Life Expectancy and Corporate Debt Markets

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Abstract

Longevity shocks shift life insurers' demand for bonds of specific maturities. We show that these shifts have real consequences for a firm's financing and investment policies. Life insurance companies increase purchases of long-term bonds when longevity increases. Consequently, long-term bond yields fall. The corporate sector absorbs these shocks by shifting to long-term debt issuances, while increasing investments in long-term assets. The effects are particularly marked where life insurers are the primary holders of a firm's debt. The response is also more pronounced for firms that rely on long-term financing and those that are financially unconstrained.

JEL classification: G12, G22, G32, J11

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1 Introduction

Although human life expectancy is on an increasing trend, year-to-year changes continue to be unpredictable. A confluence of environmental, health care, lifestyle, biological, institutional, and socioeconomic factors drive year-to-year variation in average life expectancy.[1] Take, for example, U.S. life expectancy, which increased from 71.9 years in 1974 to 78.6 years as of 2018, an annual increase of 0.15 years, on average. However, the changes came with significant ups and downs, growing 0.47 years in 1975 and falling 0.18 years in 1993.

Changes in life expectancy affect insurance companies that sell life-related and long-dated products, such as life insurance policies and annuities. Regulatory mandates require that life insurers match asset-liability duration almost annually.[2] Thus, when longevity increases, the duration of insurance liabilities increases, prompting insurance firms to hedge the duration mismatch by purchasing longer-term assets. Costly duration mismatches trigger regulatory and rating scrutiny, so life insurance firms make relatively quick adjustments to the maturity of their assets in the direction of the change in life expectancy.

Much of the maturity adjustment by life insurance companies is likely to be concentrated in their corporate bond holdings. While they could feasibly adjust the duration of their Treasury holdings and their equity portfolio,[3] corporate bonds constitute the majority of their assets. In 2018, for example, corporate bonds constituted about 56% of the invested assets of life insurance companies. Insurance companies are also major holders of outstanding corporate bonds. According to the Financial Accounts of the United States (Z.1), life insurance companies held, on average, about 46% of all domestic nonfinancial

[1] See, for example, Fuchs (2004), Shaw et al. (2005), Cutler et al. (2006), OECD (2010), Moreno-Serra and Smith (2015), Chetty et al. (2016), Chiu and Pain (2018), and Woolf and Schoomaker (2019).

[2] See NAIC (2017) and requirements under the Risk Management and Own Risk and Solvency Assessment Model Act. Furthermore, both S&P and Moody's consider duration mismatch risk in their ratings.

[3] Chen et al. (2021) examine the effect of longevity shocks on equity holdings of life insurers.

corporate bonds outstanding during 1990-2018 (see Appendix A). The importance of life insurance firms as significant holders of corporate bonds raises questions about the transmission of longevity shocks to bond yields, bond issuances, and long-term investments by corporations that rely on corporate bonds for their financing. This paper examines the following questions: How do longevity shocks affect pricing (corporate term spreads) and the issuance of corporate bonds of specific maturities? How does the corporate sector absorb these shocks? In particular, how do longevity shocks affect long-term corporate investments and the overall maturity of assets on corporate balance sheets?

We begin by documenting that life insurance companies' corporate bond portfolio duration reacts to changes in life expectancy. We notice a strong correlation between the average duration of insurers' corporate bond portfolios and changes in U.S. life expectancy (see Figure 1). In further tests, we find that life insurance companies increase the duration of their bond portfolios by about 0.7 to 0.8 years for every one-year increase in life expectancy. Importantly, they do so by actively trading bonds of specific maturities. When life expectancy increases, life insurance companies significantly increase purchases of long-term corporate bonds, while selling shorter-term investment-grade bonds.

In tests that exploit the significant geographic dispersion in longevity shocks, we examine bond trades of "local" (state-level) insurers and find that these trades respond to local longevity shocks rather than to national economic conditions. These tests take advantage of significant state-level differences in exposure to factors that drive life expectancy and confirm that two local life insurers make opposite trades in the same bond if they are located in states with negatively correlated longevity shocks.

Next, we examine the consequences of a shift in life insurers' demand for corporate bonds of specific maturities. Greenwood et al. (2010) and Badoer and James (2016) show that excess demand in segments of the term structure cannot be arbitraged away completely, which introduces predictability into the relative returns on bonds of different maturities that corporate issuers exploit by adjusting bond issuances. We find a similar dynamic at play in our setting: unexpected increases in longevity increase demand for long-term corporate bonds, thereby lowering long-term corporate bond yields and eliciting a supply response from corporate issuers who "fill the gap" by issuing longer-dated bonds.

Our remaining findings are as follows. First, we document that yield spreads between long-term and short-term bonds move inversely with changes in life expectancy. During periods of increasing life expectancy, corporate term spreads decline. Second, we find that corporations issue more long-term debt when life expectancy increases; longevity shocks are thus positively related to increases in the weighted average duration of new corporate bond issuances. Third, we show that longevity risk is mainly conveyed to the corporate sector via the insurance sector. In particular, firms whose bonds are primarily held by life insurers exhibit significantly pronounced supply elasticities in response to longevity shocks. Furthermore, that the response mainly comes from investment-grade issuers matches life insurers' demand for highly rated bonds to comply with regulatory requirements.

Finally, we find strong evidence that longevity shocks disproportionately affect the availability of credit for firms more dependent on long-term debt and financially unconstrained firms since they have the flexibility to adjust their issuances. Firms invest relatively more in research and development, increase capital expenditures, and increase the maturity of their assets when life expectancy increases. In sum, longevity shocks improve credit availability for firms that can more readily supply macro liquidity to the long-term corporate debt market. In particular, firms with a preference for long-term debt and those with fewer constraints in accessing debt markets issue more long-term bonds and deploy the proceeds to fund long-term assets.

The evidence indicates that longevity risks impart significant consequences on corporations' financing and investment policies, with the insurance sector, traditionally a considerable buyer of corporate bonds, as the primary channel. Overall, we show longevity improvements that increase demand for long-term corporate debt significantly affect the real economy by reducing long-term debt costs and stimulating long-term investment.

The paper contributes to three strands of research. First, we contribute to the emerging literature on the investment behavior of financial intermediaries, such as life insurance companies. Several recent papers examine the effect of low-interest rates on the asset adjustment decisions of insurance companies, with low rates driving a tilt toward longer-dated bonds (Domanski et al., 2017; Ozdagli and Wang, 2020; Yu, 2020). While Becker and Ivashina (2015) find evidence of excess yields in insurance companies' bond portfolios, Ozdagli and Wang (2020) find that this documented excess yield is mostly driven by a duration tilt rather than a credit risk tilt. In contrast to these papers, which focus on low-interest rates, we highlight the importance of longevity shocks in driving life insurance companies' adjustment to their corporate bond portfolios. We show that duration tilts result from maturity adjustments that life insurance companies make as they close duration mismatches caused by changes in life expectancy. Thus, we provide novel evidence that life insurance companies actively trade bonds of specific maturities in response to longevity shocks.

Second, we contribute to the literature that examines corporate debt maturity choices when bond market returns have some predictability in partially segmented bond markets. Greenwood et al. (2010) articulate the "gap-filling" theory of corporate debt maturity choice and show that firms act as macro liquidity providers by absorbing supply shocks resulting from changes in the maturity structure of government debt. Badoer and James (2016) also show that changes in the supply of long-term government debt affect corporate issuances of long-term debt. Other papers focus on market segmentation and the effect of changes in the supply of Treasury securities on corporate borrowing costs (Greenwood and Vayanos, 2010; Krishnamurthy and Vissing-Jorgensen, 2011; Vayanos and Vila, 2021).[4] Although the mechanism in our paper is similar to that in Greenwood et al. (2010), we focus on a demand shock that arises from requirements that life insurers minimize their duration risks. Such a focus allows us to demonstrate the importance of insurance firms in the transmission of exogenous shifts in life expectancy to the financing and asset mix of the corporate sector.

Finally, we contribute to the literature examining implications of demographic shifts on asset prices (Bakshi and Chen, 1994; Poterba, 2001; Goyal, 2004; Ang and Maddaloni, 2005; Geanakoplos et al., 2004; Favero et al., 2011; Chen and Yang, 2019) and responses to demand shifts caused by demographic changes (DellaVigna and Pollet, 2007, 2013; Koijen et al., 2016b,a; Cunha and Pollet, 2020). For example, DellaVigna and Pollet (2007, 2013) and Cunha and Pollet (2020) study how stock returns and corporate policies (including corporate financing, cash holding, dividend, and investment) respond to demand shifts caused by demographic changes. We provide new evidence on how longevity changes affect the duration of insurers' bond portfolios, corporate bond markets, and real economy. In particular, we study bond maturity choices, whereas previous studies often focused on equities.

[4]A broader literature examines the effect of investors' demand on asset prices (Koijen and Yogo, 2019; Koijen et al., 2020; Bretscher et al., 2020). Chaderina et al. (2021) consider dynamic corporate debt maturity and leverage choices with a time-varying market price of risk. They show firms with long-term debt are riskier.

2 Data and Variables

Our empirical analyses rely on data from several sources. We obtain detailed mortality and population data from the Human Mortality Database for the nationwide data and the U.S. Mortality Database for the state-level data.[5] The data on credit market conditions and macroeconomic variables come from the Federal Reserve Economic Data (FRED). We obtain life insurer data from the National Association of Insurance Commissioners (NAIC) filings. We obtain insurers' bond holdings from NAIC "Schedule D" fillings, including the issuer's name, bond characteristics, and holding size. Schedule D transaction data provide us with date-stamped trades, including trading prices, transaction size, and trade direction. U.S. nonfinancial firms' new corporate bond issuances come from the Mergent Fixed Income Securities Database (FISD). Financial data on bond issuers come from Compustat. We match FISD with Compustat via the issuer CUSIP obtained from the CRSP files. The sample period is 1995-2019 when NAIC data are used, 1990-2019 when FISD data are used, and 1975-2019 when Compustat data are used. Appendix B defines the variables and lists the data sources.

We estimate longevity risks for the U.S. population from 1974 to 2018 using the Human Mortality Database. We begin by obtaining the average of a population's period life expectancy (E_t) in year t, weighted by corresponding exposure, as follows:

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

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

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.[6] We then estimate longevity risk (*LongevityRisk*) as the change in the weighted average of period life expectancy, that is, E_t - E_{t-1}. We similarly construct state-level longevity shocks (*LocalLongevityRisk*) using state-level mortality data over the 1989-2018 period from the U.S. Mortality Database. Both *LongevityRisk* and *LocalLongevityRisk* are an easily interpretable, model-free measure of longevity shocks across all ages and over time.[7]

Longevity shocks are economically significant. Summary statistics reported in Table 1, Panel A, show that nationwide longevity shocks have a mean of 0.15 years annually over 1974-2018. That is, longevity increases by 3.6 hours per day. It is also volatile, with a standard deviation of 0.14 years per year. State-level longevity shocks average about 0.10 years per year and are substantially more volatile (a standard deviation of 0.21).

