, state population growth) and life insurer characteristics ($InsRBC$, $InsLeverage$, $InsROA$, $InsNPWGrowth$, and $ln(InsAssets)$). In columns (1) and (2), we further control for the credit market conditions (credit spread, $\Delta$ Treasury1Y, term spread) and macroeconomic variables (CPIGrowth, GDPGrowth).

The negative and statistically significant coefficient on $LongevityCorr_{i,j}$ ($p$<0.01) in column (1) implies that local life insurers make opposite duration adjustments when faced with negatively correlated local longevity shocks. This finding confirms that the local life insurer duration adjustments are in the same direction as the longevity shocks.[19] The results in column (2) reinforce the findings in column (1) and produce a negative and statistically significant coefficient on $SimilarLongevityShocks_{i,j}$. Thus, when two local insurers are located in states with similar longevity shocks (i.e., both states have movements in life expectancy in the same direction in a given year), the insurers make similar adjustments to the duration of their bond portfolios. The negative coefficient suggests that they are less likely to adjust the duration in opposite directions.

[19] In addition, Appendix Table IE, column (4) examines a subsample with only negative local longevity shocks. Consistent with our overall evidence, negative local longevity shocks reduce the duration of the bond portfolios of local life insurers.

Subsequent columns (3) and (4) exclude controls for nationwide macroeconomic and credit market conditions and instead include year-fixed effects. This helps eliminate the omitted variable bias caused by unobservable factors that vary over time but are constant across insurers. The results in columns (3) and (4) are almost identical to those in columns (1) and (2). Thus, our results are unlikely to be due to unobservable time-specific variables that may be correlated with insurers' bond duration adjustments.

We further explore bond-level data to provide granular evidence of insurers' responses to local longevity shocks. Since bonds are traded in the national markets, if insurers respond to common economic conditions (for example, anticipated yield changes), they will make similar bond trades. However, if insurers hedge asset-liability duration mismatches, their bond trades will be correlated with local longevity shocks. In this set of tests, we investigate whether two life insurers in different states with negatively correlated longevity shocks make opposite trades for *the same bond*.[20] By examining local life insurers' bond trades and comparing them across states with negatively correlated longevity shocks, we isolate the extent to which longevity shocks drive decisions to purchase specific bonds.

Table 6 presents evidence on the bond trades of local life insurers that face different longevity shocks. We find a strong propensity to trade the same bond in opposite directions by a pair of insurers that face negatively correlated local longevity shocks (the estimated coefficients on $\textit{LongevityCorr}_{i,j}$ and $\textit{SimilarLongevityShocks}_{i,j}$ are both negative and statistically significant). Our findings support that insurers make active maturity adjustments through their bond trades when life expectancy changes.

# 5 Effects on the term structure and aggregate issuances

We now examine how corporate term structure and aggregate bond issuances respond to longevity shocks. In preferred habitat models, the term structure exhibits some degree

[20]To minimize the influence of some minor bonds, we rank them based on their investment weights in each local life insurer's portfolio and focus on bonds above the $70^{th}$ percentile.

of segmentation because demand shocks drive prices away from fundamentals, exposing arbitrageurs to interest rate risk (Greenwood, Hanson, and Stein, 2010; Krishnamurthy and Vissing-Jorgensen, 2011; Vayanos and Vila, 2021). Therefore, when life insurers increase their purchases of long-term corporate bonds during periods of increasing life expectancy, the prices of long-term corporate bonds are expected to increase (resulting in lower yields). Term spreads should move inversely with longevity shocks.

Although predictions on term spreads are of some interest, they are not central to our tests. Instead, our primary interest is in understanding whether firms alter the maturity of their debt issuances in response to life insurers' increased demand for bonds of specific maturities. Firms' debt maturity choices are likely to respond to changes in relative spreads between long- and short-term bonds, among other considerations (Ma, 2019). They could elastically adjust the maturity of new bonds to fill the gap resulting from increased demand for long-term debt by life insurers. Thus, we expect long-term corporate debt issuances to adapt to changes in life expectancy.

We begin with a measure of aggregate annual corporate term spreads, calculated as the average difference between yields on long-term (with maturities greater than ten years) and short-term (with maturities less than three years) bonds. Figure 4, which plots these spreads against lagged longevity shocks, shows that the two series move in opposite directions, with corporate term spreads falling as life expectancy increases (the correlation between the two series is negative and strongly significant ($\rho$ = -0.23)). This inverse relation between corporate term spreads and lagged longevity shocks holds in the presence of controls for macroeconomic and credit market conditions. Column (1) of Table 7 reports estimates from tests relating corporate term spreads to lagged *LongevityShocks* after controlling for macroeconomic and credit market conditions such as *CPIGrowth*, *GDPGrowth*, *CreditSpread*, $\Delta$*Treasury1Y*, *TermSpread*, and *EBP*. As predicted, changes in corporate term spreads are negatively and significantly related to time series variation in life expectancy ($p < 0.01$).[21]

[21]The nonsignificant coefficient on the term spread variable in column (1) reflects the strong multicollinearity between longevity shocks and term spread. In unreported tests, we note that term spread has a significant and positive coefficient in regression specifications after it is orthogonalized to longevity shocks.

The remainder of this section documents supply shifts in long-term debt issues in response to demand changes for long-term bonds. Using data on new domestic corporate bond issuances from FISD, we estimate the average duration of new bond offerings weighted by issue size and plot it against the 1–period lagged *LongevityShocks* in Figure 5. The figure shows that changes in the average duration of the new bonds are strongly correlated with changes in life expectancy; the correlation between the two series is positive and significant ($\rho = 0.46$).

Column (2) of Table 7 examine whether the average duration of newly issued bonds responds to lagged longevity shocks after controlling for *CPIGrowth*, *GDPGrowth*, *CreditSpread*, $\Delta$*Treasury1Y*, *TermSpread*, and *EBP*. The results confirm that increases in the average duration of new bonds are highly responsive to increases in life expectancy, the coefficient of *LongevityShocks* being large and statistically significant ($p<0.01$), consistent with the gap filling view of the choice of debt maturity. The coefficient on $\Delta$Treasury1Y is negative ($p<0.10$), suggesting that long-term bonds are preferred by life insurers when the short-term interest rate is low (Domanski, Shin, and Sushko, 2017; Ozdagli and Wang, 2020; Yu, 2020). The evidence is also consistent with Baker, Greenwood, and Wurgler (2003), who show that time series variations in the choice of debt maturity reflect predictability in excess long-term bond returns. Meanwhile, the EBP is insignificant, suggesting that the sentiment of the credit market has little impact on the maturities of new bonds after controlling for other factors.

We document the change in relative long-term debt issue amounts in column (3), where the dependent variable is the first difference of the natural logarithm of the ratio of long-term and short-term bonds issued during the year. The positive coefficient on longevity shocks confirms that aggregate long-term bond issues increase relative to aggregate short-term bond issues in response to increases in life expectancy. The evidence in Table 7 suggests that corporate term spreads decrease when longevity increases; firms react by issuing longer-dated bonds.

# 6 Corporate responses to longevity shocks

Last, we explore the firm-level response to longevity shocks. We obtain firm-level bond issuance data from Mergent FISD, which we then match with Compustat.[22] We classify debt issues by firms in each year into four maturity buckets: short-term debt with maturities in the [0,3) year range, medium-term debt with maturities in the [3,10) year range, long-term debt with maturities in the [10,20) year range, and very long-term debt with maturities in the [20,...) year range. We then employ the following multinomial logit model to assess the relationship between the likelihood of debt issuance in various segments of the term structure and longevity shocks:

$$Issue^{j}_{i,t} = \beta \cdot LongevityShocks_{t-1} + \mathbf{X}'_{i,t-1} \cdot \lambda + \gamma_{Issuer} + \nu_{Period} + \epsilon_{i,t}, \tag{3}$$

where $Issue^{j}_{i,t}$ is a dummy variable that equals 1 if firm $i$ issues bonds in maturity bucket $j$ in year $t$ and 0 otherwise. The segment of [3,10) years is the base category because it captures the average duration of insurers' bonds. Therefore, the coefficients are interpreted in relation to this base category. We control for *CPIGrowth*, *GDPGrowth*, *CreditSpread*, $\Delta$*Treasury1Y*, and *TermSpread* to address concerns that the estimated $\beta$ reflects changes in credit market conditions or the overall macroeconomic environment facing firms. We also control for firm-specific variables that may affect a firm's propensity to issue debts of specific maturities, including *ROA*, *ln(Assets)*, *TobinsQ*, *Leverage*, *Age*, *Cash*, *EquityIssues*, *NIGrowth*, and *Tangibility*. In addition, we include indicator variables corresponding to 5-year intervals to control for the time-series variation in demand for bonds of specific maturities. Firm

[22]This matching is done in several steps. First, we match the nine-digit issuer CUSIP in FISD to the CUSIP in Capital IQ and then link it to Compustat using GVKEY. Second, the unmatched bonds are processed using the Bond-CRSP link provided by Wharton Research Data Services (based on the Trade Reporting Compliance Engine (TRACE) with coverage starting in June 2002). Third, any remaining unmatched bonds are matched to CRSP using the historical six-digit issuer CUSIP (and further linked to Compustat). Fourth, any remaining unmatched bonds are subjected to a manual matching process based on the proximity of the prospectus issuer name in the FISD to a company name in the CRSP name file (and also linked to Compustat). We can match more than 80% of the FISD bond issuers with Compustat.

fixed effects control for time-invariant heterogeneity across issuers. Standard errors are clustered at the firm level.

Table 8 reports estimates of Equation (3). We find that relative to the base category, firms are significantly more likely to issue long-term, particularly very long-term, debt when longevity increases. At the same time, they reduce short-term debt issuance. Thus, the evidence suggests a clear shift toward long-term debt issuances in response to increases in life expectancy. The estimates in column (3) imply that a one-standard-deviation increase in longevity shocks leads to a 60% increase in the likelihood of issuing very long-term bonds compared to medium-term ones. Overall, we interpret the firm-level evidence to imply that corporations act as macroliquidity providers to absorb the shock resulting from life insurers' duration adjustments; hence, they switch to longer-dated bonds when life expectancy increases.

## 6.1 Cross-sectional evidence

We then present cross-sectional tests to show that the shift in maturities of new debt issues is indeed a response to a larger demand for long-term debt from life insurers. Our first cross-sectional test focuses on firms whose bonds are already in the portfolios of life insurers. Institutions show significant persistence in their investments; they tend to invest in new issues of bonds of existing firms in their portfolio. For example, such "stickiness" exists in the context of mutual fund investment decisions (Zhu, 2021). More directly, there is a similar stickiness among life insurers, as they prefer to purchase new corporate bonds from issuers whose bonds they have previously purchased (Barbosa and Ozdagli, 2023). In doing so, insurers can economize on their fixed costs of screening and monitoring bond issuers.

