The Bond Premium in a DSGE Model with Long-Run Real and Nominal Risks

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Outline

The Bond Premium Puzzle

The equity premium puzzle: excess returns on stocks are much larger (and more variable) than can be explained by standard preferences in a DSGE model (Mehra and Prescott, 1985).

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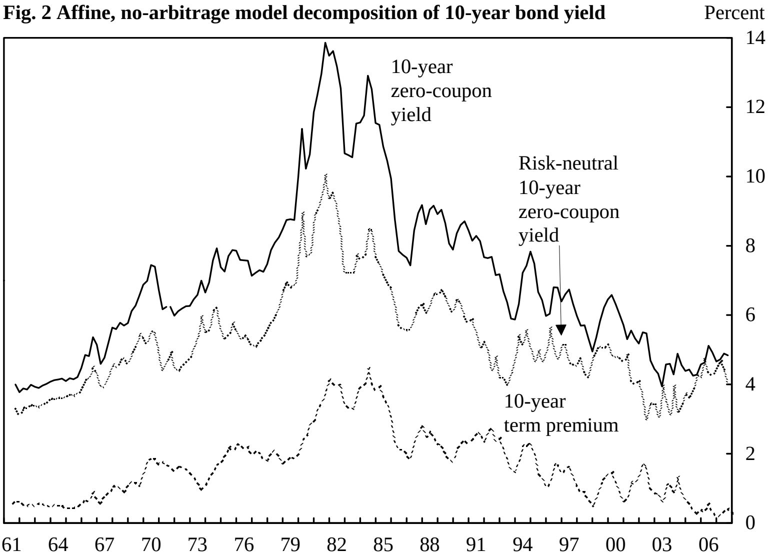
Note:

- Since Backus, Gregory, and Zin (1989), DSGE models with nominal rigidities have advanced considerably

Kim-Wright Term Premium

Fig. 2 Affine, no-arbitrage model decomposition of 10-year bond yield



Why Study the Term Premium?

The term premium is important:

- DSGE models increasingly used for policy analysis; total failure to explain term premium may signal flaws in the model
- many empirical questions about term premium require a structural DSGE model to provide reliable answers

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The equity premium has received more attention in the literature, but the term premium:

- provides an additional perspective on the model
- tests nominal rigidities in the model
- only requires modeling short-term interest rate process, not dividends
- applies to a larger volume of U.S. securities

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- Wachter (2005)
  - can resolve bond premium puzzle using Campbell-Cochrane preferences in endowment economy

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We examine to what extent the Piazzesi-Schneider results generalize to the DSGE case

Related Strands of the Literature

The Bond Premium in a DSGE Model:

- Backus-Gregory-Zin (1989), Donaldson-Johnson-Mehra (1990), Den Haan (1995), Rudebusch-Swanson (2008)

Epstein-Zin Preferences and the Bond Premium in an Endowment Economy:

- Piazzesi-Schneider (2006), Colacito-Croce (2007), Backus-Routledge-Zin (2007), Gallmeyer-Hollifield-Palomino-Zin (2007), Bansal-Shaliastovich (2008)

Epstein-Zin Preferences in a DSGE Model:

- Tallarini (2000), Croce (2007), Levin-Lopez-Salido-Nelson-Yun (2008)

Epstein-Zin Preferences and the Bond Premium in a DSGE Model:

- van Binsbergen-Fernandez-Villaverde-Koijen-Rubio-Ramirez (2008)

The Term Premium in a Standard DSGE Model

2. The Bond Premium in the Standard New Keynesian Model
   - Define Standard New Keynesian DSGE Model
   - Review Asset Pricing
   - Solve the Model
   - Results with the Standard Model

New Keynesian Model (Very Standard)

Representative household with preferences:

$$\max E_t \sum_{t=0}^{\infty} \beta^t \left(\frac{(c_t - h_t)^{1-\gamma}}{1-\gamma} - \chi_0 \frac{l_t^{1+\chi}}{1+\chi} \right)$$

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Stochastic discount factor:

$$m_{t+1} = \frac{\beta(C_{t+1} - bC_t)^{-\gamma}}{(C_t - bC_{t-1})^{-\gamma}} \frac{P_t}{P_{t+1}}$$

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Parameters: $\beta = .99$, $b = .66$, $\gamma = 2$, $\chi = 1.5$