— Table 1 about here —

Panel B shows aggregate bond market variables over 1990-2019, with a credit spread (*CreditSpread*) measuring the spread between percentage yields of Moody's Seasoned Baa Corporate Bond Index and 20-year Treasury securities (mean=2.07%). Changes in 1-year Treasury yields (Δ*Treasury-1Y*) average -0.21%, reflecting the overall low-interest-rate environment over this period. The term spread (*TermSpread*) is the spread between the percentage yields of 10- and 1-year Treasury securities (mean=1.42%). The orthogonalized term spread (*Term spread*$^{\perp}$) is estimated as residuals from a regression of the term spread

[6]We restrict the age range to 0-99 years as data for ages over 100 can be unreliable. The young cohorts are included since some life insurance products are targeted towards youths (and sold to their parents or guardians). Restricting the sample to the working ages of 20-65 years old did not materially change our results.

[7]The latent mortality index in Lee and Carter (1992) is an alternative measure of longevity risk. The Lee-Carter measure and the one we use are highly correlated (a correlation coefficient of -0.99) and yield qualitatively identical results.

on longevity risk (mean=0.57%). The excess bond premium (*EBP*), which captures bond market sentiment, has a mean of 0.11%.[8]

Annual changes in the spread between long- and short-term corporate bond yields (Δ*CorpTermSpread*) average about 0.03%.[9] On average, the dollar amount of long-term bond issuances is about 5.2 times greater than new short-term bond issuances (*LT-toSTDebt*). The mean change in the weighted average duration of new bond issuances (Δ*NewBondDuration*), weighted by issue size, is about 0.04 years.[10]

Panel C focuses on life insurer characteristics. Life insurers are large (mean assets = $6.66 billion; median = $338 million), highly levered (average total liabilities-to-assets ratio, *InsLeverage*, of 0.73), and profitable (return on assets, *InsROA*, of 2%), with an average risk-based capital (*InsRBC*) ratio of 17.57.[11] The NAIC Securities Valuation Office assigns NAIC designations to bonds on a scale of 1 to 6 based on credit ratings by approved agencies (see Appendix C). Higher-NAIC-designation bonds are of lower credit quality, and an insurer must hold more capital to cover the expected losses on that security to satisfy risk-based capital requirements. To maintain capital adequacy, insurers primarily invest in investment-grade bonds (i.e., bonds designated NAIC 1 or 2).[12] Almost 55% of bonds held by life insurers had a NAIC 1 designation (the highest quality), 27% were NAIC 2, and

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

[9] We define long-term bonds as those with maturities over 10 years and short-term bonds as those with maturities fewer than 3 years.

[10] Bond Macaulay duration estimates do not consider callability and convertibility of bonds, among other features. While that introduces noise, it also biases our results toward zero.

[11] State regulators use risk-based capital as a key metric to determine an insurer's capital adequacy. According to NAIC's Risk-Based Capital Guidelines, we estimate risk-based capital as the ratio of total available regulatory capital (assets - liabilities) to total required capital. Required capital is obtained by multiplying the book value of a bond holding with the appropriate risk weight depending on the bond's credit rating.

[12] These regulatory constraints force more constrained life insurers to engage in fire sales of downgraded bonds, which leads to price pressure (Ellul et al., 2011). Murray and Nikolova (2021) show that rating-based capital requirements affect insurers' investment demand and thereby affect corporate bond prices.

the rest were NAIC 3 or higher, indicating life insurers mostly invest in investment-grade bonds. The average change in bond portfolio duration (Δ*InsDuration*) is 0.04 years.

Panel D shows that bond issuers are large, with a mean *Assets* of $6.67 billion (median of $906 million). The average growth in long-term debt (*LTDebtGrowth*) is 8%, with R&D (*R&DIntensity*) and capital expenditure (*CAPEX*) representing 2% and 9% of total assets, respectively. The average growth rate of plant, property, and equipment (*PPEGrowth*) is 3%. Firms have an average ROA of 16%, Tobin's q of 1.63, and tangibility of 46%. Average long-term debt dependence (*LTDebtDep*), measured as the ratio of debt with maturities over five years to total debt, is 52%.

3 Changes in Life expectancy and Life Insurers' Response

3.1 Adjustments to maturity of corporate bond holdings

Because corporate bonds constitute a large fraction of life insurance companies' assets, we expect insurance companies to reduce duration mismatches by adjusting the maturity of their corporate bond holdings. If so, then we should see a significant comovement in the average duration of corporate bond holdings of life insurance firms and the estimated longevity risk of the U.S. population. The question we examine is whether the duration of insurance firms' bond holdings changes in response to changes in life expectancy after controlling for other determinants that may independently affect maturity adjustments. Finally, we conclude the section by analyzing transaction data to test whether the maturity adjustments that we documented earlier are the result of active trades of bonds of specific maturities. We also exploit the substantial geographic disparities in longevity within the

United States to examine how local longevity shocks drive the bond trades of local life insurers.

Hedging of asset-liability duration mismatches requires that life insurance companies match changes in the duration of their liabilities by adjusting the duration of their assets. One expects life insurance companies to adjust the average duration of their bond portfolio to reflect changes in life expectancy. We plot changes in the average duration of corporate bonds on life insurers' balance sheets and changes in weighted life expectancy of the U.S. population over 1995-2019.[13] As can be seen from Figure 1, changes in the average duration of life insurers' corporate bond portfolios are highly correlated with changes in life expectancy, consistent with a strong bond duration response to longevity shocks. The correlation between the two series is 0.32 (p<0.01).

— Figure 1 about here —

From Figure 1, one can clearly see that bond holdings of life insurance companies move in near-lockstep with changes in life expectancy. We test this formally in a regression framework that examines the relation between changes in the duration of corporate bond portfolios of life insurers and lagged longevity risk (the first-order differences of the weighted average period life expectancy). We estimate the following equation:

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

where Δ*InsDuration* is the change in the duration of corporate bond portfolio of life insurer i in year t; $\mathbf{X}_{i,t}$ is a vector of insurer characteristics; $\mathbf{Z}_t$ is a vector of macroeconomic

[13] The estimates of life expectancy lag changes in the bond duration by at least two quarters to ensure the longevity information is available to life insurers.

variables; ζ_i are insurer fixed effects; and $\epsilon_{i,t}$ is an idiosyncratic error. Vector $\mathbf{X}_{i,t}$ includes the natural logarithm of insurer assets (*ln(InsAssets)*); leverage (*InsLeverage*); the risk-based capital ratio (*InsRBC*); profitability (*InsROA*); and the growth of net premium written (*InsNPWGrowth*). Vector Z_t includes the following state-level and aggregate economic indicators: inflation measured by the growth of the Consumer Price Index (*CPIGrowth*); US gross domestic product (GDP) growth (*GDPGrowth*); state GDP growth (*StateGDPGrowth*); state population growth (*StatePopGrowth*); credit spread (*CreditSpread*); changes in the 1-year Treasury yield (Δ*Treasury1Y*); and the term spread (*TermSpread*). We include these variables to control for macroeconomic variables and credit market conditions, both of which could affect bond duration choices and also may be correlated with changes in life expectancy (Cutler et al., 2006; Acemoglu and Johnson, 2007). The key variable of interest is *LongevityRisk*, which is defined in Section 2.

— Table 2 about here —

As can be seen from column (1) of Table 2, the coefficient for lagged *LongevityRisk* is 0.69 (p<0.01), implying that life insurers increase the duration of their bond portfolio by about 0.69 years for every one-year increase in nationwide longevity. In column (2), we use the orthogonalized term spread instead of the term spread to separate the effects of term spreads from longevity risks on bond portfolio duration. In particular, we find results that are qualitatively similar to those reported in column (1); β is significant and positive, indicating life insurers increase the duration of their bond portfolio by about 0.78 years for every one-year increase in longevity. In either case, the response is large and relatively quick, confirming life insurers hedge longevity-induced shocks to the duration of their liabilities.

In Appendix E, we test whether these results hold for the two subperiods 1995-2005 and 2006-2019. The more recent period has seen an increase in other institutional investors, such as mutual funds, who have become more prominent holders of corporate bonds. Therefore, life insurers' share, while still high, has declined somewhat in recent years. The results for both subperiods (in columns (1) and (2), respectively) are qualitatively similar to those reported in Table 2. The economic magnitudes are similar as well. In column (3), we further account for the possibility that economic conditions may affect longevity risks and duration adjustments on life insurance firms' balance sheets by filtering out the cyclical component of industrial production growth from the measure of longevity risk. We are reassured by the fact that longevity risk measures that filter out business cycle effects produce results nearly identical to those discussed above.

Next, we control for changes in corporate bonds holdings of other institutional investors, such as pension funds and mutual funds. Column (4) of Appendix E shows that changes in the holdings of pension funds are positively related to changes in the duration of life insurers' corporate bond holdings. By contrast, changes in mutual funds' corporate bond holdings are negatively related to insurance firms' bond duration changes. Importantly, we find that even after controlling for corporate bond holdings of other institutional investors, longevity shocks positively affect insurance firms' bond maturities.

We conduct additional tests that examine two dimensions along which life insurance companies differ in the strength of their response to longevity shocks. First, some life insurers are financially constrained. More constrained insurers lack the flexibility to adjust their asset portfolio, and they will exhibit a muted response to changes in life expectancy. We use insurer size to identify constrained insurers (smaller insurers are likely to be more constrained).[14] Hence, we perform annual sorts of insurers based on median assets and then separately estimate Equation (2) for large insurers in column (3) and for small insurers in column (4) of Table 2. The results confirm our predictions: Large insurers are considerably more responsive to longevity shocks, increasing their bond portfolio duration by almost 0.91 years for a one-year increase in life expectancy, while the corresponding response for small insurers is a significantly smaller 0.47 year increase.

Second, some life insurance firms naturally hedge themselves against longevity risk and, therefore, are less affected by changes in life expectancy. These insurers have liabilities arising from a mix of life insurance and annuity products that naturally balance each other out, attenuating the effects of longevity risks on their balance sheets (Cox and Lin, 2007). We estimate the premium share as the ratio of direct premium written (DPW) of the life insurance business to premiums collected from both life insurances and annuities. We then simulate the variance of insurer liabilities to longevity shocks over the whole range of premium shares. Appendix D has the details. Results of the simulations indicate that the variance of liability portfolio is minimized when the share of premiums collected from life insurance is 81.9%. However, the typical insurer's average is 31.6% in our sample; that is, life insurers on average are far from naturally hedged.