We consider a firm to be "insurer dependent" if the proportion of its outstanding bonds held by life insurers is above the sample median. We then estimate Equation (3) separately for insurer-dependent and noninsurer-dependent firms. Consistent with the insurer channel, Panel A of Table 9 shows that insurer-dependent firms respond to longevity shocks by issuing substantially more long-term bonds and fewer short-term bonds when life expectancy increases. However, both long-term and short-term debt issuance by noninsurer-dependent firms shows little sensitivity to longevity shocks; the estimated coefficient is not statistically significant. Overall, our findings indicate that much of the response to longevity shocks is concentrated among insurer-dependent issuers.

Second, the issuer's credit rating should play a significant role since life insurers prefer investment-grade bonds. As shown in Table 4, life insurers respond to longevity shocks primarily by adjusting their holdings of investment-grade bonds (NAIC 1 and 2). Therefore, we expect investment-grade firms to be more responsive to longevity shocks than speculative-grade firms. Panel B of Table 9 presents estimates of Equation (3) separately for investment-grade and noninvestment-grade firms. Columns (1) to (3) show that investment-grade firms issue more long-term bonds and fewer short-term bonds in response to increased longevity. The estimated coefficients are statistically significant and the results are similar to those reported in Table 8. In contrast, both short-term and long-term bond issues by firms rated speculative grade do not respond significantly to longevity shocks. In short, a large portion of the corporate response is concentrated among investment-grade firms. Overall, the evidence that highly rated firms whose bonds are held primarily by life insurers respond more elastically to changes in life expectancy supports the view that life insurers act as the primary channel to convey longevity shocks into corporate debt markets.

## 6.2 Nondemographic-sensitive industries

Our tests focus on the aggregate impact of longevity shocks without tracing them back to specific age cohorts and industries. However, demographic changes could lead to shifts in demand for different goods, improving the growth prospects for firms in particular industries. DellaVigna and Pollet (2007) show that demographic patterns that affect specific sectors result in abnormal industry-level returns due to predictable demand growth, i.e., the consumption channel. Other studies show that firms in industries with high expected demand growth invest more in innovation (Acemoglu and Linn, 2004), issue more equity to finance larger investments (DellaVigna and Pollet, 2013), and hold more precautionary cash (Cunha and Pollet, 2020). Could corporate responses reflect changes in investment opportunities generated by demographic patterns that affect specific industries (e.g., firms in healthcare and pharmaceuticals, travel, and leisure)? In other words, the concern is that forecasted consumption demand shifts in specific industries (e.g., age-sensitive industries) could drive our findings.

To address this concern, we exclude the 20 industries identified by DellaVigna and Pollet (2007) as having the highest forecasted standard deviation of consumption growth, which they label as demographic-sensitive industries, most likely to be affected by demographic changes from the consumption perspective.[23] That is, we use a subsample of firms in nondemographic-sensitive industries, which are not sensitive to changes in age cohorts. We find qualitatively similar results, as reported in Internet Appendix Table IF. Firms in nondemographic-sensitive industries also respond to longevity shocks. That is, firms in nondemographic-sensitive industries are more likely to issue long-term debts when longevity increases. This suggests that longevity shocks broadly impact corporate debt issuances across different industries and they affect the economy beyond the consumption channel previously studied in the literature.

# 7 Conclusion

This paper explores how longevity shocks affect life insurers' trades of corporate bonds of specific maturities and how these duration adjustments impact corporate debt markets and debt maturity decisions of firms. Longevity shocks induce life insurers to adjust the duration of their corporate bond holdings as they need to match the duration of their assets

[23]The list in the year 2000 includes child care, children's books, children's clothing, books: college textbooks, books: K-12 school books, drugs, health insurance, funeral homes, nursing home care, construction equipment, floors, housewares, residential construction, clothing (adults), golf, jewelry, life insurance, airplanes, bicycles, and motorcycles.

to that of their liabilities. These adjustments are significant and relatively quick, and our tests indicate that a one-year increase in life expectancy results in about a 0.7-year increase in the duration of life insurers' bond portfolio in the subsequent year. Because life insurance companies hold a significant fraction of outstanding corporate bonds, any shifts in their demand affect the corporate term structure. Therefore, when life expectancy increases, the yields on long-term bonds fall compared to those on short-term bonds, i.e., corporate term spreads move inversely with longevity shocks.

Corporate issuers strategically capitalize on longevity-induced shifts in demand for longer-dated assets by issuing more long-term debt which is relatively cheap when life expectancy increases. This response is significantly more pronounced for firms whose bonds are already in the portfolios of insurance companies. It is also greater for firms with an investment-grade rating.

Our results are important in several ways. First, we demonstrate the significant impact of longevity shocks on corporate bonds. Longevity shocks could have broader effects on the economy beyond the age-sensitive industries previously studied in the literature. Second, we illustrate a plausible transmission channel for longevity shocks into the real economy, i.e., the debt financing cost channel via the insurance sector and bond markets. Finally, we show that improvements in life expectancy reduce long-term financing costs for firms and increase long-term debt issuances at firms that typically issue long-term debt.

# Appendix

## A Variable Definitions, Data Sources, and Sample Period

*Panel A: Longevity shocks*

**LongevityShocks** The first difference in the average period life expectancy of the U.S. population. The average period life expectancy is computed from the period remaining life expectancy and the corresponding exposure. We collect mortality rates, deaths, and exposure data from the Human Mortality Database (HMD). Data are available at `https://www.mortality.org`. See Mila (2019) for more details. The sample period is 1974–2018.

**LocalLongevityShocks** State-level longevity is estimated from state-level human mortality data. The Human Mortality Database (HMD) data is available at `https://usa.mortality.org`. The sample period is 1989–2018.

**LongevityCorr**$_{i,j}$ The time series correlation of longevity shocks between insurer states $i$ and $j$.

**SimilarLongevityShocks**$_{i,j}$ A dummy variable equal to 1 if longevity shocks occur in states where insurers $i$ and $j$ are above or below the sample median in a given year. Otherwise, it is 0.

*Panel B: Macro Variables and Credit Market Conditions*

**CPIGrowth** U.S. CPI growth rate. Source: Federal Reserve Economic Data (item CPIAUCSL), 1990–2019.

**GDPGrowth** U.S. GDP growth rate. Source: Federal Reserve Economic Data (item GDPC1), 1990–2019.

**StateGDPGrowth** State GDP growth rate. Source: U.S. Bureau of Economic Analysis (item SAGDP1), 1990–2019.

**StatePopGrowth** State population growth rate. Source: U.S. Bureau of Economic Analysis (item SAINC51), 1990–2019.

**IndProdGrowth** Industrial production growth rate. Source: Federal Reserve Economic Data (item INDPRO), 1990–2019.

**CreditSpread** The yield difference between Moody's Baa and 20-year Treasury bonds. Source: Federal Reserve Economic Data (item GS20), 1990–2019.

$\triangle$**Treasury1Y** Changes in the 1-year Treasury yield. Source: Federal Reserve Economic Data (item GS1), 1990–2019.

**TermSpread** The yield difference between 10-year and 1-year Treasuries. Data on 10-year and 1-year Treasury yields are from Federal Reserve Economic Data (items GS10 and GS1), 1990–2019.

**TermSpread**$^{\perp}$ The orthogonalized term spread obtained as the residuals of a regression of the term spread (the yield difference between 10-year and 1-year Treasury bonds) on longevity shocks. Data on 10-year and 1-year Treasury yields are from Federal Reserve Economic Data (items GS10 and GS1), 1990–2019.

**EBP** Excess bond premium, as in Gilchrist and Zakrajšek (2012).
Source: `www.federalreserve.gov/econresdata/notes/feds-notes/2016/files/ebp_csv.csv`.

**Amihud** Aggregate bond market Amihud illiquidity, calculated from TRACE data. We first calculate the daily Amihud illiquidity of individual bonds based on the transaction data in TRACE. Second, we computed each bond's annual average Amihud illiquidity using its daily Amihud illiquidity estimates. Third, we take a simple average of bond-level Amihud illiquidity as the bond market Amihud illiquidity measure. Source: Trade Reporting and Compliance Engine (TRACE) data, 2002–2019.

*Panel C: Bond Characteristics*

**$\triangle$CorpTermSpread** The first difference of the yield differences between long- and short-term corporate bonds. Long-term (short-term) bonds have maturities greater than 10 (below 3) years. Source: Mergent FISD, 1990–2019.

**$\triangle$ln(Long term/Short term)** The first difference of the natural logarithm of the ratio of the issue amount of long-term to short-term domestic corporate bonds. Long-term (short-term) bonds have maturities greater than 10 (below 3) years. Source: Mergent FISD, 1990–2019.

**$\triangle$NewBondDuration** The first difference in the duration of new domestic corporate bonds. We compute the Macaulay duration using data on the coupon rate, maturity, and bond prices from Mergent FISD, 1990–2019.

**$\triangle$Yield** The first difference of bond yields. Source: Mergent FISD, 1990–2019.

**$\triangle$IssueSize** The first difference in the sizes of the bonds. The size of the bond issue is measured as the ratio of long-term (or short-term) bond issues to the sum of long-term and short-term bond issues in a state. Source: Mergent FISD, 1990–2019.

*Panel D: Life Insurer Characteristics*

**$\triangle$InsDuration** The first difference of the duration of a life insurer's corporate bond portfolio. We calculate the Macaulay duration using data on the coupon rate, maturity, and bond prices. Source: NAIC, 1995–2019.

**NetBuyLTBond** Net purchase of long-term bonds of a life insurer, scaled by the market value of the insurer's bond portfolio. Long-term bonds are bonds with a duration of 10 years or more. Source: NAIC, 1995–2019.

**NetBuySTBond** Net purchase of short-term bonds of a life insurer, scaled by the market value of the insurer's bond portfolio. Short-term bonds are bonds with a duration of 3 years or less. Source: NAIC, 1995–2019.

**InsRBC** Risk-based capital ratio, calculated as the ratio of adjusted total capital to risk-based capital. A lower RBC ratio indicates a lower capital adequacy. Source: NAIC, 1995–2019.

**InsNPWGrowth** Growth rate of net premiums written. Source: NAIC, 1995–2019.

**InsROA** Profitability of an insurer estimated as net income scaled by the average total assets in current and previous years. Source: NAIC, 1995–2019.

**ln(InsAssets)** The insurer's size is measured as the natural logarithm of the total assets. Source: NAIC, 1995–2019.

**InsLeverage** The ratio of total liabilities to total assets of an insurer. Source: NAIC, 1995–2019.

**Deviation** The distance between a life insurance company's share of life insurance and the industry-level natural hedging share. The share of life insurance is calculated as the direct premium written (DPW) of life insurance scaled by the sum of DPW collected from life insurance and annuities. The industry-level natural hedging share is computed in Appendix ID.

