Internet Appendices
"Long Rates, Life Insurers, and Credit Spreads"

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D Quantitative Model

In the following sections, I match the model to empirical estimates and key moments in data in order to quantify the contribution of life insurers' duration mismatch to the observed empirical patterns and the transmission of unconventional policy.

Additional Assumption for the Quantitative Model. We need a few additional assumptions to solve the model quantitatively.

First, I assume that the dynamics of the Treasury yield is given by

$$\mathrm{d}y_t^T = \alpha_y \left(y_t^T - \overline{y}^T \right) \mathrm{d}t. \tag{D.1}$$

Second, I assume that the equity injection process follows,

$$\xi_t = \xi(A_t^I - \overline{A}^I), \quad \xi < 0,$$

so the insurer pays out dividends (raises equity) at the rate of ξ when its net worth is greater (less) than the reference level $\overline{A}^I$.

Third, I assume that the preferred-habitat investors have the following demand functions

$$\log(D_t^{P,n} / P_t^n) = \alpha^n - \beta \log P_t^n. \tag{D.2}$$

In this specification, β is the price elasticity of demand, and the intercept α^n captures the average propensity to hold bonds of rating n by the preferred-habitat investors.

Fourth, I micro-found and derive an explicit bond supply function. There are N sectors of firms. Each sector consists of a continuum of ex-ante identical firms with a mass of one. Let K_t^n denote both the total and average capital stock of sector n firms. Each firm in sector n produces the following stream of output

$$Y_t^n \mathrm{d}t = \frac{(K_t^n)^{1-\theta}}{1-\theta} \mathrm{d}t.$$

The production function features decreasing returns to scale. Firms issue corporate bonds to finance their capital. Capital is elastically supplied at a price of one. For simplicity, I assume that the firms can freely adjust capital stock and debt quantity but are not allowed to accumulate capital. As a result, their balance sheet constraint is simply $K_t^n = B_t^n$, i.e., the value of their assets K_t equals the value of their debt B_t^n.

In normal times (i.e., when jumps $\mathrm{d}J_t$ do not realize), all firms operate normally, and no bond defaults. However, when the bond market is disrupted (i.e., when a jump arrives), a fraction ν^n of sector n firms are destroyed. The affected firms lose all their capital, default on the bonds, exit the economy, and get replaced by new firms after the market disruption is over. Therefore, as in equation (3), a diversified portfolio in rating n bonds loses a ν^n fraction of its value when a jump materializes.

Myopic firms solve a static profit maximization problem where they choose capital stock and bond supply to maximize their expected profits subject to the balance sheet constraint.

$$\max_{K_t^n, B_t^n} \ \mathbb{E}_t \left[\mathbf{1}_{\{\text{survive}_t\}} \left(\frac{(K_t^n)^{1-\theta}}{1-\theta} - \phi^n \frac{B_t^n}{P_t^n} \right) \right] \quad \text{s.t.} \quad K_t^n = B_t^n.$$

The firms' profits equal their outputs subtracting the coupon payments on bonds, conditional on survival. The firm problem leads to a tractable bond supply function

$$\frac{B_t^n}{P_t^n} = \left[\frac{(P_t^n)^{1-\theta}}{\phi^n} \right]^{\frac{1}{\theta}}. \tag{D.3}$$

The bond supply B_t^n is increasing in the bond price P_t^n, implying that firms borrow more when their debt is more valuable.

Calibrated Parameters. Table D.1 discusses model calibration.

Parameter	Target
Treasuries and Annuities	
$\tau^T = 10, \tau^L = 20$	Treasury maturity = 10 yrs, Annuity maturity = 20 yrs
$\phi^T = \phi^L = 1$	Normalization
$\overline{y}^T = 2.5\%$	Average 10-year Treasury yield (2010-2020)
$\alpha_y = \xi = -2$	Half-life of shocks $\approx$ 3 qtrs
Corporate Bonds	
$\tau^1 = \tau^2 = 8.55$	Corporate bond maturity = 8.55 yrs
$\phi^1 = \phi^2 = 1$	Normalization
$\delta = 1.635$	Variance of high-yield default rates
$\theta = 0.34$	Standard Cobb-Douglas capital share ($1 - \theta = 0.66$)
Life Insurer	
$\overline{A}^I = 1$	Normalization
$a = 2$	Standard

Table D.1. **Calibrated Parameters.**

I consider two corporate bond ratings ($N = 2$) where $n = 1$ represents investment-grade bonds (NAIC 1-2), and $n = 2$ represents high-yield bonds (NAIC 3-6). Both types of corporate bonds have a maturity of 8.55 years, which is the average time to maturity of all corporate bonds in Mergent FISD. The parameter of firm production function θ is set to 0.34, matching the usual Cobb-Douglas capital share in the literature.[1]

I normalize all the coupon rates and the life insurer's reference net worth as 1 ($\phi^T = \phi^L = \phi^n = 1$). I set $\tau^T = 10$ and $\tau^L = 20$, so the maturity of Treasuries is 10 years, and the maturity of annuities is 20 years. I let the steady-state value of the 10-year Treasury yield be 2.5%, which is roughly the average observed 10-year US Treasury yield between 2010 and 2020. I set the speed of mean-reversion as $\alpha_y = \xi = 2$, in which case the half-life of Treasury yield shocks is about 3 quarters. I normalize the insurer's reference net worth to $\overline{A}^I = 1$. I use a standard value of risk aversion $a = 2$.

Estimated Parameters. I estimate a few other key parameters using empirical data. The estimated parameters are summarized in Table D.2.

I estimate the loadings on credit risk ν^1, ν^2 and the intensity of the credit risk process δ from the average annual default rates of both investment-grade and speculative

[1] To map the production function into the standard Cobb-Douglas form, we can assume that every firm has a single unit of labor supply $L_t^n = 1$ and the production function is $Y_t^n = \frac{1}{1-\theta}(K_t^n)^{1-\theta}(L_t^n)^{\theta}$.