We estimate *deviation* as the absolute difference between an insurer's life insurance premium share and the natural-hedge share estimated from the simulation. Insurers with above-median *deviation* are more exposed to longevity shocks, while those with below-median *deviation* are less exposed. Columns (5) and (6) of Table 2 show that more exposed insurers make significantly larger adjustments to changes in life expectancy, with duration increasing by 0.88 years for a one-year increase in life expectancy. By contrast, more hedged,

[14] Ge and Weisbach (2021) show that insurers' size is a better measure of insurers' financial strength compared to leverage or the RBC ratio.

less exposed insurers adjust their duration by only 0.47 years, a statistically significant difference at the 1% level.

Overall, we find strong support for life insurers changing the duration of their corporate bond portfolio in the direction of changes in life expectancy. We also find that longevity risks produce more extensive bond duration adjustments from less constrained and more exposed insurers.

Life insurance companies' large and relatively quick adjustments raise the following question: if longevity shocks are transitory and asset maturity adjustments are costly, why do life insurance companies not "wait" for the shocks to mean revert so as to avoid costly adjustments? We believe that rapid adjustments reflect the U.S. risk-based-capital regulations that require firms to evaluate the cash flows of liabilities and assets annually, sometimes even quarterly.[15] Regulators often require life insurance companies to cover their longevity liabilities at the 99% confidence level. Life insurance companies, therefore, actively manage the effect of mortality rate on their balance sheet, a critical input to their asset adequacy analysis (see the practice note by American Academy of Actuaries (2017)). Rating agencies further impose significant costs to insurers by considering asset-liability duration mismatches in assigning ratings.

3.2 Corporate bond trades

So far, we have shown that the duration of life insurance companies' bond holdings moves almost one-to-one with changes in life expectancy. If this is accomplished through active trades of bonds, positive longevity shocks should result in net purchases of long-term

[15] See NAIC's Actuarial Opinion and Memorandum Regulation (AOMR) and Actuarial Standards of Practice No. 7 and No. 22.

bonds. Table 3 examines changes in net purchases of both long- and short-term bonds. The variable *NetBuyLTBonds* is defined as purchases (net of sales) of long-term bonds (10 years or more) scaled by the market value of the insurer's bond portfolio. Similarly, the variable *NetBuySTBonds* is defined as purchases (net of sales) of short-term bonds (three years or fewer). Since regulations on risk-based capital require insurance firms to primarily hold investment-grade bonds (i.e., NAIC 1 and 2), we expect most action to occur in these rating categories.

— Table 3 about here —

Panel A presents results from regressions where the dependent variable is *NetBuyLTBonds*. As can be seen from column (1), a one-year increase in life expectancy increases net purchases of long-term bonds by 8.7% (p<0.01). In columns (2) to (7), we disaggregate bond purchases by NAIC rating, where the dependent variable is each NAIC designation's contribution to net purchases of long-term corporate bonds. The estimated coefficients show that the active adjustment is primarily concentrated in investment-grade bonds with a one-year increase in longevity increasing net purchases of long-term bonds rated NAIC 1 and 2 by 2.0% and 1.7%, respectively. In contrast, the same increase in longevity increases net purchases of long-term bonds rated NAIC 6 by only 0.2%. Panel B, which reports results for net purchases of short-term bonds (with a duration of fewer than three years), suggests insurers sell the highest-quality short-term bonds in response to increases in life expectancy. Short-term bonds of other rating categories show little response to longevity shocks. In summary, insurers actively hedge against duration risk by purchasing long-term bonds when longevity increases, with their duration adjustment concentrated on highly rated bonds.

3.3 Bond trades with geographically dispersed longevity shocks

Next, we use the substantial geographic dispersion in longevity shocks to address concerns that trades of bonds of specific maturities respond to macroeconomic variables and credit conditions, not to longevity shocks. An extensive literature documents substantial geographic disparities in longevity within the United States (Chetty et al., 2016; Dwyer-Lindgren et al., 2017; Couillard et al., 2021; Deryugina and Molitor, 2021). These disparities result from regional variations in health and environmental factors, such as smoking rate, obesity rate, the number of doctors per capita, and fine particulate matter ($PM_{2.5}$) concentrations. Regional differences in socioeconomic variables, such as median house values, income per capita, poverty rate, upward income mobility, urban population, and crime rates, also explain the variation in local longevity shocks.

Regional differences mean that life expectancy could be increasing in one state, while falling in another state. The state-level variation in life expectancy is apparent in Figure 2, where we provide snapshots of state-level longevity risks at four different points corresponding to the year at the end of each decade. Each map displays 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 declines. The figure shows considerable dispersion in state-level longevity shocks. Changes in life expectancy are positively correlated in some states and negatively in others. Longevity risks in Florida and Georgia are most correlated ($\rho = 0.88$), while Massachusetts and Alaska exhibit the lowest correlation ($\rho =$ -0.27).

— Figure 2 about here —

We exploit this variation in longevity risk correlations across states to disentangle the motives for life insurers' trades of bonds of specific maturities. Since bonds trade in national markets and if insurers are responding to anticipated yield changes, they will make similar bond trades. By contrast, if insurers hedge asset-liability duration mismatches, their bond trades will be correlated with local longevity shocks. Hence, we test whether two life insurers in different states with negatively correlated longevity shocks make opposite trades for the same bond.

We focus on a sample of geographically concentrated life insurers with at least 80% of their revenue from one state ("local life insurers"). We begin by documenting that local life insurers respond to local longevity shocks (see Appendix E.4). We then examine for a pair of life insurers whether they exhibit a higher propensity to trade the same bond in the *opposite* direction if they face negatively correlated local longevity shocks. The dependent variable is a trading direction indicator that equals one if, for a pair of local life insurers, insurers trade the same bond in the *opposite* direction and zero otherwise.

— Table 4 about here —

In column (1) of Table 4, the key variable of interest is the correlation of these two life insurers' local longevity risks ($LongevityCorr_{i,j}$). The tests control for credit market conditions (Credit spread, ΔTreasury1Y, Term spread), 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 ($ln(InsAssets)$). We find the coefficient for $LongevityCorr_{i,j}$ is negative and statistically significant (p<0.01), suggesting local life insurers make opposite trades when faced with negatively correlated local longevity shocks.

In column (2), we use a dummy variable (*SimilarLongevityRisk*$_{i,j}$) that equals one if the pair of states in which local life insurers are located have longevity shocks either above or below the sample median simultaneously in a year, and zero otherwise. We again find a negative and statistically significant coefficient for *SimilarLongevityRisk*$_{i,j}$, confirming life insurers make opposite trades when the states in which they are located have dissimilar longevity shocks. Columns (3) and (4) further control for year fixed effects and yield almost identical results. We conclude local life insurers' bond trades respond to local longevity shocks, and local insurers trade the same bond in the opposite direction when faced with negatively correlated local longevity shocks.

4 Longevity Shocks, Bond Markets, and Issuances

4.1 Corporate term spreads and maturity of new issuances

We now focus on investigating the effects of longevity shocks on corporate term spreads and the maturity of new bond issuances. With partially segmented markets, shocks to the demand for corporate bonds of specific maturities introduce predictability in the relative returns on bonds of different maturities (Greenwood and Vayanos, 2010; Vayanos and Vila, 2021). The predictability is consistent with the preferred habitat theory of the yield curve, where life insurance demand for long-maturity bonds drives interest rates at the long end of the yield curve.[16]

[16]The evidence in support of the preferred habitat theory is presented in Greenwood and Vayanos (2010), who find that pension fund demand in the United Kingdom during 2005-2006 drove yield spreads on long bonds to become negative. Similarly, Klinger and Sundaresan (2019) show that U.S. pension fund demand for long-dated interest rate swaps drove swap spreads to become negative. Greenwood and Vissing-Jorgensen (2018) show that pension and insurance demand drive the long end of the yield curve globally.

Hence, when life expectancy increases, the demand for long-term corporate bonds goes up relative to the demand for short-term bonds, with the result that long-term corporate bonds offer lower expected returns. According to Greenwood et al. (2010), limited risk capital prevents arbitrageurs from enforcing the expectations hypothesis, resulting in some residual predictability in bond returns. Badoer and James (2016) show that arbitrage costs are particularly high in the very long end of the bond market. Thus, spreads between long- and short-term corporate bonds should decline when life expectancy increases.

We start by plotting changes in yield spreads between newly issued long- and short-term bonds against longevity risk (measured as the first-order difference of the weighted average life expectancy) over 1990-2019. As can be seen from Figure 3, the two series are negatively correlated (ρ = -0.23). In our view, the most plausible mechanism for the negative correlation is the increase in demand for long-term bonds during periods of increasing life expectancy (as documented in Table 3). Such a mechanism could explain the decline in yields on long-term bonds relative to short-term bonds.

— Figure 3 about here —

We test this formally using a regression approach. The dependent variable is the change in corporate term spread, measured as the differences in average yields on long-term and short-term corporate bonds in a given year. The key variable of interest is *LongevityRisk*. We control for relevant macroeconomic and bond market variables, in particular inflation (*CPIGrowth*), economic growth (*GDPGrowth*), risk premiums in bond markets (*CreditSpread*), interest rate changes (Δ*Treasury1Y*), the Treasury term spread (*TermSpread*), and a measure of bond market sentiment (excess bond premium *EBP*).[17] In

[17]Bai et al. (2019) show downside risk, credit risk, and liquidity risk strongly predict future bond returns. *EBP* measures credit spreads over estimated default risk. Gilchrist and Zakrajšek (2012) and López-Salido

column (1) of Table 5, we find strong evidence that changes in the term spread between long- and short-term corporate bonds move inversely with longevity risk (p<0.01). Time-series variation in life expectancy is the only significant covariate in the regression; other measures of credit market conditions and macroeconomic variables are insignificant.[18] In short, we find strong evidence that corporate bond term spreads move inversely with life expectancy; when life expectancy is increasing, corporate terms spreads decline.

— Table 5 about here —

4.2 Debt issuances

Next, we examine whether corporate managers exploit the predictability of bond market returns by issuing long-term bonds to "fill the gap." Greenwood et al. (2010) and Badoer and James (2016) show that corporate issuers have a comparative advantage in responding to temporary demand shocks that introduce predictability into bond returns. In deciding whether to issue short or long maturity, firms consider their maturity profile (Choi et al., 2018).[19] However, the extensive evidence that firms engage in market timing suggests that firms also consider differences in financing costs. If the cost of deviating from their target maturity profile is modest, we expect firms to respond to relatively lower long-term yields by issuing more long-term debt.

et al. (2017) argue it could affect credit market conditions and predict economic activities. Huang and Shi (2021) provide a recent review of the determinants of corporate bond returns.