*Panel E: Firm Characteristics*

**InsurerDepFirm** For each firm, we first compute the share of its bonds held by life insurers upon issuance. Next, we calculate the average share of life insurance for each firm. Insurer-dependent (noninsurer-dependent) firms are those with life insurer shares above (below) the cross-sectional median. Source: Mergent FISD, 1990–2019.

**ROA** Firm profitability is measured as operating income before depreciation (oidbp) scaled by the average total assets (at) in current and previous years. Source: Compustat, 1975–2019.

**ln(Assets)** Firm size, the natural logarithm of total assets. Source: Compustat, 1975–2019.

**Leverage** The ratio of total debt (dltt+dlc) to total assets. Source: Compustat, 1975–2019.

**TobinsQ** Market-to-book ratio estimated as the book value of assets plus the market value of common stock (prcc_f $\times$ csho) less the sum of the book value of common stock (ceq) and deferred balance sheet taxes (txdb), divided by the book value of assets. Source: Compustat, 1975–2019.

**Age** Firm age is measured in years from the initial public offering date (*ipodate*). If *ipodate* is missing, then the age is measured in years from the first date in the CRSP. Source: Compustat, 1975–2019.

**Cash** Cash and cash equivalents (che) divided by total assets. Source: Compustat, 1975–2019.

**EquityIssues** Sale of equity (sstk) minus purchases of equity (prstkc), divided by lagged assets. Source: Compustat, 1975–2019.

**NetIncomeGrowth** Net income growth, measured as the log growth rate of net income (ni). Source: Compustat, 1975–2019.

**Tangibility** Net plant, property, and equipment (ppent), scaled by lagged total assets. Source: Compustat, 1975–2019.

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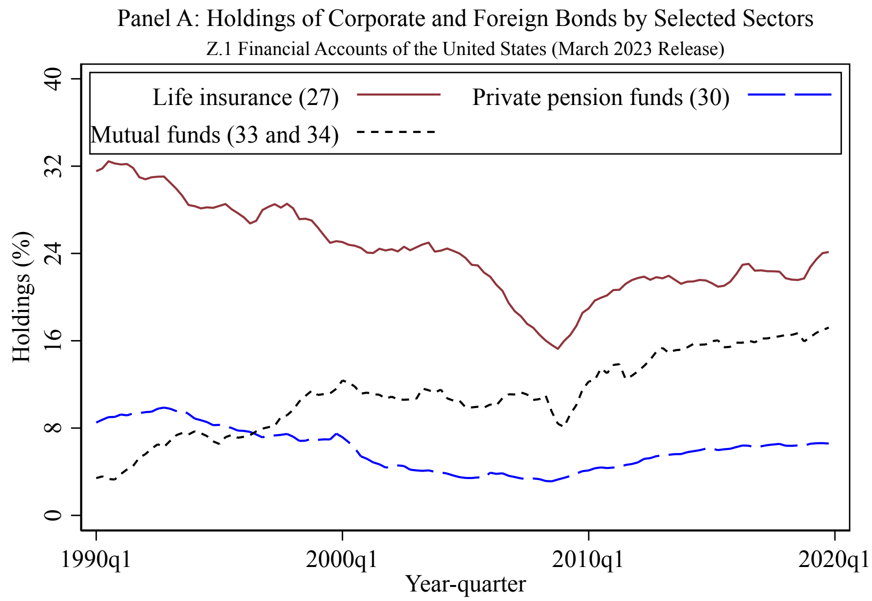


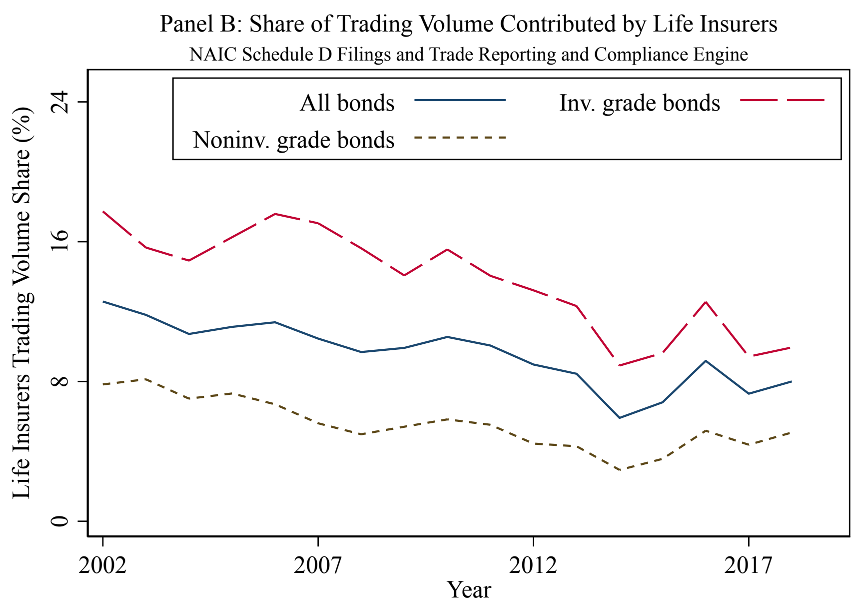




Figure 1: Large holders of corporate and foreign debt in the U.S.

Panel A plots the fraction of outstanding corporate and foreign debt held by U.S. life insurance companies, private pension funds, and mutual funds (from Table L.213 in the Z.1 Financial Accounts of the United States (March 2023 release)). Panel B plots the share of corporate bonds' annual dollar trading volume contributed by life insurers for the 2002–2018 period. The data are from NAIC "Schedule D" filings and the Trade Reporting and Compliance Engine (TRACE).

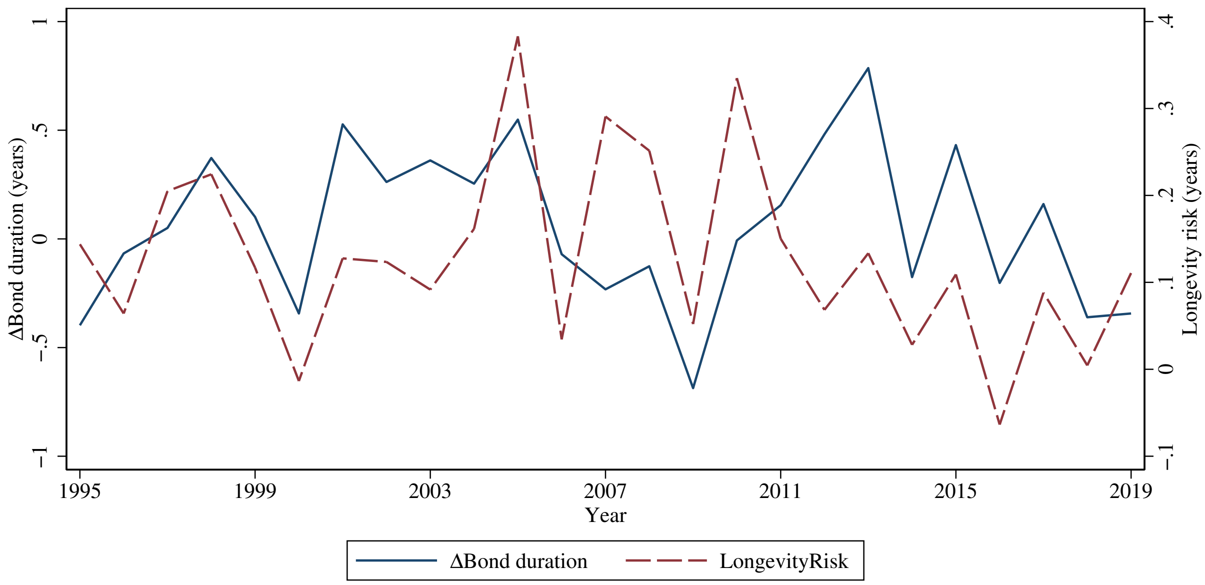
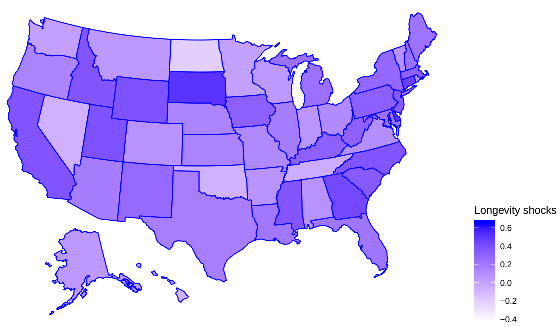
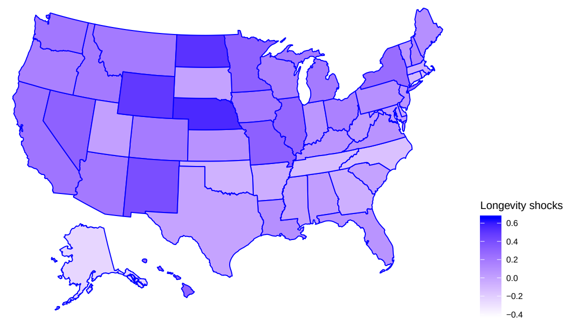



Figure 2: Changes in bond duration of life insurers and longevity shocks

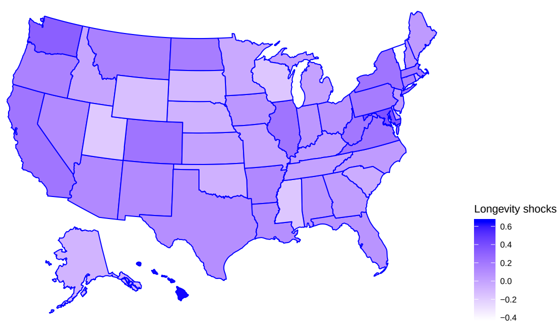
The figure plots changes in the average duration of life insurers' bond holdings (solid blue line) over the 1995–2019 period, together with the 1-year lagged longevity shocks, measured as the first-order difference of the weighted average period life expectancy (red dashed line). The data on life insurance companies' bond holdings come from the National Association of Insurance Commissioners (NAIC). We construct period life expectancy estimates using data from the Human Mortality Database.



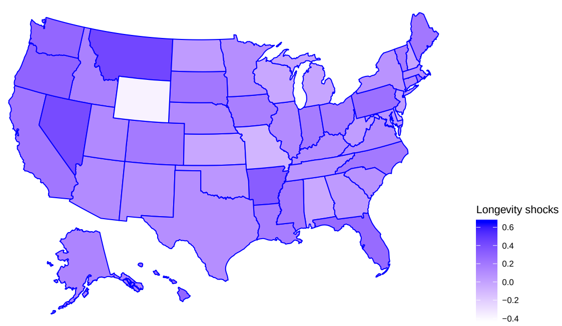

(a) State-level longevity shocks (1990)




(b) State-level longevity shocks (2000)




(c) State-level longevity shocks (2010)




(d) State-level longevity shocks (2018)

Figure 3: State-level longevity shocks across years

Snapshots of the state-level longevity shocks in 1990, 2000, 2010, and 2018. These state-level longevity shocks are estimated as changes in the weighted average of period life expectancy using state-level mortality data over the 1989–2018 period from the U.S. Mortality Database.