Parameter	Estimation Strategy / Source
Corporate Bonds	
$\nu^1 = 0.001,\ \nu^2 = 0.017$	Average default rates
$\delta = 1.635$	Variance of high-yield default rates
Life Insurer	
$\zeta^1 = 2.85$	Relative portfolio share $(w^{I,2}/w^{I,1})^{ss} = 0.059$
$\zeta^2 = 7.21$	Relative bond supply $(P^2B^2/P^1B^1)^{ss} = 0.195$
$L = 8.05$	Empirical duration mismatch
Habitat Investor	
$\beta = 1.1$	Darmouni, Siani and Xiao (2025)
$\alpha^1 = 0.47,\ \alpha^2 = 0.12$	Life insurers' share in each category (35.7%, 10.3%)

Table D.2. **Estimated Parameters.**

bonds and the variance of high-yield default rate. The average one-year default rate between 2003 and 2019 is 0.156% for investment-grade bonds and 2.829% for high-yield bonds. The standard deviation of the one-year investment-grade bond default rate is 0.004. In the model, these three moments are given by $\delta\nu^1, \delta\nu^2$ and $\sqrt{\delta}\nu^1$. I estimate values of ν^1, ν^2, δ from the data by equating the model moments to the empirical counterparts.

I estimate regulatory cost parameters ζ^1, ζ^2 using two moments: the insurer's relative portfolio share investment-grade and high-yield bonds and the relative market cap of the two types of bonds (see Table A.2). I choose the values of ζ^1, ζ^2 so the model replicates the two empirical moments in the steady state.

The annuities supply L is obtained from the empirically estimated duration mismatch (see Table 4). Under my parametrization, the insurer's duration mismatch is more severe when they are more levered (i.e., larger L). The L parameter is chosen such that the insurer's net worth increases by 6% in response to a 1% positive Treasury yield shock starting from the steady state.

For the habitat investors' demand elasticity β, I adopt the demand elasticity of mutual funds estimated by Darmouni, Siani and Xiao (2025). I then estimate the demand intercepts α^1, α^2 using the market share of life insurers in each risk category at the end of 2010.[2] In the steady state, the insurer owns 35.7% of investment-grade bonds and 10.3% high-yield bonds, which match the empirical observation.

[2]In Table A.8, I show that the co-movement of interest only exists in bonds held by life insurers. Therefore, I calibrate α^n to those bonds with life insurance ownership (see column 2 of Table A.2).

D.1 The Duration Mismatch Channel and Policy Implications

The model has several new implications for unconventional monetary policy. In recent years, the Federal Reserve has adopted policies aiming to control long-term interest rates (e.g., Quantitative Easing and Tightening). For example, since 2022, the Federal Reserve has conducted Quantitative Tightening (QT) to shrink its balance sheets and control inflation, which increases the long-term interest rate.

Next, I investigate the model implications of a positive shock to the 10-year Treasury yield, which I view as a result of a QT policy.[3] The goal of this section is to quantitatively examine the policy's impacts on corporate bond yields, spreads, and issuance, as well as the role of the duration mismatch channel in the transmission.

Specifically, I analyze the responses of key model variables to an unexpected shock that moves the 10-year Treasury yield from $y_t^T = 2.5\%$ to $y_t^T = 3.5\%$. In the following analysis, I study a situation where the default shocks J_t are not realized, so the yield change is the only shock to the system.

In particular, I consider two scenarios: (1) the full model and (2) the model with no duration mismatch. In the full model, the insurer's duration mismatch is calibrated to the empirical estimate of Section 5.1, meaning that the insurer's net worth increases by 7.18% as the Treasury yield increases by 1%. In the model with no duration mismatch, I assume that the equity injection and dividend payout process $\xi_t \mathrm{d}t$ is chosen such that the insurer's net worth A_t^I always stays constant. In this case, the net worth does not respond to the Treasury yield shock. In the broad context, we can use the full model to represent the post-crisis scenario and the model without duration mismatch to represent the pre-crisis scenario. By contrasting these two scenarios, I aim to quantitatively assess the consequences of the duration mismatch channel on the transmission of long-term interest rates.

Figure D.1 visualizes the shock and the response of insurer net worth A_t^I. The left panel plots the path of the Treasury yield, which jumps from 2.5% to 3.5% at $t = 0$ and gradually reverts back to the steady state level 2.5%. The right panel shows the change in the insurer's net worth as a percentage of its steady-state value for the two different scenarios. In the full model, the insurer's net worth rises on impact and slowly returns to the steady state value. In the model without duration mismatch, the insurer's net worth stays constant.

[3] In this paper, I view the unexpected Treasury yield shock as the end product of a QT policy and do not model the details regarding the implementation of the QT policy. See, for example, Krishnamurthy and Vissing-Jorgensen (2011), D'Amico and King (2013) and Vayanos and Vila (2021) for mechanisms of how unconventional monetary policies influence long-term interest rates.