[18]The insignificant coefficient for the term spread variable in column (1) reflects the strong multicollinearity between longevity risk and term spreads. In unreported tests, we note the term spread, orthogonal to longevity risk, has a significantly positive coefficient in regression specifications.

[19]Extensive evidence indicates that firms manage their maturity profile to manage rollover risk. Servaes and Tufano (2006) report that CFOs avoid maturity concentration. Similarly, Choi et al. (2018) show that the maturity dispersion of existing debt is an important factor in the firm's maturity choice for its new debt issuances. On the other hand, Brunnermeier and Oehmke (2013) show that some borrowers, in particular, financial institutions use short-term financing despite significant rollover risk because of an inefficient dynamic that creates incentives to shorten the maturity structure when borrowers deal with multiple creditors.

In short, we expect corporate issuers to vary the maturity of their debt issuances to absorb shocks resulting from life insurers' hedging needs. A straightforward way to test this is to examine whether the maturity of new bond offerings tilts toward longer-dated bonds as life expectancy increases. We obtain data on new domestic corporate bond issuances from FISD, estimate the average duration, weighted by issue size, and examine whether new domestic bond issuances respond to changes in life expectancy. Figure 4 plots changes in the aggregate-weighted duration of new corporate bond issuances and changes in life expectancy over 1990-2019. The plot shows the two are strongly positively correlated (ρ = 0.46), suggesting that firms tend to issue longer-term corporate bonds when expected yields on long-term bonds decline.

— Figure 4 about here —

Table 5, column (2), further examines this relationship. As before, we control for inflation (*CPIGrowth*), economic growth (*GDPGrowth*), risk premiums in bond markets (*CreditSpread*), interest rate changes (Δ*Treasury1Y*), the Treasury term-spread (*TermSpread*), and a measure of bond market sentiment (excess bond premium or *EBP*). The dependent variable in column (2) is the change in the weighted average duration of new bond issuances in a given year. The key variable of interest is *LongevityRisk*. Results show the average duration of new bond issuances increases significantly in response to increases in life expectancy, with the coefficient estimate for *LongevityRisk* being large and statistically significant (p<0.01). The evidence is consistent with the gap-filling view of debt maturity choice. The coefficient for ΔTreasury-1Y is negative (p<0.10), suggesting long-term bonds are preferred by life insurers when the short-term interest rate is low (Domanski et al., 2017; Ozdagli and Wang, 2020; Yu, 2020). The evidence is also consistent with Baker et al. (2003), who show that the time-series variation in debt maturity choice reflects predictability in excess long-term bond returns. Meanwhile, EBP is insignificant, suggesting credit market sentiment has little impact on maturities of new bond issuances after controlling for other factors.

In column (3), we consider the relative issue size of long- and short-term bonds. The dependent variable is the first difference of the natural logarithm of the ratio of long-term bonds issued to short-term bonds during the year to examine whether corporate issuers shift from short term to long term as life expectancy increases. Results confirm that aggregate long-term bond issuances increase relative to aggregate short-term bond issuances in response to increases in life expectancy.

Overall, Table 5 shows that corporate term spreads decline when longevity increases and firms react by issuing longer-dated bonds. The corporate response is consistent with previous findings that firms issue longer-dated bonds when long-term bond yields are low (Guedes and Opler, 1996; Barclay and Smith, 1995; Stohs and Mauer, 1996; Baker et al., 2003).

4.3 Corporate debt response

We have shown that yields on long-term corporate bonds fall when life expectancy increases, and corporate bond issuances tilt toward longer-term securities. One might be concerned that the corporate response reflects changes in the investment opportunities available to issuers that require long-term financing or that somehow issuers are exploiting unobservable credit market conditions that happen to be correlated with longevity shocks. For example, demographics-driven demand shifts have been known to predict industry-level abnormal returns (DellaVigna and Pollet, 2007). Furthermore, previous research has shown that firms in industries with high forecasted demand growth invest more in innovation (Acemoglu and Linn, 2004), issue more equity to finance greater capacity (DellaVigna and Pollet, 2013), and increase holdings of precautionary cash (Cunha and Pollet, 2020). Turning to longevity shocks, industry analysts expect firms in certain industries to benefit from increases in life expectancy, including firms in health care and pharmaceuticals, travel and leisure, financial services, and, to a smaller extent, food and beverages. If firms in these industries demand more long-term capital, that capital could be in the form of new equity or long-term debt.

We, therefore, examine granular data on the maturity composition of debt issuances and establish several facts to confirm that corporate issuers are indeed responding to an increase in demand for long-term debt by the life insurance sector. As will be shown below, corporate gap filing is more pronounced in the very long end of the term structure; the effect is concentrated among firms with investment-grade ratings and in firms whose bonds are predominantly held by insurance companies. We also find that results are robust to excluding firms in industries more affected by demand shifts due to increases in life expectancy.

To run these tests, we obtain firm-level bond issuance data from Mergent FISD that we match to Compustat in several steps.[20] Corporate gap filling is expected to be most prevalent at the long end of the term structure because arbitrageurs must devote more risk capital to trades involving long-term bonds (Badoer and James, 2016). Hence, we sort debt issuances into four maturity buckets: short-term debt with maturities in (0,3)-year range,

[20]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 the 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). Finally, any remaining unmatched bonds are subjected to a manual matching process based on the closeness of the prospectus issuer name in FISD to a company name in the CRSP name file (and further linked to Compustat). We could match 80% of issuances from FISD to Compustat.

medium-term debt with maturities in [3,10)-year range, long-term debt with maturities in [10,20)-year range, and very long-term debt with maturities in [20,...)-year range.

We then estimate the following multinomial logit model to relate the likelihood of debt issuances in various segments of the term structure to longevity risks:

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

where $Issue_{i,t}^{j}$ is a dummy variable that equals one if firm i issues bonds in maturity bucket j during year t, and zero otherwise. The [3,10)-year segment is the base category because it closely matches life insurers' average bond duration. The estimated coefficients are thus interpreted relative to this base category. We include several macroeconomic variables to address concerns that the estimated β reflects the effects of shifts in credit market conditions or the overall macroeconomic environment facing firms. Hence, we control for *CPIGrowth*, *GDPGrowth*, *CreditSpread*, Δ*Treasury1Y*, and *TermSpread*. We also control for firm-specific variables that may affect the firm's propensity to issue long-term debt, including *ROA*, *ln(Assets)*, *TobinsQ*, *Leverage*, *Age*, *Cash*, *EquityIssues*, *NIGrowth*, and *Tangibility*. In addition, we include indicator variables corresponding to five-year intervals to control for the time-series variation in demand for bonds of specific maturities. Firm fixed effects control for time-invariant heterogeneity across issuers. Standard errors are clustered at the firm level.

— Table 6 about here —

Table 6 shows that longevity shocks substantially increase the likelihood that firms issue very long-term bonds. By contrast, longevity shocks have a much smaller impact on shorter-maturity bonds. In particular, the coefficient estimate of longevity risk is negative and significant at the 1% level for maturities of (0,3) years relative to the base category.

Notably, it turns positive for longer maturities. It is positive and statistically significant at the 10% level for maturities of [10,20) years. It is positive and statistically significant at the 1% level for very long-term debt issuances with maturities of [20,...) years, with an estimate more than three times as large as the estimate for maturities in the [10,20)-year range. The estimates in column (3) imply that a one-standard-deviation increase in longevity risk leads to a 60% rise in the likelihood of issuing very long-term bonds relative to medium-term bonds.

Overall, the firm-level evidence shows that corporations switch to longer-dated bonds when life expectancy increases. The likelihood of long-term debt issuance, especially very long-term debt, is highly sensitive to changes in life expectancy.

4.4 Heterogeneity

If longevity shocks affect the maturity choices of firms through the life insurance sector, then firms whose bonds are primarily held by life insurers should exhibit a larger supply elasticity. Life insurers will find purchasing new corporate bonds by issuers whose bonds they have bought previously less costly than starting a new relationship. By adding to already-existing holdings and thus focusing on issuers whose bonds are already in their corporate bond portfolio, insurers can economize their fixed costs of screening and monitoring bond issuers. Zhu (2021) provides evidence of similar "stickiness" in the context of the investment decisions of mutual funds. Expecting the same stickiness for life insurers, we predict that those with a bond market "relationship" with life insurers should exhibit a more pronounced maturity response to longevity shocks.

For each issuer, we compute the proportion of its outstanding bonds that life insurers hold and define the issuer as insurer dependent if that proportion is above the median for the sample. We then estimate Equation (3) separately for insurer-dependent and non-insurer-dependent firms. Consistent with the insurance channel, Panel A of Table 7 shows that only insurer-dependent firms respond to longevity shocks; they issue more long-term bonds and fewer short-term bonds when life expectancy increases. By contrast, non-insurer-dependent firms do not respond to longevity shocks.

— Table 7 about here —

Next, we examine the heterogeneity in responses based on the issuer's credit rating. Earlier, in Table 3, we documented that life insurers primarily respond to longevity shocks mainly by increasing their holdings of investment-grade bonds (NAIC 1 and 2). It is, therefore, natural to expect much of the corporate response to be concentrated among investment-grade firms. Table 7, Panel B, tests whether investment-grade firms exhibit a larger response to longevity shocks by estimating Equation (3) separately for investment-grade and non-investment-grade firms. Columns (1) to (3) show investment-grade firms issue more long-term bonds and fewer short-term bonds in response to longevity shocks. These results are similar to those reported in Table 6. By contrast, columns (4) to (6) suggest non-investment-grade firms are insensitive to longevity shocks. Overall, we see that investment-grade firms are more responsive to longevity shocks. Given risk-based capital guidelines and the composition of insurers' portfolios of corporate bond holdings, we expect changes in longevity to predominantly affect the demand for investment-grade bonds. That the maturity response is concentrated among investment-grade issuers further supports the life insurance channel that we propose for the propagation of longevity shocks to the maturity choices of corporate issuers.

4.5 Long-term debt growth

Although our issuance results confirm that longevity shocks affect the maturity choices of firms conditional on issuing debt, the question is whether these shocks increase the aggregate amount of long-term debt on corporate balance sheets. Long-term debt growth should be larger for firms that typically borrow long term and those that are relatively unconstrained in accessing external capital markets. We test these predictions using Compustat data over 1975-2019.