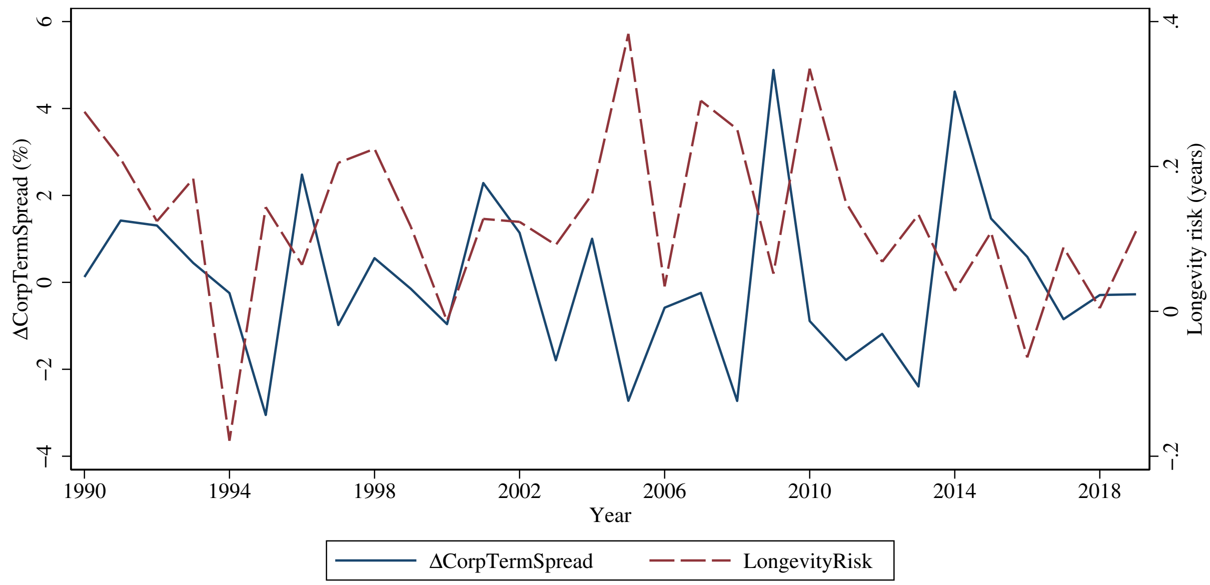



Figure 4: Changes in corporate bond term spreads and longevity shocks

This figure shows the changes in corporate bond term spreads (solid blue line) over the 1990–2019 period, together with the 1-year lagged longevity shock (red dashed line). The spread is the yield difference between long-term bonds (maturity greater than ten years) and short-term bonds (maturity less than three years).

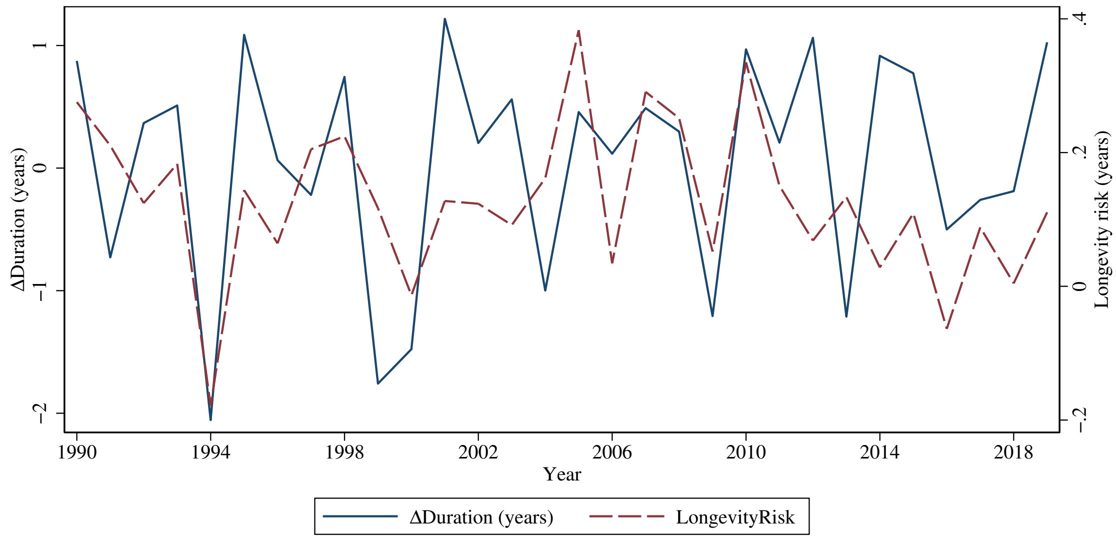



Figure 5: Changes in the average duration of new bond issues and longevity shocks

This figure shows the changes in the average duration of new bond issues (solid blue line) over the 1990–2019 period, together with the 1-year lagged longevity shock (red dashed line). The average duration of new bond issues is computed from FISD, weighted by issue size.

Table 1: Life insurance companies holdings of financial assets: levels and flows

This table presents the composition of life insurance companies' financial assets from Table L.116 in Panel A and transactions from Table F.116 in Panel B in the U.S. national accounts over the 1990-2019 period (Z.1 Financial Accounts, March 9, 2023 release). The row numbers aggregated to construct the series are in parenthesis next to the asset class. Each financial asset item in Panel A is estimated as a fraction of the total financial assets and then averaged over the available years in each five-year period. Each transaction item in Panel B is similarly estimated as a fraction of the net acquisition of financial assets (from row 3 of Table F.116) and then averaged over the available years in each five-year period.

| | All years | 1990-1994 | 1995-1999 | 2000-2004 | 2005-2009 | 2010-2014 | 2015-2019 |
|---|---|---|---|---|---|---|---|
| Panel A: Composition of financial assets (%) | | | | | | | |
| Deposits and liquid assets (2 to 4) | 1.9 | 1.3 | 1.2 | 2.3 | 2.7 | 2.1 | 1.8 |
| **Corporate bonds (10)** | **38.3** | **40.9** | **40.8** | **39.5** | **36.5** | **36.5** | **35.7** |
| Other debt (6 to 9) | 14.1 | 20.4 | 17.0 | 12.5 | 11.5 | 12.4 | 11.0 |
| Loans (11) | 11.7 | 20.7 | 13.1 | 10.0 | 9.3 | 8.1 | 8.8 |
| Corporate equities (14) | 7.9 | 6.7 | 9.2 | 8.6 | 7.7 | 7.4 | 7.7 |
| Mutual fund shares (15) | 15.3 | 3.7 | 12.7 | 16.8 | 19.2 | 19.8 | 19.8 |
| Other financial assets (16 to 20) | 10.9 | 6.4 | 6.1 | 10.4 | 13.2 | 13.9 | 15.2 |
| Panel B: Acquisitions of financial assets (%) | | | | | | | |
| Additions to liquid assets (4 to 6) | -8.7 | 0.8 | 4.1 | 1.4 | -37.8 | -20.7 | 0.1 |
| **Purchase of corporate bonds (12)** | **59.8** | **40.2** | **54.0** | **53.5** | **45.3** | **84.9** | **80.7** |
| Purchase of loans (13) | 6.4 | -16.1 | 6.2 | 5.4 | -1.8 | 8.5 | 36.2 |
| Purchase of other debt (8 to 11) | 20.6 | 48.7 | -4.7 | 5.2 | 50.7 | 21.4 | 2.2 |
| Purchase of equity (16) | 7.5 | 15.3 | 6.0 | -3.0 | 9.8 | 14.1 | 2.8 |
| Purchase of mutual fund shares (16) | 15.3 | 15.2 | 34.2 | 19.7 | 47.1 | -0.6 | -23.7 |
| Purchase of other fin. assets (18 to 22) | -0.9 | -4.2 | 0.1 | 17.7 | -13.4 | -7.6 | 1.7 |

Table 2: Summary statistics

Panel A displays summary statistics for the nationwide longevity shocks (1974-2018) and state-level longevity shocks (1989-2018). Panel B summarizes credit market conditions (1990-2019). Panel C presents the summary statistics on the life insurance companies in our sample (1995-2019). Panel D displays the characteristics of bond issuers (1975–2019). Appendix A defines the variables.

| | | | | Distribution | | | | |
|---|---|---|---|---|---|---|---|---|
| | N | Mean | SD | Min | $P25$ | Median | $P75$ | Max |
| *Panel A: Longevity shocks* | | | | | | | | |
| LongevityShocks | 45 | 0.15 | 0.14 | -0.18 | 0.06 | 0.12 | 0.22 | 0.47 |
| LocalLongevityShocks | 1,530 | 0.10 | 0.21 | -0.60 | -0.03 | 0.10 | 0.24 | 1.10 |
| *Panel B: Bond market characteristics* | | | | | | | | |
| CreditSpread | 30 | 2.07 | 0.86 | 1.11 | 1.49 | 1.95 | 2.38 | 5.25 |
| $\Delta$Treasury1Y | 30 | -0.21 | 1.39 | -3.38 | -0.77 | -0.09 | 0.44 | 3.53 |
| TermSpread | 30 | 1.42 | 1.13 | -0.38 | 0.40 | 1.56 | 2.58 | 3.22 |
| TermSpread$^{\perp}$ | 30 | 0.57 | 0.51 | -0.23 | 0.20 | 0.49 | 0.94 | 1.70 |
| EBP | 30 | 0.11 | 0.74 | -0.75 | -0.33 | -0.10 | 0.40 | 3.03 |
| $\Delta$CorpTermSpread | 30 | 0.03 | 1.91 | -3.05 | -0.98 | -0.24 | 1.14 | 4.89 |
| LTtoSTDebt | 30 | 5.20 | 4.10 | 0.43 | 1.72 | 4.23 | 7.91 | 16.51 |
| $\Delta$NewBondDuration | 30 | 0.04 | 0.91 | -2.06 | -0.50 | 0.25 | 0.77 | 1.22 |
| *Panel C: Life insurer characteristics* | | | | | | | | |
| InsAssets (MM$) | 15,523 | 6,663 | 23,996 | 0.3 | 45 | 338 | 2,413 | 326,382 |
| $\Delta$InsDuration | 15,523 | 0.04 | 1.12 | -3.84 | -0.47 | -0.04 | 0.44 | 4.69 |
| InsLeverage | 15,523 | 0.73 | 0.25 | 0.03 | 0.59 | 0.83 | 0.91 | 0.98 |
| InsRBC | 15,523 | 17.57 | 30.62 | 1.94 | 6.09 | 8.89 | 14.75 | 231.86 |
| InsROA | 15,523 | 0.02 | 0.05 | -0.17 | 0.00 | 0.01 | 0.03 | 0.21 |
| InsNPWGrowth | 15,523 | 0.11 | 1.24 | -3.17 | -0.14 | -0.01 | 0.11 | 9.64 |
| NAIC1 | 10,250 | 0.55 | 0.11 | 0.06 | 0.48 | 0.54 | 0.61 | 1.00 |
| NAIC2 | 10,250 | 0.27 | 0.10 | 0.00 | 0.21 | 0.26 | 0.32 | 0.74 |
| NAIC3 | 10,250 | 0.07 | 0.04 | 0.00 | 0.04 | 0.06 | 0.08 | 0.58 |
| NAIC4 | 10,250 | 0.07 | 0.04 | 0.00 | 0.04 | 0.07 | 0.09 | 0.62 |
| NAIC5 | 10,250 | 0.02 | 0.02 | 0.00 | 0.01 | 0.02 | 0.04 | 0.33 |
| NAIC6 | 10,250 | 0.02 | 0.02 | 0.00 | 0.00 | 0.01 | 0.03 | 0.42 |