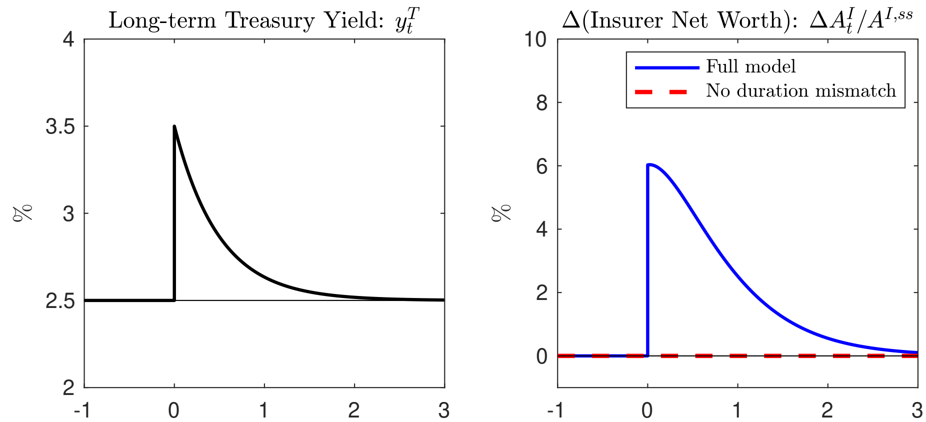

Figure D.1. **Treasury Yield Shock and the Insurer's Net Worth Responses.**

Figure D.2 plots the responses of corporate bond yields relative to the steady state. In the model without duration mismatch, the yields of both bonds 1 and bonds 2 increase with the Treasury yield. This is due to the standard portfolio rebalancing channel — the insurer reduces demand for corporate bonds as Treasuries become more attractive. In addition, higher interest rates raise risk premia, as the credit spread between bonds 1 and bonds 2 widens as the Treasury yield increases. This is consistent with the empirical results of Figure 3, where higher long-term interest rates weakly increased the credit spreads for NAIC 2 and NAIC 3 bonds before the Crisis.

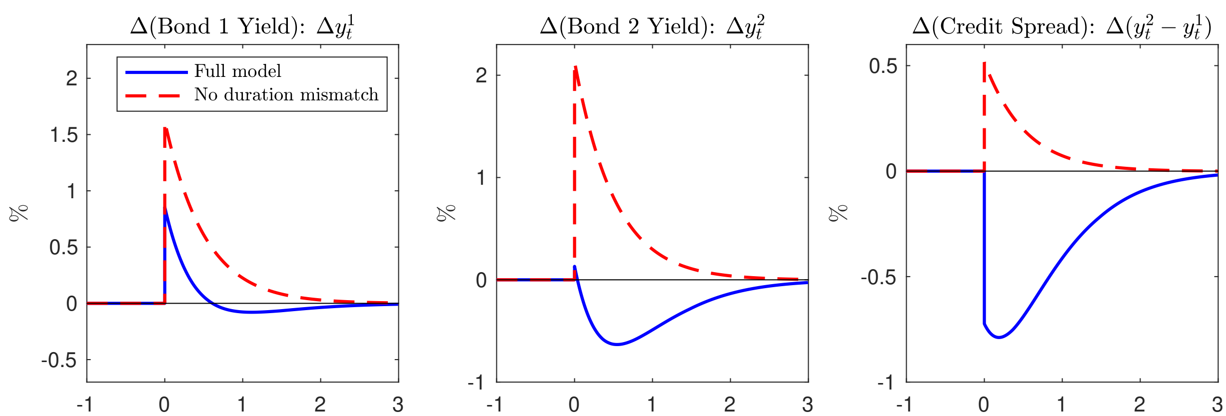

Figure D.2. **Responses of Bond Yields and Credit Spreads.**

In the full model, there is an additional duration mismatch channel, where a higher Treasury yield increases the insurer's net worth, thereby boosting its demand for corporate bonds. Quantitatively, on impact, the duration mismatch channel dampens the investment-grade bond yield response by half while reversing the high-yield bond yield response slightly. Over time, the dampening and reversing effects become stronger before the yields revert to the steady state. Further, the duration mismatch channel has a larger effect on the high-yield yield, and the credit spread between the two bonds falls by almost 0.8% as the Treasury yield rises. Thus, the QT policy unintentionally tightens the credit spread of corporate bonds. Notably, we can only generate large negative credit spread responses that are in line with Figure 3 when the insurer faces duration mismatch.

I then study whether such credit spread responses can dampen or reverse the transmission of QT to real outcomes, including bond issuance and firm investment.