New Keynesian Model (Very Standard)

Continuum of differentiated firms:

- face Dixit-Stiglitz demand with elasticity $\frac{1+\theta}{\theta}$, markup θ
- set prices in Calvo contracts with avg. duration 4 quarters
- identical production functions $y_t = A_t \bar{k}^{1-\alpha} l_t^{\alpha}$
- have firm-specific capital stocks
- face aggregate technology $\log A_t = \rho_A \log A_{t-1} + \varepsilon_t^A$

Parameters $\theta = .2$, $\rho_A = .9$, $\sigma_A^2 = .01^2$

Perfectly competitive goods aggregation sector

New Keynesian Model (Very Standard)

Government:

- imposes lump-sum taxes G_t on households
- destroys the resources it collects
- $\log G_t = \rho_G \log G_{t-1} + (1 - \rho_g) \log \bar{G} + \varepsilon_t^G$

Parameters $\bar{G} = .17\bar{Y}$, $\rho_G = .9$, $\sigma_G^2 = .004^2$

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Monetary Authority:

$$i_t = \rho_i i_{t-1} + (1 - \rho_i)\left[1/\beta + \pi_t + g_y(y_t - \bar{y}) + g_\pi(\bar{\pi}_t - \pi^*)\right] + \varepsilon_t^i$$

Parameters $\rho_i = .73$, $g_y = .53$, $g_\pi = .93$, $\pi^* = 0$, $\sigma_i^2 = .004^2$

Asset Pricing

Asset pricing:

$$p_t = d_t + E_t[m_{t+1} p_{t+1}]$$

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Zero-coupon bond pricing:

$$p_t^{(n)} = E_t[m_{t+1} p_{t+1}^{(n-1)}]$$

$$i_t^{(n)} = -\frac{1}{n} \log p_t^{(n)}$$

Notation: let $i_t \equiv i_t^{(1)}$

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$$\widetilde{p}_t^{(n)} = 1 + \delta_c \, E_t m_{t+1} \widetilde{p}_{t+1}^{(n)}$$

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Term premium:

$$\psi_t^{(n)} \equiv \log\left(\frac{\delta_c \widetilde{p}_t^{(n)}}{\widetilde{p}_t^{(n)} - 1}\right) - \log\left(\frac{\delta_c \widehat{p}_t^{(n)}}{\widehat{p}_t^{(n)} - 1}\right)$$

Solving the Model

The standard NK model above has a relatively large numer of state variables: C_{t-1}, A_{t-1}, G_{t-1}, i_{t-1}, Δ_{t-1}, $\bar{\pi}_{t-1}$, ε_t^A, ε_t^G, ε_t^i

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We solve the model by approximation around the nonstochastic steady state (perturbation methods)

- In a first-order approximation, term premium is zero
- In a second-order approximation, term premium is a constant (sum of variances)
- So we compute a *third*-order approximation of the solution around nonstochastic steady state
- Perturbation AIM algorithm in Swanson, Anderson, Levin (2006) quickly computes *n*th order approximations

Results

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- shocks in macro models have standard deviations $\approx .01$
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To make these higher-order terms important,

- need “high curvature” modifications from finance literature
- or shocks with standard deviations $\gg .01$

Additional Robustness Checks

This basic finding is extremely robust:

- Campbell-Cochrane habits: $\bar{\psi}^{(10)} = 2.4$ bp, sd$(\psi^{(10)}) = 0.1$ bp
- "best fit" parameters: $\bar{\psi}^{(10)} = 10.6$ bp, sd$(\psi^{(10)}) = 1.3$ bp
- larger models (CEE): $\bar{\psi}^{(10)} = 1.0$ bp, sd$(\psi^{(10)}) = 0.1$ bp
- models with investment
- internal habits
- markup shocks
- nominal wage rigidities
- real wage rigidities
- time-varying π_t^* (long-run risk)

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Basic problem: even if agents in these habit-based models are very risk averse, in a DSGE setting they are able to offset the risk that they hate (high-frequency variation in C)

Epstein-Zin Preferences

Modify the standard NK model to incorporate Epstein-Zin preferences.