Table 2: Continued

| | N | Mean | SD | Distribution | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | Min | $P25$ | Median | $P75$ | Max |
| *Panel D: Firm characteristics* | | | | | | | | |
| Assets (MM$) | 48,131 | 6,669 | 24,314 | 3 | 213 | 906 | 4,058 | 847,409 |
| ROA | 48,131 | 0.16 | 0.07 | -0.25 | 0.11 | 0.15 | 0.20 | 0.38 |
| TobinsQ | 48,131 | 1.63 | 1.07 | 0.52 | 1.00 | 1.29 | 1.88 | 7.80 |
| Leverage | 48,131 | 0.28 | 0.15 | 0.00 | 0.17 | 0.28 | 0.38 | 0.91 |
| Age | 48,131 | 17.14 | 12.54 | 0.00 | 7.00 | 15.00 | 24.00 | 60.00 |
| Cash | 48,131 | 0.08 | 0.10 | 0.00 | 0.02 | 0.05 | 0.11 | 0.62 |
| EquityIssue | 48,131 | 0.01 | 0.07 | -0.15 | -0.00 | 0.00 | 0.01 | 0.53 |
| NIGrowth | 48,131 | 0.06 | 0.72 | -2.69 | -0.17 | 0.08 | 0.31 | 2.55 |
| Tangibility | 48,131 | 0.46 | 0.28 | 0.02 | 0.23 | 0.40 | 0.67 | 1.30 |

Table 3: Effect of longevity shocks on life insurers' bond portfolio duration

The table reports results from panel regressions of changes in life insurer's bond portfolio duration ($\Delta InsDuration_{i,t}$) on longevity shocks ($LongevityShocks_{t-1}$). The control variables include credit market conditions, macroeconomic variables, insurer characteristics, and insurer fixed effects. Columns (4) and (5) sort insurers on their size. Columns (6) and (7) sort them on their exposure to longevity shocks. Appendix A defines the variables. Standard errors are clustered by insurers, and $t$-statistics are reported in parentheses. The sample period is 1995-2019. $^{*}p < 0.10$, $^{**}p < 0.05$, and $^{***}p < 0.01$.

| | | | | Insurers Size | | Longevity Exposure | |
|---|---|---|---|---|---|---|---|
| | | | | Large | Small | High | Low |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| LongevityShocks | 0.687*** | 0.713*** | 0.686*** | 0.907*** | 0.471*** | 0.884*** | 0.471*** |
| | (7.7) | (8.1) | (3.8) | (8.7) | (3.2) | (5.3) | (4.1) |
| TermSpread | 0.091*** | 0.073*** | 0.022 | 0.101*** | 0.072*** | 0.096*** | 0.084*** |
| | (9.3) | (7.3) | (1.4) | (8.2) | (4.6) | (4.6) | (6.8) |
| ReachingForYield | | 0.146*** | | | | | |
| | | (10.0) | | | | | |
| DerivativeHedging | | | 0.525*** | | | | |
| | | | (3.8) | | | | |
| $\Delta$Treasury1Y | -0.036*** | -0.037*** | -0.013 | -0.045*** | -0.028* | -0.057*** | -0.031** |
| | (-3.6) | (-3.6) | (-0.5) | (-3.9) | (-1.7) | (-3.4) | (-2.3) |
| CreditSpread | 0.085*** | 0.067*** | 0.227*** | 0.016 | 0.141*** | 0.099** | 0.111*** |
| | (3.8) | (3.0) | (5.5) | (0.6) | (3.8) | (2.3) | (3.9) |
| CPIGrowth | -0.028** | -0.006 | -0.025 | -0.055*** | -0.003 | -0.057*** | -0.014 |
| | (-2.4) | (-0.5) | (-1.3) | (-4.6) | (-0.1) | (-2.9) | (-0.9) |
| GDPGrowth | 0.102*** | 0.060*** | 0.185*** | 0.080*** | 0.114*** | 0.127*** | 0.114*** |
| | (8.8) | (4.8) | (7.5) | (5.8) | (6.1) | (6.0) | (7.7) |
| StateGDPGrowth | 2.044*** | 1.663*** | 2.299*** | 2.406*** | 2.043** | 0.580 | 2.624*** |
| | (3.8) | (3.2) | (2.9) | (3.4) | (2.6) | (0.6) | (3.8) |
| StatePopGrowth | -9.279*** | -3.992 | -5.941 | -6.269 | -10.714** | -11.709* | -11.435** |
| | (-2.6) | (-1.1) | (-1.2) | (-1.6) | (-2.1) | (-1.7) | (-2.5) |
| Ln(InsAssets) | -0.010 | -0.052*** | -0.118*** | 0.006 | 0.030 | -0.082* | 0.008 |
| | (-0.5) | (-2.6) | (-3.1) | (0.2) | (0.7) | (-1.7) | (0.3) |
| InsLeverage | 0.103 | 0.088 | 0.164 | 0.169 | -0.036 | 0.424 | 0.071 |
| | (0.8) | (0.7) | (0.7) | (0.8) | (-0.2) | (1.1) | (0.5) |

Table 3 Continued

| | | | | Insurers Size | | Longevity Exposure | |
|---|---|---|---|---|---|---|---|
| | | | | Large | Small | High | Low |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| RBCRatio | -0.001 | -0.001 | -0.002 | -0.003 | -0.001 | -0.001 | -0.001 |
| | (-1.1) | (-1.3) | (-1.3) | (-1.0) | (-1.1) | (-0.6) | (-0.9) |
| InsROA | -0.162 | -0.168 | -0.245 | -0.013 | -0.181 | -0.001 | -0.136 |
| | (-0.5) | (-0.6) | (-0.5) | (-0.0) | (-0.5) | (-0.0) | (-0.4) |
| NPWGrowth | 0.022** | 0.024** | 0.036** | 0.011 | 0.038** | 0.031** | 0.012 |
| | (2.4) | (2.5) | (2.5) | (1.0) | (2.4) | (2.1) | (0.9) |
| Insurer FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| $R^2$ | 0.071 | 0.080 | 0.095 | 0.091 | 0.077 | 0.108 | 0.077 |
| Observations | 15,523 | 15,523 | 8,391 | 7,746 | 7,741 | 4,026 | 9,531 |

Table 4: Longevity shocks and life insurers' bond trades

This table examines changes in net purchases of long-term (Panel A) and short-term bonds (Panel B) by insurers in response to changes in life expectancy. Net purchases are scaled by the market value of an insurer's bond portfolio. Long-term bonds have a duration of 10 years or more. Short-term bonds have a duration of three years or less. Column (1) reports estimates of all bond purchases, while columns (2) to (7) report estimates of bond purchases by bond ratings based on six NAIC rating designations. We control for macroeconomic indicators, credit market conditions, and insurer characteristics (see variables in Table 3, column (1)). Variable definitions are collected in Appendix A. Standard errors are clustered by insurers, and $t$-statistics are reported in parentheses. The sample period is 1995-2019. $^{*}p<0.10$, $^{**}p<0.05$, and $^{***}p<0.01$.

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| | | *Bonds with the NAIC Designation* | | | | | |
| | *All bonds* | 1 | 2 | 3 | 4 | 5 | 6 |
| *Panel A:* **Net purchases of long-term bonds** | | | | | | | |
| LongevityShocks | 0.088*** | 0.020*** | 0.017*** | 0.005*** | 0.006*** | 0.002*** | 0.002** |
| | (4.2) | (2.6) | (4.1) | (4.5) | (4.3) | (3.4) | (2.4) |
| Macro controls | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Bond market controls | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Insurer controls | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Insurer fixed effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| $R^2$ | 0.042 | 0.030 | 0.033 | 0.019 | 0.019 | 0.018 | 0.017 |
| N | 14,241 | 14,241 | 14,241 | 14,241 | 14,241 | 14,241 | 14,241 |
| *Panel B:* **Net purchases of short-term bonds** | | | | | | | |
| LongevityShocks | -0.018* | -0.013** | -0.001 | -0.001 | 0.002** | 0.000 | 0.000 |
| | (-1.8) | (-2.4) | (-0.4) | (-1.3) | (2.5) | (0.7) | (0.7) |
| Macro controls | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Bond market controls | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Insurer controls | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Insurer fixed effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| $R^2$ | 0.024 | 0.026 | 0.018 | 0.010 | 0.015 | 0.009 | 0.010 |
| N | 14,241 | 14,241 | 14,241 | 14,241 | 14,241 | 14,241 | 14,241 |

Table 5: Local longevity shocks and local life insurers' duration adjustments

We run panel regressions of the duration adjustment directions of two local life insurers against the comovement between local longevity shocks. The dependent variable is a dummy, which is equal to one if two local life insurers ($i$ and $j$) adjust the duration of their bond portfolios in opposite directions and zero otherwise. Local life insurers make at least 80% of their sales in the state in which they are located. Local longevity shocks represent state-level shocks. Columns (1) and (3) use the correlation coefficient of local longevity shocks faced by insurers (*LongevityCorr*$_{i,j}$). Columns (2) and (4) use a dummy variable (*SimilarLongevityShocks*$_{i,j}$) that equals one if two states have longevity shocks above or below their sample medians simultaneously and zero otherwise. We control for state characteristics (state GDP growth, state population growth) and life insurer characteristics (risk-based capital ratio ($InsRBC$), leverage ($InsLeverage$), return on assets ($InsROA$), growth rate of net premium written ($InsNPWGrowth$), and size ($ln(InsAssets)$)) in all regressions. In columns (1) and (2), we further control for credit market conditions (Credit spread, $\Delta$Treasury1Y, Term spread) and macroeconomic variables (CPIGrowth, GDPGrowth), while in columns (3) and (4), we include year fixed effects. Appendix A defines the variables and lists the data sources. Standard errors are clustered by states of insurer$_i$ and insurer$_j$, and $t$-statistics are in parentheses. The sample period is 1995-2019. $^{*}p<0.10$, $^{**}p<0.05$, and $^{***}p<0.01$.