Table 8 examines whether the corporate response is more pronounced for firms with a preference for long-term debt. Following Foley-Fisher et al. (2016), we use the lagged ratio of long-term debt to total debt as a measure of a firm's long-term debt dependence. The key variable of interest is the interaction between longevity risk and the firm's long-term debt dependence. The dependent variable in column (1) is the growth of outstanding long-term debt (with a maturity of longer than five years). If longevity risks disproportionately increase long-term debt growth at firms more reliant on long-term debt, then the coefficient for the interaction term will be positive. We include the usual firm controls. Firm fixed effects absorb firm-level time-invariant heterogeneity, while year fixed effects control for macro effects. We also cluster standard errors at the firm level. Column (1) shows firms that depend more on long-term debt issuances exhibit higher long-term debt growth when longevity increases. These results are consistent with the earlier results based on new bond issuances that are reported in Table 6.

— Table 8 about here —

In column (2), we examine whether less financially constrained firms are more responsive to longevity shocks. We consider a firm as financially constrained if the Whited-Wu index (Whited and Wu, 2006) is above the sample median. The variable *WhitedWu* equals one for constrained firms, and zero otherwise. We then interact longevity risk with the *WhitedWu* indicator variable. The estimated coefficient for the interaction term is negative and statistically significant ($p<0.05$), indicating that financial constraints matter in determining the firm's response to longevity shocks. Financially unconstrained firms issue more long-term debt when longevity increases relative to constrained firms.

4.6 The real effects of longevity shocks

Do larger long-term debt issuances lead to more long-term investments? Milbradt and Oehmke (2015) develop an integrated model in which financing frictions on the liability side affect firms' investment decisions on the asset side. When firms with long-term projects face difficulties obtaining long-term financing, they invest in alternative, shorter-term projects. Now, suppose longevity shocks reduce the cost of long-term finance and increase its availability. In that case, firms naturally will be expected to adjust their asset side investments and fund more long-term projects. We investigate the following questions in this section: Do longevity shocks increase the maturity of assets on corporate balance sheets? Do firms increase their capital and R&D expenditures?

As before, we expect the long-term debt supply response to be larger for firms with greater financial flexibility and for those with a stronger preference for issuing longer-term debt. Thus, we expect the investment response to be greater for such firms. In columns (3) and (4) of Table 6, we ask whether firms more dependent on long-term debt financing and those that are relatively financially unconstrained respond to longevity risks by increasing capital expenditures. The key variable of interest in column (3) is the interaction between longevity risk and the long-term debt dependence measure. In column (4), the key variable of interest is the interaction term between longevity risk and the indicator variable for financially constrained firms (*WhitedWu*).

We find that firms significantly increase capital expenditures in response to longevity risk when they depend more on long-term debt financing. The estimated coefficient for the interaction term between longevity risk and long-term debt dependence is positive and significant at the 1% level in column (3). Thus, firms more likely to issue long-term debt increase investments in fixed assets during periods of higher life expectancy. Column (4) shows that the capital expenditure response is muted for financially constrained firms. In other words, the reaction of financially unconstrained firms to longevity risks is significantly pronounced; these firms increase their capital expenditures more compared to firms with less financial flexibility.

In columns (5) and (6), we examine the R&D response of firms to longevity shocks. The results in column (5) are consistent with those for capital expenditures and confirm that firms dependent on long-term financing invest significantly more in R&D than firms less dependent on long-term finance. However, in column (6), we find that financial constraints are unimportant in determining the effect of longevity risk on R&D intensity.

The last two columns of Table 6 examine asset maturity. Following Stohs and Mauer (1996), we compute asset maturity as [ACT / (ACT+PPENT)] × (ACT/COGS) + [(PPENT / (ACT + PPENT)] × (PPENT/DP), where ACT is current assets total, PPENT is net property, plant, and equipment, COGS is the cost of goods sold, and DP is depreciation and amortization. The results in column (7) show that firms dependent on long-term debt increase asset maturities when longevity increases. In column (8), we find that financially unconstrained firms show larger increases in asset maturity. Overall, the results suggest that financially unconstrained firms increase their long-term borrowings by larger amounts during periods of higher life expectancy. Financially unconstrained firms also invest more in long-term assets and increase their asset maturity.

5 Conclusion

In this paper, we examine how longevity shocks affect corporate bond markets, with consequences for firms' long-term financing and investment decisions. We show that life insurance companies react to unexpected changes in life expectancy by adjusting the maturity of their corporate bond portfolios. As life insurance companies hold a major fraction of outstanding corporate bonds, any shifts in their demand affect the long end of the corporate term structure. Hence, when life expectancy increases, yields on long-term bonds fall relative to those on short-term bonds.

We find that corporate issuers exploit longevity-induced shifts in demand for longer-dated assets by issuing more long-term debt when life expectancy increases. The response is significantly more pronounced for firms whose bonds are already in the portfolio of insurance companies. The response is also larger for firms with an investment-grade rating, with the financial flexibility to access bond markets and those that depend on long-term debt.

Our results are significant in several ways. First, we show the sizable impact of longevity shocks on corporate bonds and highlight the economic effects of the insurance sector on the corporate sector. Second, we illustrate a plausible channel through which longevity shocks are transmitted to the real economy via the insurance sector and bond markets. Third and finally, we show that improvements in life expectancy reduce long-term financing costs for a sector of the economy, allowing these firms to invest more in R&D and fixed assets.

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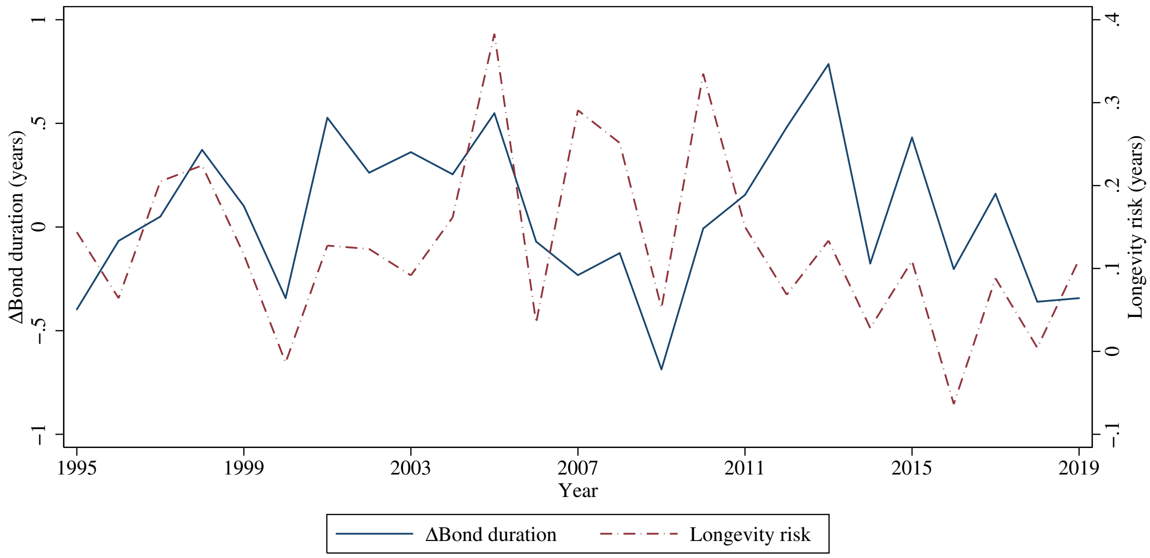
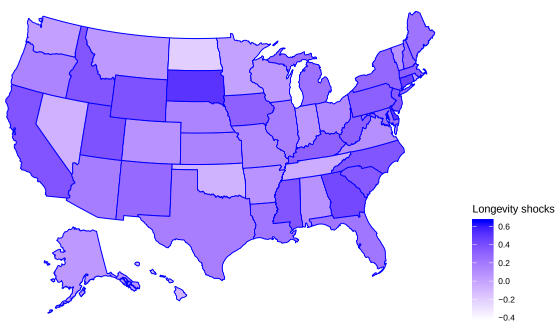
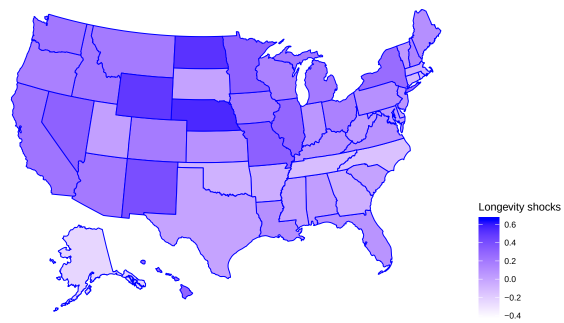


Figure 1 Changes in bond duration of life insurers and longevity risk

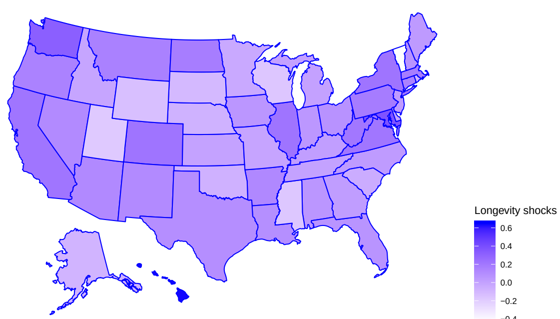
The figure plots changes in the average duration of life insurers' bond holdings (blue solid line) and longevity risk, measured as the first-order difference of the weighted average period life expectancy (red dashed line) over the 1995-2019 period. The data on life insurance companies' bond holdings come from NAIC. Life expectancy estimates are based on data from the Human Mortality Database.