The model then has three key ingredients:

1. Intrinsic nominal rigidities
   - makes bond pricing interesting
2. Epstein-Zin preferences
   - makes households risk averse
3. Long-run risk (productivity or inflation)
   - introduces a risk households cannot offset
   - makes bonds risky

Epstein-Zin Preferences

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We'll use standard NK utility kernel:

$$u(c_t, l_t) \equiv \frac{c_t^{1-\gamma}}{1-\gamma} - \chi_0 \frac{l_t^{1+\chi}}{1+\chi},$$

Epstein-Zin Preferences

Household optimality conditions with EZ preferences:

$$\begin{aligned}
\mu_t \, u_1\big|_{(c_t,l_t)} &= P_t \lambda_t \\
-\mu_t \, u_2\big|_{(c_t,l_t)} &= w_t \lambda_t \\
\lambda_t &= \beta E_t \lambda_{t+1} (1 + r_{t+1}) \\
\mu_t &= \mu_{t-1} \left(E_{t-1} V_t^{1-\alpha} \right)^{\alpha/(1-\alpha)} V_t^{-\alpha}, \quad \mu_0 = 1
\end{aligned}$$

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\end{aligned}
$$

Stochastic discount factor:

$$
m_{t,t+1} \equiv \frac{\beta u_1\big|_{(c_{t+1},l_{t+1})}}{u_1\big|_{(c_t,l_t)}} \left(\frac{V_{t+1}}{\left(E_t V_{t+1}^{1-\alpha}\right)^{1/(1-\alpha)}} \right)^{\alpha} \frac{P_t}{P_{t+1}}
$$

Results

Table 2: Empirical and Model-Based Unconditional Moments

Variable	U.S. Data	EU Preferences	"best fit" EZ Preferences
sd[C]	1.19	1.42	2.53
sd[L]	1.71	2.56	2.21
sd[w^r]	0.82	2.08	1.52
sd[π]	2.52	2.25	2.71
sd[i]	2.71	1.90	2.27
sd[$i^{(10)}$]	2.41	0.54	1.03
mean[$\psi^{(10)}$]	1.06	.010	1.05
sd[$\psi^{(10)}$]	0.54	.000	.184
mean[$i^{(10)} - i$]	1.43	$-$.047	0.99
sd[$i^{(10)} - i$]	1.33	1.43	1.33
mean[$x^{(10)}$]	1.76	.015	1.04
sd[$x^{(10)}$]	23.43	6.56	9.02
memo: quasi-CRRA		2	75

Long-Run Risks

4. Long-Run Risks
   - Long-Run Inflation Risk
   - Long-Run Real Risk

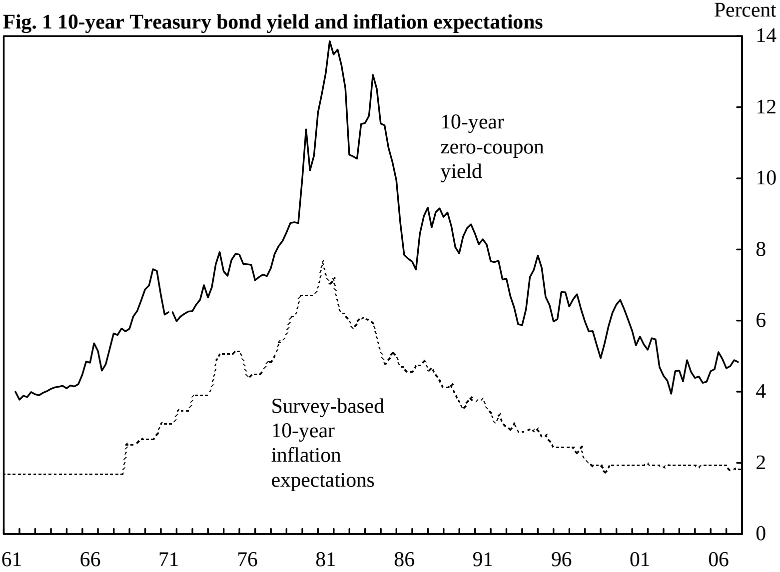
Long-Run Inflation Risk

Introduce long-run inflation risk to make long-term bonds more risky:

- same idea as Bansal-Yaron (2004), but with nominal risk rather than real risk
- long-term inflation expectations more observable than long-term consumption growth
- other evidence (Kozicki-Tinsley, 2003, Gürkaynak, Sack, Swanson, 2005) that long-term inflation expectations in the U.S. vary