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| LongevityCorr$_{i,j}$ | -0.024$^{***}$ | | -0.024$^{***}$ | |
| | (-5.3) | | (-5.3) | |
| SimilarLongevityShocks$_{i,j}$ | | -0.009$^{***}$ | | -0.007$^{***}$ |
| | | (-5.7) | | (-3.4) |
| Insurer controls | Yes | Yes | Yes | Yes |
| Insurer$_i$ FE | Yes | Yes | Yes | Yes |
| Insurer$_j$ FE | Yes | Yes | Yes | Yes |
| State macroeconomic controls | Yes | Yes | Yes | Yes |
| U.S. macroeconomic controls and credit market conditions | Yes | Yes | No | No |
| Year FE | No | No | Yes | Yes |
| $R^2$ | 0.010 | 0.010 | 0.017 | 0.018 |
| Observations | 778,246 | 744,576 | 778,246 | 744,576 |

Table 6: Local longevity shocks and local life insurers' bond trades

We run panel regressions of the trading directions of two local life insurers against the correlation between local longevity shocks. The dependent variable is a dummy that equals one if two local life insurers ($i$ and $j$) trade the same bond in opposite directions and zero otherwise. Local life insurers make at least 80% of their revenues from the state they are in. Local longevity shocks represent state-level longevity shocks. We compute and rank bonds based on their investment weights in each insurer, and only bonds on the top $70^{th}$ percentile are included. Columns (1) and (3) use the correlation coefficient of local longevity shocks faced by insurers (*LongevityCorr*$_{i,j}$). Columns (2) and (4) use a dummy variable (*SimilarLongevityShocks*$_{i,j}$) that equals one if two states have longevity shocks above or below their sample medians simultaneously and zero otherwise. We control for macroeconomic variables, credit market conditions, and insurer characteristics, as in Table 5. Columns (3) and (4) include year fixed effects in place of macroeconomic variables. Appendix A defines the variables and lists the data sources. Standard errors are clustered by states of insurer$_i$ and insurer$_j$, and $t$-statistics are in parentheses. The sample period is 1995-2019. $^{*}p<0.10$, $^{**}p<0.05$, and $^{***}p<0.01$.

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| LongevityCorr$_{i,j}$ | -0.026$^{**}$ | | -0.026$^{**}$ | |
| | (-2.3) | | (-2.3) | |
| SimilarLongevityShocks | | -0.004$^{**}$ | | -0.005$^{***}$ |
| | | (-2.1) | | (-2.7) |
| Insurer controls | Yes | Yes | Yes | Yes |
| Insurer$_i$ FE | Yes | Yes | Yes | Yes |
| Insurer$_j$ FE | Yes | Yes | Yes | Yes |
| State macroeconomic controls | Yes | Yes | Yes | Yes |
| U.S. macroeconomic controls and credit market conditions | Yes | Yes | No | No |
| Year FE | No | No | Yes | Yes |
| $R^2$ | 0.042 | 0.042 | 0.046 | 0.046 |
| Observations | 173,376 | 172,695 | 173,376 | 172,695 |

Table 7: Longevity shock, yields and bond issues

This table reports results from regressions of yields, maturities and issue size of bond issues against longevity shocks. Column (1) examines changes in term spreads between long- and short-term corporate bonds. Column (2) studies changes in the average duration of new bond issues, weighted by issue size. Column (3) examines changes in the relative issue size of long-term and short-term bonds. Appendix A defines the variables. $t$-statistics, shown in parentheses, are computed from standard errors using Newey-West corrections of two lags. The sample period is 1990-2019. $^{*}p<0.10$, $^{**}p<0.05$, and $^{***}p<0.01$.

| | (1) ΔCorporate term spread | (2) ΔNewBondDuration | (3) Δln(Long term /Short term) |
|---|---|---|---|
| LongevityShocks | -6.358*** | 2.904*** | 2.227*** |
| | (-3.0) | (3.0) | (3.6) |
| CPIGrowth | 0.282 | -0.141 | -0.001 |
| | (0.9) | (-1.0) | (-0.0) |
| GDPGrowth | 0.129 | 0.006 | -0.120 |
| | (0.3) | (0.0) | (-1.5) |
| CreditSpread | -0.050 | -0.093 | -0.139 |
| | (-0.1) | (-0.3) | (-0.9) |
| ΔTreasury1Y | -0.221 | -0.256* | -0.206* |
| | (-1.0) | (-2.0) | (-1.8) |
| TermSpread | 0.691 | -0.032 | 0.058 |
| | (1.4) | (-0.2) | (0.7) |
| EBP | -0.015 | -0.085 | -0.085 |
| | (-0.0) | (-0.5) | (-1.0) |
| $Constant$ | -1.077 | 0.194 | 0.200 |
| | (-0.5) | (0.2) | (0.4) |
| $R^2$ | 0.260 | 0.366 | 0.561 |
| Observations | 30 | 30 | 30 |

Table 8: Corporate responses to longevity shocks: Bond maturity choices

This table reports results from multinomial logit regression of bond maturity choice against longevity shocks. We classify bonds into four categories: short-term bonds (with a maturity of fewer than three years), medium-term bonds (with a maturity between 3 and 10 years), long-term bonds (with a maturity between 10 and 20 years), and extra long-term bonds (with a maturity longer than 20 years). We use medium-term bonds (with a maturity between 3 and 10 years) as the base category. We control for macroeconomic indicators, credit market conditions, and firm characteristics in all regressions. Appendix A defines the variables. Standard errors are clustered by firm, and $t$-statistics are in parentheses. The sample period is 1990-2019. $^{*}p<0.10$, $^{**}p<0.05$, and $^{***}p<0.01$.

| | Bond issuances, by maturity | | |
|---|---|---|---|
| | $<3$ years | $[10,20)$ years | $\geq 20$ years |
| | (1) | (2) | (3) |
| LongevityShocks | -3.516*** | 0.692* | 2.658*** |
| | (-2.8) | (2.0) | (6.3) |
| CPIGrowth | 0.234 | 0.050 | 0.012 |
| | (1.1) | (1.3) | (0.3) |
| GDPGrowth | 0.592*** | 0.039 | 0.043 |
| | (3.0) | (1.0) | (1.0) |
| CreditSpread | 0.262 | -0.005 | -0.155** |
| | (0.9) | (-0.1) | (-2.2) |
| ΔTreasury1Y | 0.029 | 0.021 | -0.060 |
| | (0.2) | (0.5) | (-1.3) |
| TermSpread | -0.063 | 0.095** | 0.014 |
| | (-0.4) | (2.5) | (0.3) |
| ROA | -0.760 | 0.821 | 1.301* |
| | (-0.4) | (1.5) | (1.7) |
| ln(Assets) | 1.042*** | 0.287*** | 0.819*** |
| | (8.9) | (9.5) | (15.4) |
| TobinsQ | 0.245*** | 0.064 | 0.094 |
| | (2.7) | (1.6) | (1.6) |
| Leverage | -1.224 | -0.917*** | -2.099*** |
| | (-1.4) | (-3.7) | (-6.0) |
| Age | 0.032*** | 0.005* | 0.024*** |
| | (3.7) | (1.9) | (6.7) |

Table 8 Continued

| | Bond issuances, by maturity | | |
|---|---|---|---|
| | $<$ 3 years | $[10, 20)$ years | $\geq$ 20 years |
| | (1) | (2) | (3) |
| Cash | -4.146 | -0.323 | -1.399$^{*}$ |
| | (-1.4) | (-0.6) | (-1.9) |
| EquityIssue | -3.132 | -0.341 | -2.259$^{***}$ |
| | (-1.1) | (-0.9) | (-3.3) |
| NIGrowth | -0.000 | 0.007 | 0.029$^{**}$ |
| | (-0.0) | (0.7) | (2.4) |
| Tangibility | 0.241 | -0.105 | 0.972$^{***}$ |
| | (0.5) | (-0.8) | (5.5) |
| Years 1995-1999 | 1.526$^{**}$ | 0.380$^{***}$ | 1.136$^{***}$ |
| | (2.3) | (2.6) | (6.7) |
| Years 2000-2004 | 1.664$^{**}$ | 0.566$^{***}$ | 0.675$^{***}$ |
| | (2.2) | (3.6) | (3.6) |
| Years 2005-2009 | 1.163$^{**}$ | 0.359$^{***}$ | -0.528$^{***}$ |
| | (2.0) | (3.2) | (-3.6) |
| Years 2010-2014 | 0.830 | 0.173 | -0.363$^{**}$ |
| | (1.3) | (1.5) | (-2.5) |
| $Constant$ | -16.670$^{***}$ | -2.625$^{***}$ | -8.249$^{***}$ |
| | (-9.8) | (-6.6) | (-13.7) |
| $R^2$ | 0.122 | | |
| Observations | 6,806 | | |

Table 9: Maturity choices by insurer-dependent and highly-rated firms

This table reports results from multinomial logit regression of bond maturity choice against longevity shocks for firms classified by insurer dependence (Panel A) and debt rating (Panel B). The base category is medium-term bonds (with a maturity between three and ten years). Insurer-dependent (non-insurer-dependent) firms have life insurer shares above (below) the cross-sectional median. Investment grade firms are designated NAIC 1 or 2. Both panels use the same controls used in Table 8. Appendix A defines the variables. Standard errors are clustered by firm, and $t$-statistics are in parentheses. The sample period is 1995-2019 for Panel A and 1990-2019 for Panel B. $^{*}p<0.10$, $^{**}p<0.05$, and $^{***}p<0.01$.