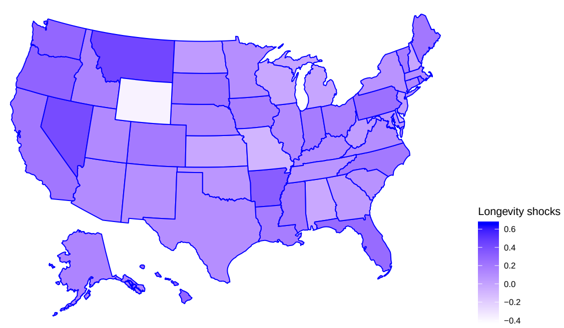
(a) State-level longevity risk (1990)



(b) State-level longevity risk (2000)



(c) State-level longevity risk (2010)



(d) State-level longevity risk (2018)

Figure 2 State-level longevity risk across years

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

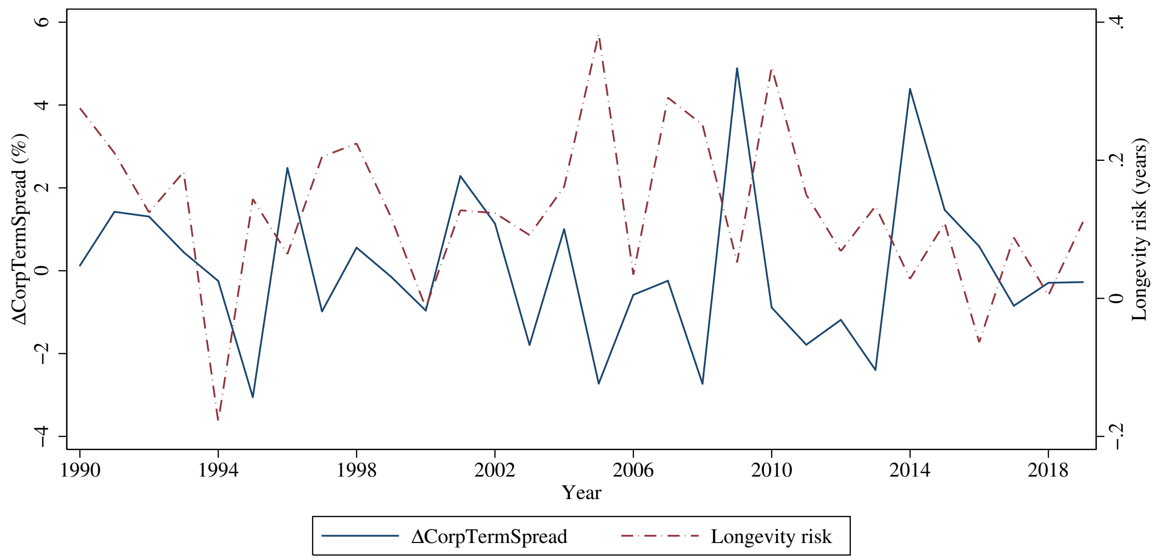


Figure 3 Changes in corporate bond term spread and longevity risk

This figure shows the changes in term spreads for corporate bonds (blue solid line) and longevity risk, measured as the first-order difference of the weighted average period life expectancy (red dashed line) over the 1989-2018 period. Spread is the yield difference between long-term bonds (maturity longer than 10 years) and short-term bonds (maturity less than three years).

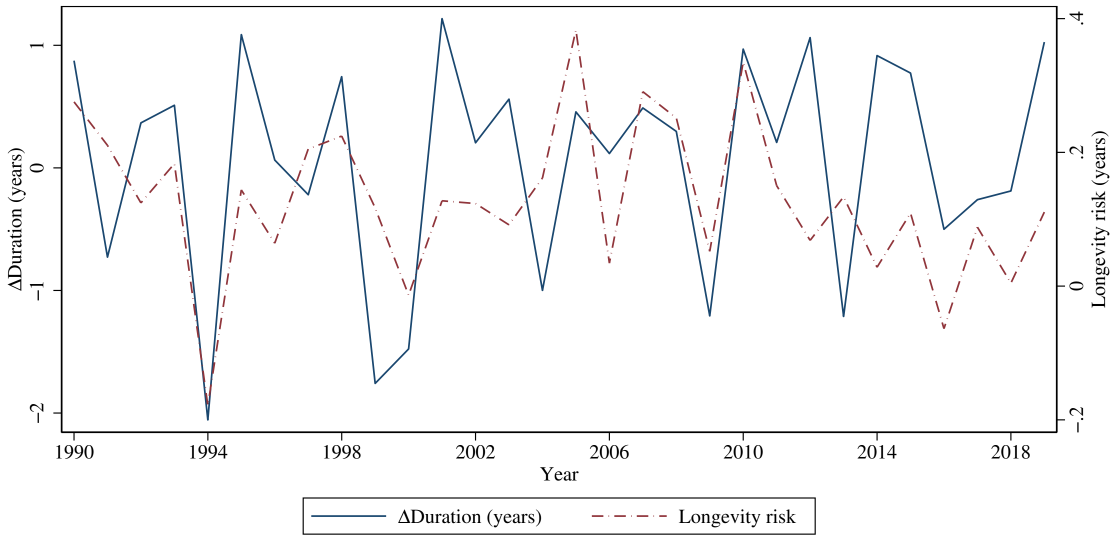


Figure 4 Changes the average duration of new bond issuances and longevity risk

The figure shows changes in the average duration of new bond issuances (blue solid line) and longevity risk, measured as the first-order difference of the weighted average period life expectancy (red dashed line) over the 1989-2018 period. The average duration of new bond issuances is computed from FISD, weighted by issue size.

Table 1 Summary statistics

Panel A displays summary statistics for the nationwide longevity risk (1974-2018) and state-level longevity risks (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 characteristics of bond issuers (1975–2019). Appendix B defines the variables.

				Distribution				
	N	Mean	SD	Min	$P25$	Median	$P75$	Max
Panel A: Longevity risk								
LongevityRisk	45	0.15	0.14	-0.18	0.06	0.12	0.22	0.47
LocalLongevityRisk	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
ΔTreasury1Y	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
ΔCorpTermSpread	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
ΔNewBondDuration	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
ΔInsDuration	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 1: Continued

	N	Mean	SD	Distribution				
				Min	*P*25	Median	*P*75	Max
Panel D: Firm characteristics								
Assets (MM$)	48,131	6,669	24,314	3	213	906	4,058	847,409
LTDebtGrowth	48,131	0.08	0.50	-0.86	-0.10	-0.02	0.11	3.34
R&DIntensity	48,131	0.02	0.03	0.00	0.00	0.00	0.01	0.24
PPEGrowth	48,131	0.03	0.09	-0.19	-0.01	0.01	0.05	0.56
CAPEX	48,131	0.09	0.08	0.00	0.04	0.06	0.11	0.45
AssetMat	48,131	7.24	7.60	0.55	2.46	4.24	8.83	40.14
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
LTDebtDep	48,131	0.52	0.28	0.00	0.31	0.52	0.73	1.00

Table 2 Life insurers' responses to longevity shocks

The dependent variable is the changes in a life insurer's bond portfolio duration (ΔInsDuration). We control for macroeconomic indicators, credit market conditions, and insurer characteristics. Column (1) uses the Treasury term spread ($TermSpread$). Column (2) uses the Treasury term spread orthogonal to longevity shocks ($TermSpread^{\perp}$). Columns (3) and (4) differentiate between large and small insurers, which are classified by median assets. Columns (5) and (6) examine insurers with high or low exposure to longevity risks due to different product mixes of annuities and life insurances. Appendix B defines the variables. Standard errors are clustered by insurer, and t-statistics are reported in parentheses. The sample period is from 1995-2019. $^{*}p$ <0.10, $^{**}p$ <0.05, and $^{***}p$ <0.01.

			Insurers Size		Exposure	
			Large	Small	High	Low
	(1)	(2)	(3)	(4)	(5)	(6)
LongevityRisk	0.687***	0.782***	0.907***	0.471***	0.884***	0.471***
	(7.7)	(8.8)	(8.7)	(3.2)	(5.3)	(4.1)
TermSpread	0.091***		0.101***	0.072***	0.096***	0.084***
	(9.3)		(8.2)	(4.6)	(4.6)	(6.8)
TermSpread$^{\perp}$		0.155***				
		(7.1)				
ΔTreasury1Y	-0.036***	-0.029***	-0.045***	-0.028*	-0.057***	-0.031**
	(-3.6)	(-2.7)	(-3.9)	(-1.7)	(-3.4)	(-2.3)
CreditSpread	0.085***	0.077***	0.016	0.141***	0.099**	0.111***
	(3.8)	(3.4)	(0.6)	(3.8)	(2.3)	(3.9)
CPIGrowth	-0.028**	-0.036***	-0.055***	-0.003	-0.057***	-0.014
	(-2.4)	(-3.0)	(-4.6)	(-0.1)	(-2.9)	(-0.9)
GDPGrowth	0.102***	0.088***	0.080***	0.114***	0.127***	0.114***
	(8.8)	(7.9)	(5.8)	(6.1)	(6.0)	(7.7)
StateGDPGrowth	2.044***	1.547***	2.406***	2.043**	0.580	2.624***
	(3.8)	(2.9)	(3.4)	(2.6)	(0.6)	(3.8)
StatePopGrowth	-9.279***	-9.738***	-6.269	-10.714**	-11.709*	-11.435**
	(-2.6)	(-2.7)	(-1.6)	(-2.1)	(-1.7)	(-2.5)

Table 2 Continued

			Insurers Size		Exposure	
			Large	Small	High	Low
	(1)	(2)	(3)	(4)	(5)	(6)
ln(InsAssets)	-0.010	-0.003	0.006	0.030	-0.082*	0.008
	(-0.5)	(-0.2)	(0.2)	(0.7)	(-1.7)	(0.3)
InsLeverage	0.103	0.078	0.169	-0.036	0.424	0.071
	(0.8)	(0.6)	(0.8)	(-0.2)	(1.1)	(0.5)
RBCRatio	-0.001	-0.001	-0.003	-0.001	-0.001	-0.001
	(-1.1)	(-1.0)	(-1.0)	(-1.1)	(-0.6)	(-0.9)
InsROA	-0.162	-0.178	-0.013	-0.181	-0.001	-0.136
	(-0.5)	(-0.6)	(-0.0)	(-0.5)	(-0.0)	(-0.4)
NPWGrowth	0.022**	0.021**	0.011	0.038**	0.031**	0.012
	(2.4)	(2.2)	(1.0)	(2.4)	(2.1)	(0.9)
Insurer FE	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.071	0.069	0.091	0.077	0.108	0.077
Observations	15,523	15,523	7,746	7,741	4,026	9,531

Table 3 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. The 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 2, column (1)). Appendix B defines the variables. Standard errors are clustered by insurer, 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**							
LongevityRisk	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**							
LongevityRisk	-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 4 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 are insurers that make at least 80% of their revenues from the state they are located in. Local longevity risk represents state-level longevity shocks. Column (1) uses the correlation coefficient of local longevity shocks faced by insurers ($LongevityCorr_{i,j}$). Column (2) uses a dummy variable ($SimilarLongevityRisk_{i,j}$) that equals one if two states have longevity shocks above or below their sample medians simultaneously, and zero otherwise. Columns (3) and (4) further control for year fixed effects. In all regressions, we control for macroeconomic indicators, credit market conditions, and insurer characteristics. Appendix B 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)	
SimilarLongevityRisk		-0.009***		-0.007***
		(-5.7)		(-3.4)
CPIGrowth	-0.002	-0.006**		
	(-0.6)	(-2.2)		
GDPGrowth	0.014***	0.013***		
	(4.0)	(3.5)		
CreditSpread	0.028***	0.022***		
	(4.1)	(3.3)		
ΔTreasury1Y	-0.003	-0.003		
	(-1.2)	(-1.4)		
TermSpread	0.009**	0.006*		
	(2.7)	(1.9)		
$StateGDPGrowth_i$	0.178	0.193	-0.071	-0.078
	(0.7)	(0.8)	(-1.0)	(-1.0)
$StatePopGrowth_i$	-1.251***	-1.065**	-0.223	-0.266
	(-2.7)	(-2.4)	(-1.3)	(-1.4)
$InsRBC_i$	-0.000	-0.000	-0.000	-0.000
	(-0.6)	(-0.4)	(-1.0)	(-0.8)
$InsLeverage_i$	0.001	0.000	-0.004	-0.008
	(0.0)	(0.0)	(-0.2)	(-0.4)