Long-Run Inflation Risk

Fig. 1 10-year Treasury bond yield and inflation expectations



Long-Run Inflation Risk

Suppose:

$$\pi_t^* = \rho_\pi^* \pi_{t-1}^* + \varepsilon_t^{\pi^*}$$

Long-Run Inflation Risk

Suppose:

$$\pi_t^* = \rho_\pi^* \pi_{t-1}^* + \varepsilon_t^{\pi^*}$$

Then:

- inflation is volatile, but not risky
- in fact, long-term bonds act like insurance: when $\pi^* \uparrow$, then $C \uparrow$ and $p^{(10)} \downarrow$
- result: term premium is *negative*

Long-Run Inflation Risk

Consider instead:

$$\pi_t^* = \rho_\pi^* \pi_{t-1}^* + (1 - \rho_\pi^*)\theta_{\pi^*}(\overline{\pi}_t - \pi_t^*) + \varepsilon_t^{\pi^*}$$

Long-Run Inflation Risk

Consider instead:

$$\pi_t^* = \rho_\pi^* \pi_{t-1}^* + (1 - \rho_\pi^*)\theta_{\pi^*}(\overline{\pi}_t - \pi_t^*) + \varepsilon_t^{\pi^*}$$

- θ_{π^*} describes pass-through from current π to long-term π^*
- Gürkaynak, Sack, and Swanson (2005) found evidence for $\theta_{\pi^*} > 0$ in U.S. bond response to macro data releases
- makes long-term bonds act less like insurance: when technology/supply shock, then $\pi \uparrow$, $C \downarrow$, and $p^{(10)} \downarrow$ supply shocks become very costly
- The term premium is *positive*, closely associated with θ_{π^*}

Results

Table 4: Model-Based Moments with Long-Run Inflation Risk

Variable	U.S. Data	EU Preferences & LR Risk	EZ Prefs & LR Risk
sd[C]	1.19	1.92	1.86
sd[L]	1.71	3.33	1.73
sd[w^r]	0.82	2.55	1.45
sd[π]	2.52	5.00	3.22
sd[i]	2.71	4.74	2.99
sd[$i^{(10)}$]	2.41	3.32	1.94
mean[$\psi^{(10)}$]	1.06	.002	.748
sd[$\psi^{(10)}$]	0.54	.001	.431
mean[$i^{(10)} - i$]	1.43	$-$.062	.668
sd[$i^{(10)} - i$]	1.33	1.60	1.11
mean[$x^{(10)}$]	1.76	.003	.737
sd[$x^{(10)}$]	23.43	16.96	11.83
memo: quasi-CRRA		2	65

Long-Run Productivity Risk

Following Bansal and Yaron (2004), introduce long-run real risk to make the economy more risky:

Assume productivity follows:

$$\log A_t^* = \rho_{A^*} \log A_{t-1}^* + \varepsilon_t^{A^*}$$

$$\log A_t = \log A_t^* + \varepsilon_t^A$$

where $\rho_{A^*} = .98$, $\sigma_{A^*} = .002$, and $\sigma_A = .005$.

- makes the economy much riskier to agents
- increases volatility of stochastic discount factor

Results

Table 3: Model-Based Moments with Long-Run Productivity Risk

Variable	U.S. Data	EU Preferences & LR Risk	EZ Prefs & LR Risk
sd[C]	1.19	0.92	2.95
sd[L]	1.71	1.03	1.32
sd[w^r]	0.82	1.43	1.90
sd[π]	2.52	1.12	3.14
sd[i]	2.71	1.17	2.88
sd[$i^{(10)}$]	2.41	0.65	1.84
mean[$\psi^{(10)}$]	1.06	.005	.872
sd[$\psi^{(10)}$]	0.54	.000	.183
mean[$i^{(10)} - i$]	1.43	$-$.018	.758
sd[$i^{(10)} - i$]	1.33	0.64	1.15
mean[$x^{(10)}$]	1.76	.005	.859
sd[$x^{(10)}$]	23.43	4.39	11.59
memo: quasi-CRRA		2	35

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3. Epstein-Zin preferences can solve bond premium puzzle in endowment economy, are much more promising in NK DSGE framework:
   agents are risk-averse and cannot offset long-run real or nominal risks
4. Long-run risks reduce the required quasi-CRRA, increase volatility of risk premia, help fit financial moments