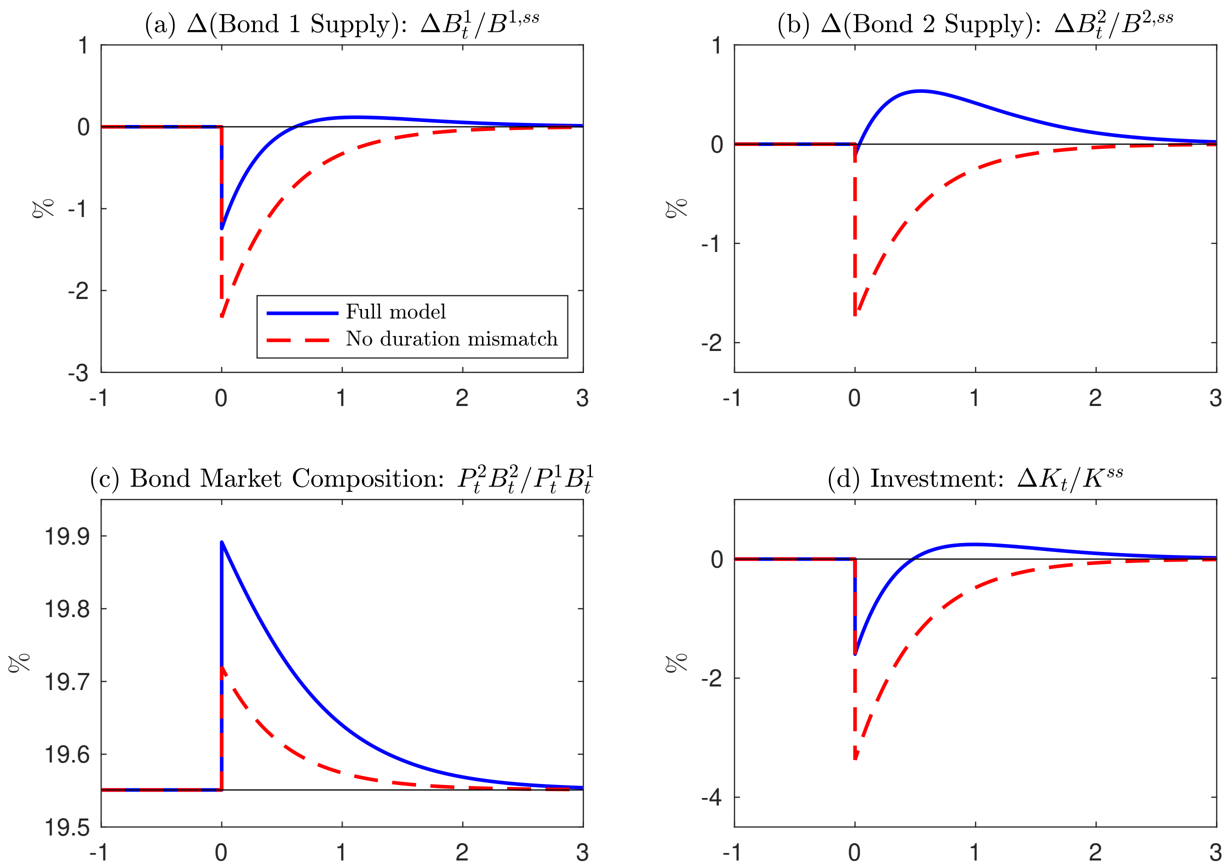

Figure D.3. **Responses of Bond Supply and Investment.**

Panels (a) and (b) of Figure D.3 plot the responses of the supply of bonds 1 and 2. In the model without duration mismatch, the surge in the Treasury yield drives up corporate bond yields. In response, firms borrow less, showing that the policy is effective at cooling the bond market, at least when the life insurer is not subject to duration mismatch. In the full model, the duration mismatch channel counteracts the increase in corporate bond yields. Quantitatively, the results demonstrate that the duration mismatch channel can offset half of the contraction in investment-grade bond supply and even generate an unintended expansionary effect on high-yield bond supply.

Panel (c) of Figure D.3 shows the relative market cap of bond 2 relative to bond 1. The QT policy tilts the market towards the high-yield segment, even more so in the full model, where credit spreads fall in response to the positive long-term interest rate shock. The results demonstrate that QT potentially alters the composition of the bond market, favoring risky issuers over safe ones.

Panel (d) of Figure D.3 displays the aggregate investment response. Absent the duration mismatch channel, firms disinvest more than 3% of their capital following the Treasury yield increase. The investment response is also heavily muted in the full model, at about 40% of that in the model without duration mismatch.

Quantitative Easing (QE) is the opposite of QT, where the Fed purchases long-term Treasuries and lowers long-term interest rates. Empirical evidence shows that QE and central bank asset purchases can effectively lower long rates (e.g., Krishnamurthy and Vissing-Jorgensen, 2011; D'Amico and King, 2013; Vayanos and Vila, 2021), which potentially boosts economic activities. However, my results show that the effects of QE are achieved at the cost of increased corporate bond credit spreads, which offsets some of the postulated economic benefits of QE. Similar to QT, the duration mismatch channel could dampen the transmission of QE to the yields and issuance of investment-grade bonds and even reverse the effects of QE on the yields and issuance of high-yield bonds. Overall, the results of this section suggest that unconventional monetary policies that target the long-term interest rate could have large unintended effects in the corporate bond market due to life insurers' duration mismatch.

D.2 Quantitative Model: Numerical Solution Method

Consider the insurer's net worth dynamics

$$\begin{aligned}
\frac{\mathrm{d}A_t^I}{A_t^I} &= \left[w_t^{I,0}\mu_t^{r,T} + \sum_{n=1}^{N} w_t^{I,n}\mu_t^{r,n} - w_t^{I,L}\mu_t^{r,L} - \sum_{n=1}^{N}\frac{1}{2}(\zeta^n w_t^{I,n})^2 + \xi_t\right]\mathrm{d}t + \sum_{n=1}^{N} w_t^{I,n}\sigma_t^{r,n}(\mathrm{d}J_t - \delta \mathrm{d}t) \\
&= \left[w_t^{I,0}\mu_t^{r,T} + \sum_{n=1}^{N} w_t^{I,n}(\mu_t^{r,n} - \delta\sigma_t^{r,n}) - w_t^{I,L}\mu_t^{r,L} - \sum_{n=1}^{N}\frac{1}{2}(\zeta^n w_t^{I,n})^2 + \xi_t\right]\mathrm{d}t + \sum_{n=1}^{N} w_t^{I,n}\sigma_t^{r,n}\mathrm{d}J_t \\
&:= \mu_t^{A,I}\mathrm{d}t + \sigma_t^{A,I}\mathrm{d}J_t.
\end{aligned}$$

Suppose $P_t^n = P^n(y_t^T, A_t^I)$. By Ito's Lemma,

$$\begin{aligned}
\mathrm{d}r_t^n &= \frac{\phi^n - \lambda^n P_t^n}{P_t^n}\mathrm{d}t + \frac{\mathrm{d}P_t^n}{P_t^n} - \nu^n \mathrm{d}J_t \\
&= \underbrace{\frac{1}{P_t^n}\left[(\phi^n - \lambda^n P_t^n) + \frac{\partial P_t^n}{\partial y_t^T}\alpha_y\left(y_t^T - \bar{y}^T\right) + \frac{\partial P_t^n}{\partial A_t^I}A_t^I\mu_t^{A,I}\right]}_{:=\mu_t^{r,n} - \delta\sigma_t^{r,n}}\mathrm{d}t + \underbrace{\left[1 - \frac{P^n(y_t^T, A_t^I - \sigma_t^{A,I})}{P^n(y_t^T, A_t^I)} - \nu^n\right]}_{:=\sigma_t^{r,n}}\mathrm{d}J_t
\end{aligned}$$