Table 4 Continued

	(1)	(2)	(3)	(4)
InsROA_i	0.027	0.024	0.043	0.044
	(0.6)	(0.5)	(1.1)	(1.1)
InsNPWGrowth_i	0.000	0.000	-0.000	-0.000
	(0.6)	(0.5)	(-0.1)	(-0.3)
$\ln(\text{InsAsset})_i$	-0.009***	-0.009**	-0.008***	-0.007**
	(-2.9)	(-2.4)	(-2.9)	(-2.2)
StatePopGrowth_j	0.429**	0.452*	0.095	0.101
	(2.0)	(2.0)	(0.9)	(0.9)
StatePopGrowth_j	-1.147**	-0.993**	-0.258	-0.334
	(-2.6)	(-2.4)	(-1.4)	(-1.5)
InsRBC_j	0.000	0.000	-0.000	-0.000
	(1.5)	(1.3)	(-0.3)	(-0.4)
InsLeverage_j	0.012	0.008	0.002	-0.006
	(0.8)	(0.5)	(0.2)	(-0.4)
InsROA_j	-0.002	0.017	0.004	0.021
	(-0.1)	(0.5)	(0.1)	(0.7)
InsNPWGrowth_j	0.001	0.001	0.000	0.000
	(1.3)	(1.3)	(0.2)	(0.6)
$\ln(\text{InsAsset})_j$	-0.005	-0.006*	-0.005	-0.004
	(-1.5)	(-1.8)	(-1.7)	(-1.4)
Insurer_i FE	Yes	Yes	Yes	Yes
Insurer_j FE	Yes	Yes	Yes	Yes
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 5 Longevity risk and new bond issuances

This table reports results from regressions of new bond characteristics against longevity risk. Column (1) examines changes in the term spread between long-term and short-term corporate bonds. Column (2) looks at changes in the average duration of new bond issuances, with the average computed from FISD, weighted by issue size. Column (3) examines changes in the relative issue size of long-term bonds to short-term bonds. In all regressions, we control for macroeconomic and credit market conditions. Appendix B 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)
LongevityRisk	-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 6 Corporate responses to longevity shocks: Bond maturity choices

This table reports results from multinomial logit regressions of bond maturity choice against longevity risk. We classify bonds into four categories: short-term bonds (with a maturity fewer than 3 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. In all regressions, we control for macroeconomic indicators, credit market conditions, and firm characteristics. Appendix B 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	≥ 20 years
	(1)	(2)	(3)
LongevityRisk	-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)

Table 6 Continued

	Bond issuances, by maturity		
	< 3 years	$[10, 20)$ years	≥ 20 years
	(1)	(2)	(3)
Age	0.032***	0.005*	0.024***
	(3.7)	(1.9)	(6.7)
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 7 Maturity choices: Heterogeneity

This table reports results from multinomial logit regressions of bond maturity choice against longevity risk for firms sorted by insurer dependence (Panel A) and debt rating (Panel B). Medium-term bonds (with a maturity between three and 10 years) are the base category. Insurer-dependent (non-insurer-dependent) firms are those with life insurer shares above (below) the cross-sectional median. Investment-grade firms are designated NAIC 1 or 2. Both panels use the same controls employed in Table 6. Appendix B 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)
LongevityRisk	-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
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			Non-investment-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)
LongevityRisk	-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
Period indicators	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.068			0.106		
Observations	4,415			2,391		

Table 8
Corporate responses to longevity shocks

This table runs panel regressions to examine the impacts of longevity risk on corporate long-term debt and long-term investment, with firms differentiated by long-term debt dependence. Long-term debt dependence is the ratio of debt with maturities in excess of five years. We examine long-term debt growth (in columns (1) and (2)), R&D intensity (in columns (3) and (4)), capital expenditures (in columns (5) and (6)), and asset maturity (in columns (7) and (8)). We include controls for various firm characteristics and firm and year fixed effects. Appendix B defines the variables. Standard errors are clustered by firm, and t-statistics are in parentheses. ***, **, and * indicate 1%, 5%, and 10% two-tailed statistical significance, respectively. The sample period is 1975-2019. $^{*}p<0.10$, $^{**}p<0.05$, and $^{***}p<0.01$.

	Long-term debt growth		Capital expenditures		R&D expenditures		Asset maturity	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
LongevityRisk × LTDebtDep	0.132**		0.021***		0.005***		1.886***	
	(2.0)		(3.1)		(2.8)		(4.8)	
LTDebtDep	-0.488***		0.001		-0.001		0.301***	
	(-26.7)		(0.6)		(-1.3)		(2.7)	
LongevityRisk × WhitedWu		-0.072**		-0.018***		0.001		-0.893***
		(-2.1)		(-4.5)		(0.8)		(-3.9)
WhitedWu		-0.008		0.002		0.000		0.085
		(-0.7)		(1.4)		(0.3)		(1.0)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adjusted-R^2	0.129	0.089	0.605	0.605	0.881	0.881	0.870	0.871
Observations	48,131	47,602	48,131	47,602	48,131	47,602	48,131	47,602

Appendices

A Corporate bond markets and life insurers

Figure A plots the market shares of domestic nonfinancial corporate bonds held by life insurers, mutual funds, and pensions over 1990-2018, using data from the Financial Accounts of the United States (Z.1). Life insurers are the most prominent investors, holding more than 50% of nonfinancial corporate bonds in earlier years. While their market share has decreased after the financial crisis, they continue to be significant holders of corporate bonds (holding 35% of the nonfinancial corporate market in 2018). On average, life insurers held about 46% of corporate bonds over 1990-2018.

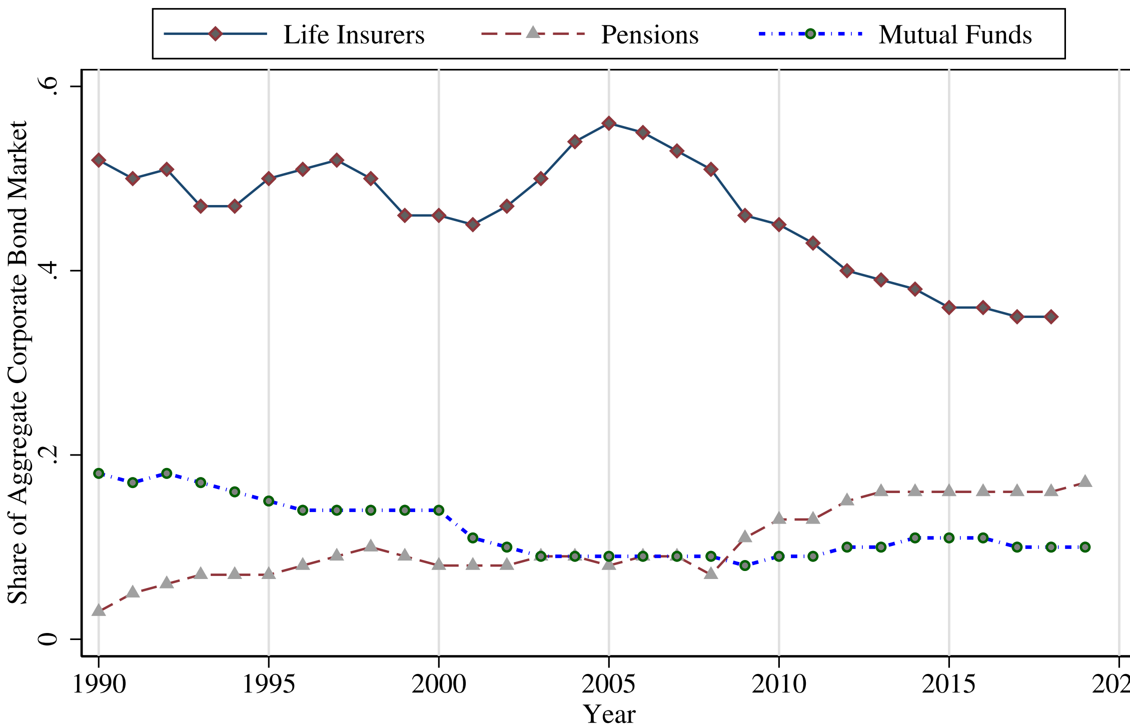


Figure A Corporate bond market shares of institutional investors

This plot shows the market shares of domestic nonfinancial corporate bonds held by life insurers, mutual funds, and pensions over 1990-2018. Data are from Financial Accounts of the United States (Z.1).

B Variable Definitions and Data Sources

Panel A: Longevity Risk

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

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

LongevityCorr$_{i,j}$ The time-series correlation of longevity risks between the states of insurers i and j.

SimilarLongevityRisk$_{i,j}$ A dummy variable that equals one if the longevity risks in states where insurers i and j are located are both above or below the sample median in a given year. It is otherwise zero.

Panel B: Macro Variables and Credit Market Conditions

CPIGrowth US CPI growth rate. Source: Federal Reserve Economic Data (item CPIAUCSL), 1990-2019.

GDPGrowth US GDP growth rate. Federal Reserve Economic Data (item GDPC1), 1990-2019.

StateGDPGrowth State GDP growth rate. US Bureau of Economic Analysis (item SAGDP1), 1990-2019.

StatePopGrowth State population growth rate. US Bureau of Economic Analysis (item SAINC51), 1990-2019.

IndProdGrowth Industrial production growth rate. Federal Reserve Economic Data (item INDPRO), 1990-2019.

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

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

TermSpread The yield difference between 10-year and 1-year Treasuries. Data of 10-year and 1-year treasuries yields are from Federal Reserve Economic Data (item GS10 and GS1), 1990-2019.

TermSpread$^{\perp}$ Orthogonalized term spread obtained as residuals from a regression of term spread (the yield difference between 10-year and 1-year treasuries) on longevity risk. Data of 10-year and 1-year treasuries yields are from Federal Reserve Economic Data (item 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`.

△PensionShare Changes in the market share of corporate bonds held by pensions. Federal Reserve Economic Data (item BOGZ1FL593063045Q), 1995-2019.

△MFShare Changes in the market share of corporate bonds held by mutual funds. Federal Reserve Economic Data (item BOGZ1FL653063043Q), 1995-2019.

Panel C: Bond Characteristics

△CorpTermSpread The first difference of the yield difference between long- and short-term corporate bonds. Long-term (short-term) bonds are defined as bonds with maturities above 10 (below 3) years. *Source:* Mergent FISD, 1990-2019.