*Panel A: Sorted by insurer dependence*

| | Insurer-dependent firms | | | Non-insurer-dependent firms | | |
|---|---|---|---|---|---|---|
| | Bond issuances, by maturity | | | Bond issuances, by maturity | | |
| | $<3$ years | $[10,20)$ years | $\geq 20$ years | $<3$ years | $[10,20)$ years | $\geq 20$ years |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| LongevityShocks | -4.734$^{*}$ | 1.559$^{**}$ | 2.779$^{***}$ | -4.330 | 0.709 | 0.791 |
| | (-1.7) | (2.1) | (3.6) | (-1.4) | (1.2) | (1.0) |
| Macro controls | Yes | Yes | Yes | Yes | Yes | Yes |
| Credit conditions | Yes | Yes | Yes | Yes | Yes | Yes |
| Insurer controls | Yes | Yes | Yes | Yes | Yes | Yes |
| Firm controls | Yes | Yes | Yes | Yes | Yes | Yes |
| Period indicators | Yes | Yes | Yes | Yes | Yes | Yes |
| $R^2$ | 0.110 | | | 0.133 | | |
| Observations | 2,932 | | | 3,067 | | |

*Panel B: Sorted by debt rating*

| | Investment-grade firms | | | Speculative-grade firms | | |
|---|---|---|---|---|---|---|
| | Bond issuances, by maturity | | | Bond issuances, by maturity | | |
| | $<3$ years | $[10,20)$ years | $\geq 20$ years | $<3$ years | $[10,20)$ years | $\geq 20$ years |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| LongevityShocks | -3.339$^{***}$ | 1.451$^{***}$ | 3.377$^{***}$ | 5.514 | -0.189 | 1.758 |
| | (-2.6) | (2.9) | (6.7) | (0.6) | (-0.4) | (1.5) |
| Macro controls | Yes | Yes | Yes | Yes | Yes | Yes |
| Credit conditions | Yes | Yes | Yes | Yes | Yes | Yes |
| Insurer controls | Yes | Yes | Yes | Yes | Yes | Yes |
| Firm controls | Yes | Yes | Yes | Yes | Yes | Yes |
| Period indicators | Yes | Yes | Yes | Yes | Yes | Yes |
| $R^2$ | 0.068 | | | 0.106 | | |
| Observations | 4,415 | | | 2,391 | | |

# Internet Appendix

## IA U.S. Life Expectancy and Longevity Shocks, 1950–2018

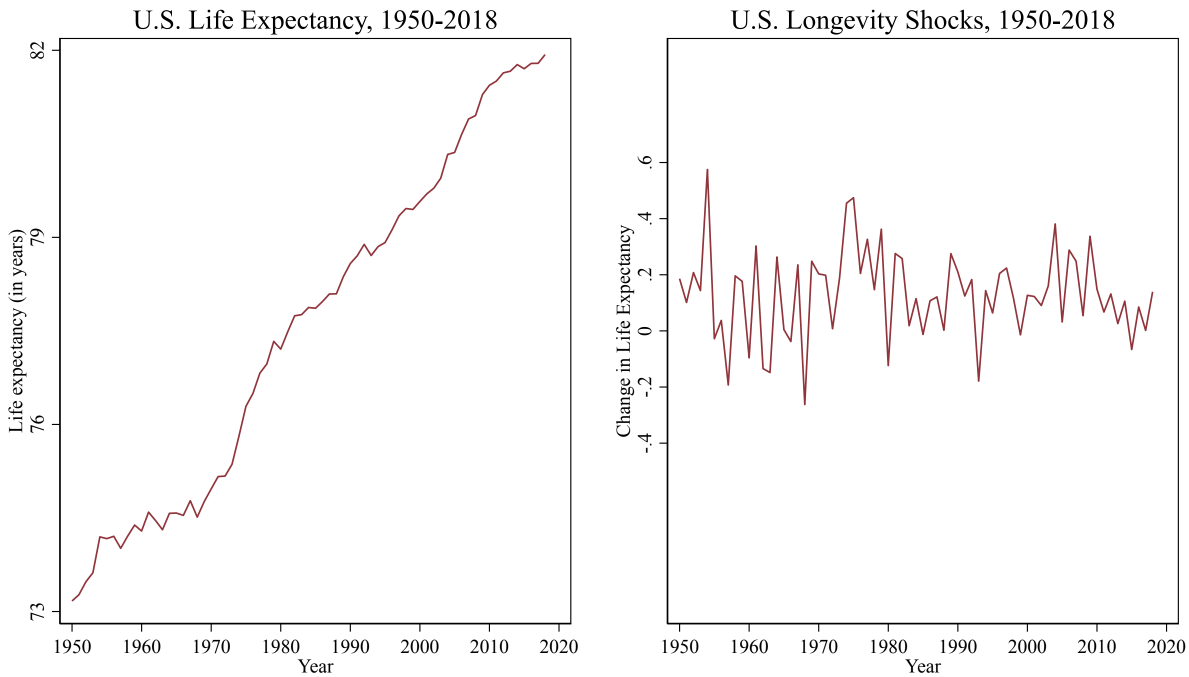



Figure A.1: U.S. Life Expectancy and Longevity Shocks, 1950-2018

The figure plots the weighted average period life expectancy in the U.S. population and changes in life expectancy over the period of 1950-2018. We construct life expectancy estimates using data from the Human Mortality Database.

## IB Holdings of Corporate and Foreign Bonds by Major Sectors, 1990–2019

This table presents the average holdings of corporate and foreign bonds by major sectors reported in the U.S. national accounts. The data are from Table L.213 of the U.S. national accounts for the 1990-2019 period (Z.1 Financial Accounts (March 9, 2023 release). The holdings of each sector (row numbers in parentheses) are expressed as a percentage of total bonds outstanding (row 1 of L.213) and averaged over the available years in each five-year period. The aggregate data shows that life insurers are important players in corporate debt markets.

| | All years | Five-year periods | | | | | |
|---|---|---|---|---|---|---|---|
| | 1990-2019 | 1990-1994 | 1995-1999 | 2000-2004 | 2005-2009 | 2010-2014 | 2015-2019 |
| *All sectors* | *100.0* | *100.0* | *100.0* | *100.0* | *100.0* | *100.0* | *100.0* |
| Household sector (13) | 10.6 | 14.3 | 16.5 | 10.3 | 8.5 | 10.9 | 3.1 |
| Federal/state government (14 and 15) | 1.5 | 1.0 | 1.4 | 1.8 | 1.6 | 1.7 | 1.7 |
| Banks (16, 19 to 21) | 7.8 | 9.0 | 6.2 | 8.3 | 10.3 | 7.5 | 5.7 |
| Property-casualty insurance (24) | 3.9 | 4.7 | 4.1 | 3.7 | 2.9 | 3.7 | 4.1 |
| **Life insurance companies (27)** | **24.1** | **30.5** | **27.3** | **24.4** | **18.9** | **21.1** | **22.3** |
| Private pension funds (30) | 6.0 | 9.2 | 7.4 | 4.7 | 3.5 | 5.1 | 6.4 |
| Government retirement funds (30 to 32) | 5.2 | 7.6 | 6.5 | 4.7 | 3.8 | 4.5 | 4.4 |
| Mutual funds (33 and 34) | 11.1 | 5.7 | 9.0 | 11.1 | 10.2 | 14.2 | 16.2 |
| Closed-end funds and ETF (35 and 36) | 1.4 | 0.9 | 0.8 | 0.7 | 0.9 | 1.9 | 3.5 |
| Other institutions (37, 40 to 44) | 7.3 | 5.7 | 8.0 | 10.7 | 11.2 | 5.3 | 2.7 |
| Rest of the world (45) | 20.2 | 11.6 | 12.9 | 18.8 | 23.9 | 24.7 | 29.4 |
| Discrepancy (48) | 0.8 | -0.2 | -0.2 | 0.8 | 4.3 | -0.7 | 0.5 |

## IC NAIC Designation and Risk-based Capital Requirements for Bonds

This table reports the NAIC designation of bonds based on S&P ratings and the corresponding risk-based capital (RBC) requirement for life insurers in 2018. See more details at `https://www.naic.org/`.

| | S&P ratings | RBC |
|---|---|---|
| NAIC Designation 1 | AAA/AA+/AA/AA-/A+/A/A- | 0.39% |
| NAIC Designation 2 | BBB+/BBB/BBB- | 1.26% |
| NAIC Designation 3 | BB+/BB/BB- | 4.46% |
| NAIC Designation 4 | B+/B/B- | 9.70% |
| NAIC Designation 5 | CCC+/CCC/CCC- | 22.31% |
| NAIC Designation 6 | CC/C/D | 30.00% |

## ID Natural Hedge Ratio of Life Insurance Companies

We derive the natural hedge ratio of life insurance by assuming a mortality process similar to the seminal Lee-Carter model (Lee and Carter, 1992). The Lee-Carter model assumes that the logarithm of $m_{x,t}$, the mortality rate for age $x$ in year $t$, has the following linear relationship:

$$\log\left(m_{x,t}\right) = \alpha_x + \beta_x \kappa_t, \tag{D.1}$$

where $\alpha_x$ is a static age function specifying the general shape of mortality by age, $\beta_x \kappa_t$ captures the age-period effect, with $\kappa_t$ reflecting the overall mortality trend (period-related effect) and $\beta_x$ modulating its effect across ages (age-related effect). $\kappa_t$ is commonly known as the mortality index, which captures the overall level of mortality improvement. The Lee-Carter model is only identifiable up to a transformation. Therefore, in the literature, it is conventional to impose the following parameter constraints to circumvent the identification problem:

$$\sum_t \kappa_t = 0, \qquad \sum_x \beta_x = 1. \tag{D.2}$$

Based on the Lee-Carter model, the probability that an individual aged $x$ dies in year $t$, $q_{x,t}$, can be computed from $m_{x,t}$ through the approximation, $q_{x,t} \approx 1 - \exp(-m_{x,t})$. This approximation implicitly assumes a stationary population and that the force of mortality over each year of integer age and each calendar year is a constant. Let $S_{x,t}(T)$ be the *ex post* probability that an individual aged $x$ at time $t$ would have survived to time $t+T$, then

$$S_{x,t}(T) = \prod_{s=1}^{T} \Big(1 - q_{x+s-1,t+s}\Big). \tag{D.3}$$

Let $\mathcal{F}_t$ be the filtration up to and including time $t$. Then, $q_{x,t}$ is unknown prior to time $t$ and $S_{x,t}(T)$ is unknown before time $t+T$. We further define the expected survival probability as

$$p_{x,u}\Big(T, \kappa_t\Big) = \mathsf{E}\Big(S_{x,u}(T)|\mathcal{F}_t\Big) = \mathsf{E}\Big(S_{x,u}(T)|\kappa_t\Big). \tag{D.4}$$

When $u = t$, we call $p_{x,u}\Big(T, \kappa_t\Big)$ a spot survival probability, whereas when $u > t$, we call it a forward survival probability.

Let us assume that the life insurer has an annuity portfolio for cohorts from the same population aged $x_1, x_2, \dots, x_k$ at time 0. The annuity pays each annuitant \$1 at the end of each year until death. Thus, the annuity plan's future liability per survival annuitant at time $t$ is calculated as

$$FL_t^A = \frac{1}{k} \sum_{x=x_1}^{x_k} \sum_{s=1}^{\infty} (1+r)^{-s} p_{x,t}(s, \kappa_t), \tag{D.5}$$

where $r$ is the annual interest rate and superscript $A$ denotes an annuity business line.

Now, let us consider the life insurance business. Similar to $S_{x,t}(T)$, we can define $D_{x,t}(T)$ as the *ex post* probability that an individual aged $x$ at time $t$ would have survived to time $t+T-1$ and died in year $t+T$. Then we have

$$D_{x,t}(T) = \prod_{s=1}^{T-1}\Big(1 - q_{x+s-1,t+s}\Big) \cdot q_{x+T-1,t+T}. \tag{D.6}$$

Given $D_{x,t}(T)$, we can define the expected death probability as

$$q_{x,u}\Big(T, \kappa_t\Big) = \mathsf{E}\Big(D_{x,u}(T)|\mathcal{F}_t\Big) = \mathsf{E}\Big(D_{x,u}(T)|\kappa_t\Big). \tag{D.7}$$

Assume that the life insurer provides life insurance for the same cohort from the same population. Then, the insurance's future liability per death at time $t$ can be expressed as

$$FL_t^L = \frac{1}{k}\sum_{x=x_1}^{x_k}\sum_{s=1}^{\infty}(1+r)^{-s}q_{x,t}(s,\kappa_t), \tag{D.8}$$

where superscript $L$ denotes a life insurance business line.

