Examining the Bond Premium Puzzle in a DSGE Model

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Federal Reserve Bank of Dallas
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Outline

1. Motivation and Background
2. The Term Premium in a Benchmark New Keynesian Model
3. Benchmark Results
4. Slow-Moving Habits and Labor Market Frictions
5. Conclusions
The bond premium puzzle: excess returns on long-term bonds are much larger (and more variable) than can be explained by standard preferences in a DSGE model (Backus, Gregory, and Zin, 1989).
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Note:

- Since Backus, Gregory, and Zin (1989), DSGE models with nominal rigidities have advanced considerably
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## Table 2: Summary Statistics for Four Measures of the Term Premium on the 10-year Bond, 1994–2006

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<tr>
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<tbody>
<tr>
<td>Bernanke, Reinhart, and Sack</td>
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</tr>
<tr>
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</tr>
<tr>
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Means and standard deviations in basis points
The Bond Premium Puzzle

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means and standard deviations in basis points.
Kim-Wright Term Premium

Kim-Wright Term Premium on 10-Year Zero-Coupon Bond

Percent

0.0 0.5 1.0 1.5 2.0 2.5 3.0

92 93 94 95 96 97 98 99 00 01 02 03 04 05 06
Why Study the Bond Premium Puzzle?

The bond premium puzzle 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 puzzle has received more attention in the literature, but the bond premium puzzle:

- 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
Recent Studies of the Bond Premium Puzzle

- Wachter (2005)
  - can resolve bond premium puzzle using Campbell-Cochrane preferences in endowment economy
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Moreover, in the present paper, we show:

- in the Christiano, Eichenbaum, Evans (2006) model, term premium is 1 bp
The Term Premium in a Benchmark New Keynesian Model

- Define Benchmark New Keynesian Model
- Review Asset Pricing
- Solve the Model
Benchmark 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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Benchmark model: let $h_t \equiv bC_{t-1}$
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Benchmark model: let $h_t \equiv bC_{t-1}$

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: $\beta = .99$, $b = .66$, $\gamma = 2$, $\chi = 1.5$
Benchmark New Keynesian Model (Very Standard)

Continuum of differentiated firms:
- face Dixit-Stiglitz demand with elasticity $\frac{1+\theta}{\theta}$, markup $\theta$
- set prices in Calvo contracts with avg. duration 4 quarters
- identical production functions $y_t = A_t \bar{k}^{1-\alpha} l^\alpha$
- 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
Motivation

Benchmark DSGE Model

Benchmark Results

Slow-Moving Habits & Labor Frictions

Conclusions

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

Monetary Authority:

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

Parameters $\rho_i = .73$, $g_y = .53$, $g_\pi = .93$, $\pi^* = 0$, $\sigma^2_i = .004^2$
Asset Pricing

Asset pricing:

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

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 \( i_t \equiv i_t^{(1)} \)
The Term Premium in the Benchmark Model

In DSGE framework, convenient to work with a default-free consol, a perpetuity that pays $1, $c_1$, $c_2$, $c_3$, ... (nominal)

Price of the consol:

$$p(\infty)_t = 1 + \delta c E_t m_t + \frac{1}{p(\infty)_t}$$

Risk-neutral consol price:

$$p(\infty)_{rn}_t = 1 + \delta c e^{-it} E_t p(\infty)_{rn}_t + \frac{1}{p(\infty)_{rn}_t}$$

Term premium:

$$\log(p(\infty)_t) - \log(p(\infty)_{rn}_t)$$
The Term Premium in the Benchmark Model

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The Term Premium in the Benchmark Model

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Risk-neutral consol price:

\[
p_t^{(\infty)rn} = 1 + \delta_c e^{-i_t} E_t p_t^{(\infty)rn}
\]

Term premium:

\[
\log \left( \frac{\delta_c p_t^{(\infty)}}{p_t^{(\infty)} - 1} \right) - \log \left( \frac{\delta_c p_t^{(\infty)rn}}{p_t^{(\infty)rn} - 1} \right)
\]
The benchmark model above has a relatively large number of state variables: $C_{t-1}, A_{t-1}, G_{t-1}, i_{t-1}, \Delta_{t-1}, \bar{\pi}_t, \varepsilon^A_t, \varepsilon^G_t, \varepsilon^i_t$.
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We solve the model by approximation around the nonstochastic steady state (perturbation methods)
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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.
Results

In the benchmark NK model:

- mean term premium: **2.0 bp**
- unconditional standard deviation of term premium: **0.1 bp**
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Intuition:

- shocks in macro models have standard deviations $\approx 0.01$
- 2nd-order terms in macro models $\sim (0.01)^2$
- 3rd-order terms $\sim (0.01)^3$
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To make these higher-order terms important,
- need “high curvature” modifications from finance literature
- or shocks with standard deviations $\gg 0.01$
## Robustness of Results