△ln(Long term/Short term) The first difference of the natural logarithm of the ratio of issue amount of long-term to short-term domestic corporate bonds. Long-term (short-term) bonds are defined as maturities above 10 (below 3) years. *Source:* Mergent FISD, 1990-2019

△NewBondDuration The first difference of duration of new domestic corporate bonds. We compute Macaulay duration, using data of coupon rate, maturity, and bond prices from Mergent FISD, 1990-2019

Panel D: Life Insurer Characteristics

△InsDuration The first difference of the duration of a life insurer's corporate bond portfolio. We compute Macaulay duration using data of 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 this insurer's bond portfolio. Long-term bonds are bonds with durations of ten years or more. *Source:* NAIC, 1995-2019

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

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

InsNPWGrowth Growth rate of net premium written. *Source:* NAIC, 1995-2019

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

ln(InsAssets) Size of an insurer measured as the natural logarithm of total assets. *Source:* NAIC, 1995-2019

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

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

Panel E: Firm Characteristics

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

ROA Firm profitability measured as operating income before depreciation (oidbp) scaled by the average total assets (at) in the 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 debts (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 × csho) less the sum of the book value of common stock (ceq) and balance sheet deferred taxes (txdb), divided by the book value of assets. *Source:* Compustat, 1975-2019

Age Firm age measured as years from the IPO date. If Compustat variable "ipodate" is missing, it is measured as years from the first date in CRSP. *Source:* Compustat, 1975-2019

Cash Ratio of cash and cash equivalents (che) to 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 log growth rate of net income (ni). *Source:* Compustat, 1975-2019

Tangibility The value of net plant, property and equipment (ppent), scaled by lagged total assets. *Source:* Compustat, 1975-2019

LTDebtGrowth The first difference of the value of long-term debts, scaled by lagged total assets. Long-term debt is defined as debt with maturities in excess of five years (dltt-dd1-dd2-dd3-dd4-dd5). *Source:* Compustat, 1975-2019

R&D R&D intensity measured as R&D expenditure (xrd) scaled by lagged total assets. *Source:* Compustat, 1975-2019

CAPEX capital expenditures (capex) scaled by lagged total assets. *Source:* Compustat, 1975-2019.

AssetMat Asset maturity is (act/(act+ppent)) × (act/cogs) + (ppent/(act+ppent)) × (ppent/dp), where act is current asset, ppent is net property, plant and equipment, cogs is cost of goods sold, and dp is depreciation and amortization (Stohs and Mauer, 1996). *Source:* Compustat, 1975-2019

LTDebtDep The ratio of debt with maturities in excess of five years (dltt-dd1-dd2-dd3-dd4-dd5) in total debts (dltt+dlc). *Source:* Compustat, 1975-2019

WhitedWu Indicator variable that takes a value of one for financially constrained firms identified as those with Whited-Wu index (Whited and Wu, 2006) above the median for the sample. It takes a value of zero otherwise.

C NAIC Designation and Risk-based Capital Requirement of Bonds

This table reports the NAIC designations 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%

D Natural Hedging Share of Life Insurances

We derive the natural hedging share of life insurances by assuming a mortality process similar to the seminal Lee-Carter model (Lee and Carter, 1992). 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 α_x is a static age function specifying the general shape of mortality by age; $\beta_x \kappa_t$ captures the age-period effect, with κ_t reflecting overall mortality trend (period-related effect) and β_x modulating its effect across ages (age-related effect). In particular, κ_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. As a result, 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 during 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 over each calendar year is 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 $\mathscr{F}_t$ be the filtration up to and including time t. Then $q_{x,t}$ is unknown prior to t and $S_{x,t}(T)$ is known prior to time $t+T$. We further define the expected survival probability as

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

When $u = t$, we call $p_{x,u}\Big(T, \kappa_t\Big)$ a spot survival probability, while 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 $x_1, x_2, \ldots, x_k$ at time 0. The annuity pays each annuitant \$1 at the end of each year until death. Hence 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 a superscript of A denotes an annuity business line.

Now let us consider the life insurance business. Similar to $S_{x,t}(T)$, we can also 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

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

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 a superscript of 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 who are 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 US total population.

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

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

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

5. The US mortality index is estimated using all the available mortality data from the HMD, with the sample period from 1933 to 2018 and the 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 natural hedge based on $N = 10,000$ rounds of simulation generated from the Lee-Carter model in Equation (D.1).

Suppose the insurer's portfolio contains X shares of annuities and let θX be the number of shares of life insurances 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 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 the annuity and life insurances, respectively, then the proportion of premiums collected from 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 risk. This result is robust to different cohort sets, and other annuity and term life insurance horizons. Life insurers are far away from the natural hedging ratio since the average industry share of life insurance is 31.6% over 1995-2019.

E Robustness Checks

E.1 Subperiod Analyses

While life insurers are the largest investors in corporate bond markets, their market share has decreased since 2005. To check if our results hold after this date, we repeated our analyses over subperiods 1995-2005 and 2006-2019. Table E, columns (1) and (2) report regression results for these subperiods. While the earlier subperiod has more robust responses to longevity shocks (coefficient of 1.209), the later subperiod still shows significant responses to longevity shocks (coefficient of 0.720 and $p < 0.01$).

E.2 Business Cycles

Confounding impacts of business cycles may influence longevity risk if, for example, economic conditions affect health status and hence life expectancy (see, e.g., Cutler et al. (2006) and Acemoglu and Johnson (2007)). We thus need to differentiate the effects of longevity risk from other economic shocks. While already controlling for aggregate and state-level economic indicators, including GDP growth and CPI growth, we further consider longevity shocks orthogonal to business cycles to address this concern directly. We measure business cycles as the cyclical component of industrial production growth, computed from the Hodrick–Prescott filter. We then regress longevity risk against the cyclical component of industrial production growth and use residuals as the orthogonalized longevity risk (Longevity risk$^{\perp}$) to repeat the previous analyses. Table E, column (3) reports the results, showing they are similar to those reported in Table 2, including magnitudes.

E.3 Other institutional investors

Other significant investors in corporate bond markets could also affect bond markets, for example, pensions and mutual funds. As shown in Figure A, the market share of mutual funds increases over time. Similar to life insurers, pensions also face longevity shocks, though responses of mutual funds remain unclear. To further control for institutional investor impacts, we add changes in the market share of corporate bonds held by pensions (Δ *PensionShare*) and mutual funds (Δ *MFShare*) to the regression. Table E, column (4) shows longevity risk remains significantly positive, with magnitudes similar to those reported in Table 2.

E.4 Local (state-level) longevity risk

We examine local life insurers' responses to local longevity shocks in Table E, column (5). Local life insurers are firms with at least 80% of revenues from one state. We use state-level US Mortality Data to estimate the longevity risks in each state. Cross-state variations of longevity risk provide greater testing capability. Column (5) regresses the changes in local life insurers' bond portfolio duration to local longevity shocks. The state-level tests confirm life insurers adjust their bond portfolio duration according to local longevity shocks.

Table E Life insurers' responses to longevity shocks: Robustness checks

The dependent variable is the changes in a life insurer's bond portfolio duration ($\Delta InsDuration$). We control for macroeconomic indicators, credit market conditions, and insurer characteristics. Columns (1) and (2) consider subperiods 1995-2005 and 2006-2019. Column (3) 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 (4) controls for other institutional investors, i.e., changes in the market share of corporate bonds held by pensions ($\Delta PensionShare$) and mutual funds ($\Delta MFShare$). Column (5) considers responses of local life insurers (with at least 80% of revenue from one state) to local (state-level) longevity shocks ($LocalLongevityRisk$). Appendix B provides detailed variable definitions. Standard errors are clustered by insurer, and t-statistics are reported in parentheses. The sample period is 1995-2019. $^{*}p$ <0.10, $^{**}p$ <0.05, and $^{***}p$ <0.01.

	Subperiods		Business	Other	Local
	1995-2005	2006-2019	cycles	institutions	longevity
	(1)	(2)	(3)	(4)	(5)
LongevityRisk	1.209***	0.720***		0.681***	
	(5.1)	(4.0)		(7.3)	
Longevity risk$^{\perp}$			0.771***		
			(8.6)		
ΔPensionShare				5.004***	
				(2.8)	
ΔMFShare				-10.494***	
				(-7.9)	
LocalLongevityRisk					0.408***
					(4.1)
TermSpread	0.172***	0.022	0.100***	0.122***	0.065***
	(9.5)	(1.5)	(10.2)	(11.6)	(4.3)
ΔTreasury1Y	-0.085*	-0.011	-0.029***	-0.059***	-0.054**
	(-1.8)	(-0.4)	(-2.9)	(-4.2)	(-2.6)
CreditSpread	0.046	0.225***	0.074***	-0.064**	0.090*
	(0.8)	(5.5)	(3.3)	(-2.1)	(1.7)
CPIGrowth	0.118	-0.024	-0.027**	-0.060***	-0.037
	(1.6)	(-1.2)	(-2.3)	(-4.8)	(-1.6)
GDPGrowth	0.132***	0.183***	0.101***	0.077***	0.104***
	(4.6)	(7.4)	(8.7)	(6.5)	(3.8)

Table E Continued

	Subperiods		Business	Other	Local
	1995-2005	2006-2019	cycles	institutions	longevity
	(1)	(2)	(3)	(4)	(5)
StateGDPGrowth	-1.466*	2.336***	1.973***	1.153**	2.305
	(-1.7)	(3.0)	(3.7)	(2.1)	(1.2)
StatePopGrowth	10.852	-5.663	-9.482***	-6.462*	-11.575***
	(1.6)	(-1.2)	(-2.7)	(-1.8)	(-2.8)
ln(InsAssets)	0.080*	-0.122***	-0.010	-0.015	-0.010
	(1.8)	(-3.2)	(-0.5)	(-0.8)	(-0.4)
InsLeverage	0.380*	0.176	0.101	0.106	-0.246
	(1.8)	(0.7)	(0.8)	(0.9)	(-1.2)
RBCRatio	0.001	-0.002	-0.001	-0.001	-0.002***
	(1.2)	(-1.3)	(-1.1)	(-1.2)	(-3.6)
InsROA	0.564	-0.249	-0.167	-0.163	-0.357
	(1.2)	(-0.5)	(-0.6)	(-0.6)	(-0.5)
NPWGrowth	0.006	0.036**	0.022**	0.022**	0.021
	(0.5)	(2.5)	(2.4)	(2.3)	(1.3)
Insurer FE	Yes	Yes	Yes	Yes	Yes
R^2	0.156	0.094	0.072	0.076	0.067
Observations	7060	8391	15523	15523	5689