The natural hedge simulation is based on the following assumptions:

1. The insurer provides both annuity and life insurance to cohorts aged $x_1 = 35, x_2 = 36, \ldots, x_k = 80$ at time 0. The mortality experience of these individuals is identical to that of the total U.S. population.

2. The annuity plan pays each individual \$1 at the end of each year until death or year 20, whichever comes first.

3. The 20-year term life insurance pays \$1 upon death.

4. The interest rate is assumed to be $r = 1\%$ per annum. The interest rate remains constant over time.

5. The U.S. mortality index is estimated using all available mortality data from the HMD, with the sample period from 1933 to 2018 and an age range of 0-99.

6. To match the endpoint of the sample period, we set time 0 at the end of 2018.

7. We evaluate the effectiveness of the natural hedge based on $N = 10,000$ rounds of simulation generated from the Lee-Carter model in Equation (D.1).

Suppose that the insurer's portfolio contains $X$ shares of annuities, and let $\theta X$ be the number of shares of life insurance in the portfolio. Then, the insurer's total liability at time

0 is $FL_0 = (FL_0^A + \theta FL_0^L)X$. To achieve a natural hedge, the insurer wishes to minimize the variance of its portfolio's future liability, that is,

$$\min_{\theta} \mathsf{Var}(FL_0), \tag{D.9}$$

where $FL_0 = (FL_0^A + \theta FL_0^L)X$.

Let $P^A$ and $P^L$ be the total premiums collected from annuities and life insurance, respectively, and then the proportion of premiums collected from the life insurance business is calculated as

$$\frac{P^L}{P^A + P^L} = \frac{\theta \mathsf{E}(FL_0^L)}{\mathsf{E}(FL_0^A) + \theta \mathsf{E}(FL_0^L)}. \tag{D.10}$$

The optimal ratio ($\frac{P^L}{P^A+P^L}$) is 81.9% in our simulation. That is, a portfolio of 81.9% of life insurance is naturally hedged against longevity shocks. This result is robust to different cohort sets and annuity and term life insurance horizons. Life insurers are far from the natural hedging ratio because the average industry share of life insurance is 31.6% from 1995 to 2019.

## IE Insurers' responses to longevity shocks: Further tests

In columns (1)-(4), the dependent variable is the change in a life insurer's bond portfolio duration ($\Delta$*InsDuration*). Column (1) adds the average Amihud illiquidity of corporate bonds ($Amihud$) as an additional control to our baseline specification. Column (2) uses longevity shocks orthogonal to business cycles, with the latter measured as the cyclical component of industrial production growth computed from the Hodrick–Prescott filter. Column (3) considers responses of local life insurers (with at least 80% of revenue from one state) to local (state-level) longevity shocks ($LocalLongevityShocks$). Column (4) considers a subsample of negative local longevity shocks. In column (5), the dependent variable is the change in a property and casualty (P&C) insurer's bond portfolio duration ($\Delta$*InsDuration*). We control for macroeconomic indicators, credit market conditions, and insurer characteristics. Appendix A provides detailed variable definitions. Standard errors are clustered by insurers, and $t$-statistics are reported in parentheses. The sample period is 1995-2019, except for column (1), where we include $Amihud$, which limits us to 2002-2019. $^{*}p<0.10$, $^{**}p<0.05$, and $^{***}p<0.01$.

| | Life insurers | | | | P&C insurers |
|---|---|---|---|---|---|
| | Illiquidity | Business cycles | Local longevity | Negative local longevity | |
| | (1) | (2) | (3) | (4) | (5) |
| LongevityShocks | 0.628*** | | | | 0.097 |
| | (5.3) | | | | (1.1) |
| Amihud | -0.734*** | | | | |
| | (-5.4) | | | | |
| LongevityShocks$^{\perp}$ | | 0.771*** | | | |
| | | (8.6) | | | |
| LocalLongevityShocks | | | 0.408*** | 1.154** | |
| | | | (4.1) | (2.3) | |
| TermSpread | 0.072*** | 0.100*** | 0.065*** | -0.016 | 0.010 |
| | (5.6) | (10.2) | (4.3) | (-0.5) | (1.0) |
| $\Delta$Treasury1Y | -0.020 | -0.029*** | -0.054** | -0.096** | -0.165*** |
| | (-1.2) | (-2.9) | (-2.6) | (-2.4) | (-16.0) |
| CreditSpread | 0.250*** | 0.074*** | 0.090* | -0.057 | -0.014 |
| | (7.0) | (3.3) | (1.7) | (-0.4) | (-0.6) |
| CPIGrowth | 0.036* | -0.027** | -0.037 | -0.153** | -0.062*** |
| | (1.9) | (-2.3) | (-1.6) | (-2.4) | (-5.1) |
| GDPGrowth | 0.164*** | 0.101*** | 0.104*** | 0.089 | 0.076*** |
| | (8.5) | (8.7) | (3.8) | (1.5) | (5.2) |

Table IE Continued

| | Life insurers | | | | P&C insurers |
|---|---|---|---|---|---|
| | Illiquidity | Business cycles | Local longevity | Negative local longevity | |
| | (1) | (2) | (3) | (4) | (5) |
| StateGDPGrowth | 1.537** | 1.973*** | 2.305 | 4.365 | 1.045** |
| | (2.4) | (3.7) | (1.2) | (1.4) | (2.2) |
| StatePopGrowth | 0.210 | -9.482*** | -11.575*** | -18.795*** | 8.778*** |
| | (0.0) | (-2.7) | (-2.8) | (-4.2) | (4.1) |
| Ln(InsAssets) | -0.085*** | -0.010 | -0.010 | -0.137** | -0.049** |
| | (-3.0) | (-0.5) | (-0.4) | (-2.2) | (-2.0) |
| InsLeverage | 0.229 | 0.101 | -0.246 | 0.226 | 0.091 |
| | (1.3) | (0.8) | (-1.2) | (0.7) | (0.8) |
| RBCRatio | -0.002 | -0.001 | -0.002*** | -0.003 | 0.000 |
| | (-1.6) | (-1.1) | (-3.6) | (-1.5) | (0.4) |
| InsROA | -0.333 | -0.167 | -0.357 | -1.033 | -0.281 |
| | (-0.8) | (-0.6) | (-0.5) | (-1.1) | (-1.2) |
| NPWGrowth | 0.038*** | 0.022** | 0.021 | -0.033 | 0.027 |
| | (3.2) | (2.4) | (1.3) | (-1.3) | (1.4) |
| Insurer FE | Yes | Yes | Yes | Yes | Yes |
| $R^2$ | 0.087 | 0.072 | 0.067 | 0.199 | 0.065 |
| Observations | 11,447 | 15,523 | 5,689 | 1,238 | 28,045 |

## IF Corporate responses to longevity shocks: Nondemographic-sensitive industries

This table reports results from multinomial logit regression of bond maturity choice against longevity shocks, using a subsample of firms in nondemographic-sensitive industries only. Demographic-sensitive industries are classified as in DellaVigna and Pollet (2007). We classify bonds into four categories: short-term bonds (with a maturity of fewer than three years), medium-term bonds (with a maturity between 3 and 10 years), long-term bonds (with a maturity between 10 and 20 years), and extra long-term bonds (with a maturity longer than 20 years). We use medium-term bonds (with a maturity between 3 and 10 years) as the base category. We control for macroeconomic indicators, credit market conditions, and firm characteristics in all regressions. Appendix A defines the variables. Standard errors are clustered by firm, and $t$-statistics are in parentheses. The sample period is 1990-2019. $^{*}p<0.10$, $^{**}p<0.05$, and $^{***}p<0.01$.

| | Bond issuances, by maturity | | |
|---|---|---|---|
| | $<3$ years | $[10,20)$ years | $\geq 20$ years |
| | (1) | (2) | (3) |
| LongevityRisk | -3.403$^{*}$ | 1.478$^{***}$ | 2.999$^{***}$ |
| | (-1.9) | (2.8) | (5.2) |
| CPIGrowth | 0.583$^{*}$ | 0.019 | 0.004 |
| | (1.8) | (0.3) | (0.1) |
| GDPGrowth | 0.940$^{***}$ | 0.100$^{*}$ | 0.081 |
| | (3.2) | (1.8) | (1.4) |
| CreditSpread | -0.458 | -0.007 | -0.123 |
| | (-1.2) | (-0.1) | (-1.3) |
| $\Delta$Treasury1Y | -0.332 | -0.067 | -0.100 |
| | (-1.6) | (-1.1) | (-1.6) |
| TermSpread | -0.262 | 0.054 | -0.038 |
| | (-1.2) | (1.0) | (-0.6) |
| ROA | 0.098 | 0.944 | -0.637 |
| | (0.0) | (1.3) | (-0.7) |
| Ln(Assets) | 1.081$^{***}$ | 0.285$^{***}$ | 0.657$^{***}$ |
| | (7.2) | (6.4) | (9.2) |
| TobinsQ | 0.110 | 0.052 | 0.064 |
| | (0.7) | (0.9) | (0.9) |
| Leverage | 1.223 | -0.425 | -1.196$^{**}$ |
| | (0.8) | (-1.0) | (-2.2) |
| Age | 0.031$^{***}$ | 0.004 | 0.026$^{***}$ |
| | (2.6) | (1.3) | (5.6) |

Table IF Continued

| | Bond issuances, by maturity | | |
|---|---|---|---|
| | $< 3$ years | $[10, 20)$ years | $\geq 20$ years |
| | (1) | (2) | (3) |
| Cash | -0.766 | -0.455 | -2.211 |
| | (-0.2) | (-0.5) | (-1.6) |
| EquityIssue | -1.051 | -0.550 | -2.360*** |
| | (-0.4) | (-0.9) | (-2.7) |
| NIGrowth | -0.018 | 0.001 | 0.040** |
| | (-0.3) | (0.1) | (2.2) |
| Tangibility | 0.224 | -0.024 | 0.870*** |
| | (0.4) | (-0.1) | (3.5) |
| Year 1995-1999 | 0.828 | 0.465** | 1.157*** |
| | (0.9) | (2.1) | (4.9) |
| Year 2000-2004 | 0.050 | 0.334 | 0.308 |
| | (0.1) | (1.4) | (1.2) |
| Year 2005-2009 | 0.436 | 0.184 | -0.529*** |
| | (0.6) | (1.0) | (-2.7) |
| Year 2010-2014 | -0.221 | 0.210 | -0.447** |
| | (-0.3) | (1.2) | (-2.2) |
| $Constant$ | -17.495*** | -2.893*** | -6.667*** |
| | (-7.8) | (-4.8) | (-8.1) |
| $R^2$ | 0.103 | | |
| Observations | 3296 | | |