Plugging $\mu_t^{r,n}$ into $\mu_t^{A,I}$, we can solve for $\mu_t^{A,I}$ as

$$\mu_t^{A,I} = \left[1 - \sum_n w_t^{I,n}\frac{A_t^I}{P_t^n}\frac{\partial P_t^n}{\partial A_t^I}\right]^{-1}.$$

$$
\left\{ w_t^{I,0}\mu_t^{r,T} - w_t^{I,L}\mu_t^{r,L} + \sum_n w_t^{I,n}\frac{1}{P_t^n}\left[\phi^n - \lambda^n P_t^n + \frac{\partial P_t^n}{\partial y_t^T}\alpha_y\left(y_t^T - \overline{y}^T\right)\right] - \sum_n \frac{1}{2}(\zeta^n w_t^{I,n})^2 + \xi_t \right\}.
$$

To obtain a solvable partial differential equation, we now add the time dimension and postulate $P_t^n = P^n(t, y_t^T, A_t^I)$. By Ito's Lemma,

$$
\begin{aligned}
\mathrm{d}r_t^n &= \frac{\phi^n - \lambda^n P_t^n}{P_t^n}\mathrm{d}t + \frac{\mathrm{d}P_t^n}{P_t^n} - \nu^n \mathrm{d}J_t \\
&= \underbrace{\frac{1}{P_t^n}\left[(\phi^n - \lambda^n P_t^n) + \frac{\partial P_t^n}{\partial t} + \frac{\partial P_t^n}{\partial y_t^T}\alpha_y\left(y_t^T - \overline{y}^T\right) + \frac{\partial P_t^n}{\partial A_t^I}A_t^I\mu_t^{A,I}\right]}_{:=\mu_t^{r,n} - \delta\sigma_t^{r,n}}\mathrm{d}t \\
&\quad + \underbrace{\left[1 - \frac{P^n(y_t^T, A_t^I - \sigma_t^{A,I})}{P^n(y_t^T, A_t^I)} - \nu^n\right]}_{:=\sigma_t^{r,n}}\mathrm{d}J_t.
\end{aligned}
$$

The first-order condition of the portfolio choice problem is

$$
\mu_t^{r,n} - \mu_t^{r,T} = a\delta\sigma_t^{A,I}\sigma_t^{r,n} + (\zeta^n)^2 w_t^{I,n}.
$$

Plugging in the expression for $\mu_t^{r,n}$ and μ_t^T, we get

$$
\begin{aligned}
&\frac{1}{P_t^n}\left[(\phi^n - \lambda^n P_t^n) + \frac{\partial P_t^n}{\partial t} + \frac{\partial P_t^n}{\partial y_t^T}\alpha_y\left(y_t^T - \overline{y}^T\right) + \frac{\partial P_t^n}{\partial A_t^I}A_t^I\mu_t^{A,I}\right] \\
&\quad - \left[\frac{(\phi^T - \lambda^T P_t^T)}{P_t^T} - \frac{1}{y_t^T + \lambda^T}\alpha_y\left(y_t^T - \overline{y}^T\right)\right] + \delta\sigma_t^{r,n} = a\delta\sigma_t^{A,I}\sigma_t^{r,n} + (\zeta^n)^2 w_t^{I,n}.
\end{aligned}
$$

Therefore, we get the following system of partial differential equations:

$$
\begin{aligned}
\frac{\partial P_t^n}{\partial t} = &-\alpha_y\left(y_t^T - \overline{y}^T\right)\frac{\partial P_t^n}{\partial y_t^T} - \left(A_t^I\mu_t^{A,I}\right)\frac{\partial P_t^n}{\partial A_t^I} \\
&+ \left[y_t^T - \frac{1}{y_t^T + \lambda^T}\alpha_y\left(y_t^T - \overline{y}^T\right) + \lambda^n + (a\sigma_t^{A,I} - 1)\delta\sigma_t^{r,n} + (\zeta^n)^2 w_t^{I,n}\right]P_t^n - \phi^n,
\end{aligned}
\tag{D.4}
$$

where

$$
B_t^n = \left(1/\phi^n\right)^{\frac{1}{\theta}}\left(P_t^n\right)^{\frac{1-\theta}{\theta}}, \qquad D_t^n = \alpha^n(P_t^n)^{-\beta}, \qquad w_t^{I,n} = P_t^n(B_t^n - D_t^n)/A_t^I
$$

$$
\mu_t^{A,I} = \left[1 - \sum_n w_t^{I,n}\frac{A_t^I}{P_t^n}\frac{\partial P_t^n}{\partial A_t^I}\right]^{-1}.
$$

$$\left\{ w_t^{I,0}\mu_t^{r,T} - w_t^{I,L}\mu_t^{r,L} + \sum_n w_t^{I,n}\frac{1}{P_t^n}\left[\phi^n - \lambda^n P_t^n + \frac{\partial P_t^n}{\partial y_t^T}\alpha_y\left(y_t^T - \bar{y}^T\right)\right] - \sum_n \frac{1}{2}(\zeta^n w_t^{I,n})^2 + \xi_t \right\}$$

$$\sigma_t^{r,n} = 1 - \frac{P^n(y_t^T, A_t^I - \sigma_t^{A,I})}{P^n(y_t^T, A_t^I)} - \nu^n$$

Finally, $\sigma_t^{A,I}$ is obtained by solving the following system of equations

$$\begin{aligned}
\sigma_t^{A,I} &= \sum_{n=1}^{N} w_t^{I,n}\sigma_t^{r,n} \\
&= \sum_{n=1}^{N} w_t^{I,n}\left[1 - \frac{P^n(y_t^T, A_t^I - \sigma_t^{A,I})}{P^n(y_t^T, A_t^I)} - \nu^n\right] \\
&= \sum_{n=1}^{N} w_t^{I,n}(1-\nu^n) - \sum_{n=1}^{N} w_t^{I,n}\frac{P^n(y_t^T, A_t^I - \sigma_t^{A,I})}{P^n(y_t^T, A_t^I)},
\end{aligned}$$

which can be simplified to

$$\sigma_t^{A,I} - \sum_{n=1}^{N} w_t^{I,n}(1-\nu^n) + \sum_{n=1}^{N} w_t^{I,n}\frac{P^n(y_t^T, A_t^I - \sigma_t^{A,I})}{P^n(y_t^T, A_t^I)} = 0.$$

I solve the PDE system (D.4) using a finite difference method. I start with a guess for $P^n(0, y_t^T, A_t^I)$ and iterate backward through time until the system converges.

E The Duration Management Channel

In this section, I discuss an extension model with a continuum of bonds of different durations where the life insurer has a duration management motive.

Assumptions. As in Section 2.2, I make two simplifying assumptions to make the model tractable.

Assumption 3 *Treasury yields are expected to be constant.*

As we will next introduce bonds with different durations, it is no longer appropriate to assume that corporate bonds are short-term, as in Assumption 1. Instead, I assume that the credit default risk is small and its impact on credit spreads is negligible (as confirmed in Section 4). As a result, credit spreads in this model will almost entirely be driven by regulatory costs.

Assumption 4 *Default risk is negligible compared to regulatory costs, i.e., $\zeta^n \gg \nu^n \approx 0$.*

Assets. In the baseline model of Section 2, the insurer's asset portfolio consists of a single long-term Treasury bond and N corporate bonds. In the extended model, I instead assume that there exists a continuum of Treasuries. As in the baseline model, under the simplifying assumptions, the yield of a Treasury bond is given by

$$y^T = \frac{\phi^T}{P^T} - \lambda^T.$$

The duration of the Treasury bond is then

$$D^T = -\frac{1}{P^T}\frac{\partial P^T}{\partial y^T} = \frac{1}{y^T + \lambda^T} = \frac{P^T}{\phi^T}.$$

Instead of assuming that the decaying rate λ^T is constant, there exists a continuum of Treasuries with different decaying rates λ^T, which takes value within the range $[\underline{\lambda}^T, \overline{\lambda}^T]$. The Treasury yields are still exogenously given. I denote the resulting range of Treasury durations as $[\underline{D}^T, \overline{D}^T]$.

Similarly, for each credit rating n, I assume that there exists a continuum of corporate bonds with different decaying rates. Like Treasuries, we can write the duration of a corporate bond as

$$D^n = \frac{1}{y^n + \lambda^n} = \frac{P^n}{\phi^n}.$$

Ceteris paribus, it can be shown that bonds with a higher decaying rate have lower prices. Hence, there exists a one-to-one and downward-sloping mapping from λ^n to D^n in equilibrium. Suppose that the decaying rate of rating n corporate bonds λ^n takes values within the range $[\underline{\lambda}^n, \overline{\lambda}^n]$. We can then denote the range of durations of rating n corporate bonds as $[\underline{D}^n, \overline{D}^n]$.

As we are primarily interested in credit spreads between bonds with matching durations, I assume that the available durations of Treasuries coincide with those of the corporate bonds. In other words, the distributions of λ^T and λ^n are chosen such that

$$[\underline{D}^T, \overline{D}^T] = [\underline{D}^n, \overline{D}^n] = [\underline{D}, \overline{D}]. \tag{E.1}$$

I further assume that the range of durations is time-invariant. In other words, following a surprise change in interest rates, the distributions of λ^T and λ^n will adjust accordingly to ensure that the durations of Treasuries and corporate bonds still fall within $[\underline{D}, \overline{D}]$.

Under Assumptions 3 and 4, the return rate of a Treasury equals its yield,

$$\frac{\mathrm{d}r^{T,D}}{\mathrm{d}t} = y^{T,D}.$$

where $y^{T,D}$ is the yield of a Treasury with duration D. For a corporate bond of rating n, the return process is given by equation (3),

$$\mathrm{d}r^n = \frac{\phi^n - \lambda^n P^n}{P^n}\mathrm{d}t + \frac{\mathrm{d}P^n - \nu^n P^n \mathrm{d}J_t}{P_t}. \tag{E.2}$$

Since credit risk is small ($\nu^n \approx 0$) and the Treasury yields are expected to be constant ($\mathrm{d}P^n = 0$), we can similarly simplify the return of corporate bonds to

$$\frac{\mathrm{d}r^{n,D}}{\mathrm{d}t} = y^{n,D} = \frac{\phi^n}{P^{n,D}} - \lambda^{n,D}.$$

where $y^{T,D}, P^{n,D}, \lambda^{n,D}$ are the yield, price, and decaying rate of a rating n corporate bond with duration D.

In addition, there exists a zero-duration asset ("cash"), that is in unlimited supply and has a return rate of y^0, $\mathrm{d}r^0 = y^0\mathrm{d}t$.

The Insurer's Portfolio Problem. The insurer has a net worth of A^I, and it first chooses how to allocate its net worth across durations. I denote the insurer's portfolio weight in duration-D assets as $w^{I,D}$. It invests the remaining wealth, in the zero-duration assets, so the portfolio weight in cash is $w^{I,0} = 1 - \int_{\underline{D}}^{\overline{D}} w^{I,D}\mathrm{d}D + w^{I,L}$.

Second, within each duration D, the insurer chooses how to allocate its holdings between Treasuries and corporate bonds. I use $\theta^{n,D}$ to denote the insurer's holdings of rating n bonds of duration D as a fraction of its total assets of duration D. Similarly, its holdings of duration-D Treasuries as a fraction of its total duration-D assets is then $\theta^{T,D} = 1 - \sum_n \theta^{n,D}$.

Under Assumption 4, the portfolio problem can then be written as[4]

$$\max_{w^{I,D},\, \theta^{T,D},\, \theta^{n,D},\, w^{I,0}} \quad \overbrace{\int_{\underline{D}}^{\overline{D}} w^{I,D}\left[\theta^{T,D}y^{T,D} + \sum_{n=1}^{N}\theta^{n,D}y^{n,D}\right]\mathrm{d}D + w^{I,0}y^0}^{\text{expected asset return}} \tag{E.3}$$
$$\underbrace{-\frac{1}{2}\sum_{n=1}^{N}\int_{\underline{D}}^{\overline{D}}\left(\zeta^n w^{I,D}\theta^{n,D}\right)^2\mathrm{d}D}_{\text{regulatory cost}} - \underbrace{\frac{\psi}{2}(\text{Duration Gap})^2}_{\text{duration management}},$$
$$\text{s.t.}\quad w^{I,0} = 1 - \int_{\underline{D}}^{\overline{D}} w^{I,D}\mathrm{d}D + w^{I,L}, \quad \theta^{T,D} = 1 - \sum_{n=1}^{N}\theta^{n,D}.$$

The new term $\frac{\psi}{2}(\text{Duration Gap})^2$ captures the insurer's duration management motive, and the duration gap is defined as:

$$\text{Duration Gap} := \frac{1}{A^I}\left(A^I\int_{\underline{D}}^{\overline{D}} w^{I,D}D\mathrm{d}D - LD_L\right).$$

Here, D_L is the duration of annuities, LD_L is the total duration of the insurer's liabilities, and $A^I\int_D w^{I,D}D\mathrm{d}D$ is the total duration of the insurer's assets. The insurer incurs

[4]Here, I omit the terms related to annuity returns since the portfolio weight in annuities is exogenously given in equilibrium.

disutility from non-zero duration gaps, and the constant $\psi > 0$ measures the strength of the duration management motive. As I am mainly interested in the situation where the insurer has a negative duration gap, I assume that Duration Gap < 0 in equilibrium.

Habitat Demand and Bond Supply. In the spirit of Vayanos and Vila (2021), I assume that both the habitat demand and the supply of corporate bonds are segmented by duration. In particular, corporate bonds of rating n and duration D have a reduced-form habitat demand function $HD^{n,D}(P^{n,D})$ that is decreasing in the price $P^{n,D}$. Similarly, the supply of corporate bonds of rating n and duration D is given by an increasing function $B^{n,D}(P^{n,D})$. The market for corporate bonds of rating n and duration D clears when the insurer's demand and the habitat demand sum to the total supply,

$$w^{I,D}\theta^{n,D}A^I + P^{n,D}HD^{n,D} = P^{n,D}B^{n,D}. \tag{E.4}$$

Credit Spread Dynamics. Solving the problem (E.3), the first-order conditions with respect to the portfolio weights within durations $\theta^{n,D}$ are

$$y^{n,D} - y^{T,D} = (\zeta^n)^2 w^{I,D}\theta^{n,D}.$$

We can therefore write the insurer's demand for bonds of rating n and duration D as

$$w^{I,D}\theta^{n,D}A^I = \frac{y^{n,D} - y^{T,D}}{(\zeta^n)^2/A^I}, \tag{E.5}$$

Note that the insurer's demand (E.5) and the market clearing condition (E.4) are exactly analogous to those in the baseline model, i.e., equations (6) and (9). It then follows from the proof of Proposition 1 that, if the insurer has a negative duration gap, an increase in interest rates (e.g., a uniform increase in Treasury yields across all durations) reduces the insurer's effective risk aversion $(\zeta^n)^2/A^I$ and lowers the credit spreads $y^{n,D} - y^{T,D}$ for all rating n and duration D.

The Duration Management Channel. Next, we analyze how the insurer allocates its portfolio across durations. The first-order conditions with respect to $w^{I,D}$ are

$$y^D - y^0 = \sum_{n=1}^{N} \left(\zeta^n\theta^{n,D}\right)^2 w^{I,D} + \psi(\text{Duration Gap})D.$$

Here y^D is the average yield of duration-D bonds in the insurer's portfolio,

$$y^D = y^{T,D} + \sum_{n=1}^{N} \theta^{n,D}(y^{n,D} - y^{T,D}).$$

When Duration Gap < 0, we can further rewrite the first order condition as

$$w^{I,D} = \frac{(y^D - y^0) + \psi D|\text{Duration Gap}|}{\sum_{n=1}^{N}\left(\zeta^n \theta^{n,D}\right)^2}.$$

The first term in the numerator, $(y^D - y^0)$, captures the effect of term spreads on the insurer's portfolio decisions. Ceteris paribus, the insurer holds more long-term assets when the term spread is higher.

The duration management channel influences the insurer's portfolio allocations via the second term, $\psi D|\text{Duration Gap}|$. When interest rates increase, the insurer's duration gap shrinks ($|\text{Duration Gap}| \downarrow$),[5] which can reduce the insurer's demand for long-duration assets ($w^{I,D} \downarrow$). Moreover, the effect of the duration management channel is stronger in bonds of higher durations.

In richer models with a term structure of interest rates (e.g., Vayanos and Vila, 2021), such demand shifts across durations from the insurance sector can lead to significant impacts on the yield curve (Domanski, Shin and Sushko, 2017; Greenwood and Vissing-Jorgensen, 2018). However, since the focus of the current paper is on the credit spreads between bonds with matching durations, I leave a more thorough analysis of the impacts of the duration management channel on the term structure of corporate bonds for future research.

F Full Regression Tables

[5] In this model, the duration gap shrinks because the duration of the insurer's liabilities D^L becomes shorter when Treasury yields increase.

	(1)	(2)	(3)	(4)
NAIC 2 $\times \Delta y_t^{(10)}$	0.024	-0.134**	-0.085*	-0.136***
	[0.398]	[-2.182]	[-1.848]	[-3.245]
NAIC 3 $\times \Delta y_t^{(10)}$	-0.063	-0.751***	-0.510***	-0.679***
	[-0.507]	[-3.330]	[-2.734]	[-3.809]
NAIC 4 $\times \Delta y_t^{(10)}$	-0.254	-1.377***	-0.946***	-1.170***
	[-1.017]	[-4.681]	[-3.487]	[-4.588]
NAIC 5 $\times \Delta y_t^{(10)}$	-0.224	-3.689***	-4.327***	-2.653***
	[-0.356]	[-4.345]	[-3.085]	[-4.815]
NAIC 6 $\times \Delta y_t^{(10)}$	0.423	-10.721***	-6.779**	-10.149***
	[0.289]	[-3.864]	[-2.131]	[-2.988]
Volume $\times \Delta y_t^{(10)}$	0.000	-0.000**	-0.000***	-0.000**
	[0.331]	[-2.567]	[-2.761]	[-2.320]
Time to Maturity $\times \Delta y_t^{(10)}$	0.011	-0.014**	0.009*	0.002
	[1.399]	[-2.208]	[1.815]	[0.536]
Size $\times \Delta y_t^{(10)}$	0.000**	0.000***	0.000***	0.000***
	[2.512]	[3.887]	[3.145]	[3.509]
Coupon Rate $\times \Delta y_t^{(10)}$	-0.019	0.027	-0.048**	-0.001
	[-0.846]	[1.437]	[-2.234]	[-0.054]
Coupon Freq $\times \Delta y_t^{(10)}$	0.007	0.159***	-0.057*	0.085***
	[0.479]	[3.083]	[-1.826]	[2.688]
1-month NAIC k Default % $\times \Delta y_t^{(10)}$	-0.216*	0.191	-0.286	0.584*
	[-1.891]	[0.629]	[-0.820]	[1.718]
Fixed-Price Call Option $\times \Delta y_t^{(10)}$			-0.112	
			[-1.118]	
Make-Whole Call Option $\times \Delta y_t^{(10)}$			-1.425*	
			[-1.974]	
Hybrid Call Option $\times \Delta y_t^{(10)}$			-1.570**	
			[-2.061]	
Moneyness $\times \Delta y_t^{(10)}$			0.018**	
			[2.235]	
ΔMerton EDF				0.084***
				[9.032]
Sample Period	Pre-2007	Post-2009	Post-2009	Post-2009
Duration-Time FE	✓	✓	✓	✓
Bond FE	✓	✓	✓	✓
Observations	297003	1069943	801946	693579
R-squared	0.230	0.239	0.213	0.316

Table F.1. **Main Results.**

	Pre-2007	Post-2009
$\mathbf{1}_{\{k=\mathrm{HY}\}} \times \Delta y_t^{(10)}$	-0.136	0.939**
	[-0.371]	[2.006]
New Issue Maturity$_{kt} \times \Delta y_t^{(10)}$	0.140	0.044
	[1.071]	[0.361]
Default Rate$_{kt}$	0.651	0.108
	[1.112]	[0.288]
NAIC FE	✓	✓
Time FE	✓	✓
R^2	.589	.725

Table F.2. **Bond Issuance.**

	Pre-2007	2010-2022	2023-2024
$\Delta y_t^{(10)}$	-0.009	6.369***	2.978
	[-0.008]	[6.665]	[1.632]
S&P 500 Return	1.037***	1.192***	0.744***
	[14.457]	[18.706]	[5.705]
R^2	.648	.728	.263
Observations	260	676	104

Table F.3. **Insurer Risk Exposure.**

	Pre-2007	Post-2009
γ	-0.099	-9.038**
	[-0.059]	[-2.675]
β	-0.933	4.102*
	[-0.913]	[2.058]
Time to Maturity $\times \Delta y_t^{(10)}$	0.031	0.155**
	[0.541]	[2.800]
Default Rate$_{kt}$ $\times \Delta y_t^{(10)}$	-0.311	-0.503
	[-1.899]	[-0.794]
Volume $\times \Delta y_t^{(10)}$	-0.000	-0.000
	[-0.197]	[-1.819]
Coupon Rate $\times \Delta y_t^{(10)}$	0.195	-0.313***
	[1.199]	[-4.617]
Coupon Frequency $\times \Delta y_t^{(10)}$	-0.080	-0.072
	[-1.010]	[-0.966]
Size $\times \Delta y_t^{(10)}$	0.000	0.000
	[0.614]	[0.788]
Insurer Share	-0.005	-0.003
	[-1.073]	[-0.802]
Time FE	✓	✓
First-stage F	54.467	110.164
Observations	4506	7894

Table F.4. **RDD.**

Panel A: All Insurers.

	$h=3m$			$h=6m$		
$(\text{VA Share})_{j,2009} \times \Delta y_t^{(10)}$	0.243***	0.224***	0.225***	1.001***	0.944***	0.943***
	[4.820]	[4.230]	[4.140]	[11.417]	[9.129]	[9.182]
$\log(\text{Net Assets})_{j,t} \times \Delta y_t^{(10)}$		0.100	0.123		0.358***	0.348**
		[1.074]	[1.245]		[2.697]	[2.477]
$(\text{RBC Ratio})_{j,t} \times \Delta y_t^{(10)}$			0.015			-0.006
			[1.599]			[-0.506]
Insurer FE	✓	✓	✓	✓	✓	✓
Time FE	✓	✓	✓	✓	✓	✓
R^2	.021	.022	.022	.034	.036	.036
Observations	27518	27409	27305	23755	23651	23582

Panel B: VA Insurers.

	$h=3m$			$h=6m$		
$(\text{VA Share})_{j,2009} \times \Delta y_t^{(10)}$	0.177**	0.165*	0.187**	0.845***	0.852***	0.854***
	[2.085]	[1.859]	[2.026]	[6.558]	[6.551]	[6.491]
$\log(\text{Net Assets})_{j,t} \times \Delta y_t^{(10)}$		-0.164	-0.044		0.107	0.132
		[-0.632]	[-0.166]		[0.345]	[0.405]
$(\text{RBC Ratio})_{j,t} \times \Delta y_t^{(10)}$			0.101			0.017
			[1.513]			[0.361]
Insurer FE	✓	✓	✓	✓	✓	✓
Time FE	✓	✓	✓	✓	✓	✓
R^2	.035	.035	.035	.045	.045	.045
Observations	11144	11144	11105	10266	10266	10237

Table F.5. **Bond Transaction.**

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