### Table 1: Alternative Parameterizations of Baseline Model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Baseline case</th>
<th>Low case</th>
<th>High case</th>
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<tbody>
<tr>
<td></td>
<td>value</td>
<td>mean[$\psi_t$]</td>
<td>value</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>2</td>
<td>.5</td>
<td>-1.4</td>
</tr>
<tr>
<td>$\chi$</td>
<td>1.5</td>
<td>0</td>
<td>.8</td>
</tr>
<tr>
<td>$b$</td>
<td>.66</td>
<td>0</td>
<td>1.6</td>
</tr>
<tr>
<td>$\rho_A$</td>
<td>.9</td>
<td>.7</td>
<td>.4</td>
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<tr>
<td>$\sigma^2_A$</td>
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<td>.005$^2$</td>
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<tr>
<td>$\rho_i$</td>
<td>.73</td>
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</tr>
<tr>
<td>$g_\pi$</td>
<td>.53</td>
<td>.05</td>
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<tr>
<td>$g_y$</td>
<td>.93</td>
<td>0</td>
<td>4.0</td>
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<tr>
<td>$\pi^*$</td>
<td>0</td>
<td>0</td>
<td>-</td>
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# Robustness of Results

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<table>
<thead>
<tr>
<th>Parameter</th>
<th>Baseline case value</th>
<th>Low case value</th>
<th>Low case mean[$\psi_t$]</th>
<th>High case value</th>
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<td>$\gamma$</td>
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<td>.7</td>
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Models with Giant Shocks

Hördahl, Tristani, Vestin (2006) match level of term premium using:

- NK model very similar to our benchmark model
- giant technology shocks: $\rho_a = .986, \sigma_a = .0237$
- in our benchmark model, imply consol term premium of 100bp
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Ravenna and Seppälä (2007) match level of term premium using:
- NK model similar to above
- preferences: $\frac{(c_t - bC_{t-1})^{1-\gamma}}{1 - \gamma} - \xi_t \chi_0 \frac{I_t^{1+\chi}}{1 + \chi}$
- giant preference shocks: $\rho_\xi = .95, \sigma_\xi = .08$
- in our benchmark model, imply consol term premium of 29.8bp
Models with Giant Shocks

Table 3: Unconditional Moments

<table>
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<tr>
<th>Variable</th>
<th>Baseline</th>
<th>HTV</th>
<th>RS</th>
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<tr>
<td>mean[$\psi$]</td>
<td>2.0</td>
<td>100.3</td>
<td>29.8</td>
</tr>
<tr>
<td>standard deviations measured in percent</td>
<td></td>
<td></td>
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<tr>
<td>sd[$C$]</td>
<td>1.24</td>
<td>12.7</td>
<td>5.23</td>
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<tr>
<td>sd[$Y$]</td>
<td>0.79</td>
<td>7.98</td>
<td>3.30</td>
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<tr>
<td>sd[$L$]</td>
<td>2.40</td>
<td>9.64</td>
<td>5.16</td>
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<tr>
<td>sd[$w']$</td>
<td>1.89</td>
<td>12.6</td>
<td>10.1</td>
</tr>
<tr>
<td>sd[$\pi$]</td>
<td>2.20</td>
<td>15.5</td>
<td>7.84</td>
</tr>
<tr>
<td>standard deviations measured in basis points</td>
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<td></td>
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</tr>
<tr>
<td>sd[$i$]</td>
<td>209</td>
<td>1560</td>
<td>772</td>
</tr>
<tr>
<td>sd[ytm]</td>
<td>53</td>
<td>1049</td>
<td>290</td>
</tr>
<tr>
<td>sd[$\psi$]</td>
<td>0.1</td>
<td>228</td>
<td>13.7</td>
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### Models with Giant Shocks

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<tr>
<td>sd[$ytm$]</td>
</tr>
<tr>
<td>sd[$\psi$]</td>
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</tbody>
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Slow-Moving Habits and Labor Market Frictions

- Campbell-Cochrane Habits
- Campbell-Cochrane Habits with Labor Market Frictions
Campbell-Cochrane Habits

Preferences: \[
\frac{(c_t - H_t)^{1-\gamma}}{1 - \gamma} - \chi_0 \frac{l_t^{1+\chi}}{1 + \chi}
\]

Habits defined implicitly by \[S_t \equiv \frac{C_t - H_t}{C_t},\] where:

\[
\log S_t = \phi \log S_{t-1} + (1 - \phi) \log S + \frac{1}{\bar{S}} \left( \sqrt{1 - 2(\log S_{t-1} - \log S)} - 1 \right) (\Delta \log C_t - E_{t-1} \Delta \log C_t)
\]

Campbell-Cochrane calibrate \(\phi = .87, \bar{S} = .0588\)
Campbell-Cochrane Habits: Results

Recall: Wachter (2005) resolves bond premium puzzle using:

- Campbell-Cochrane habits
- *endowment economy*
- random walk consumption
- exogenous process for inflation
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However, incorporating Campbell-Cochrane habits into our benchmark DSGE model implies:
- mean term premium: 3.7 bp
- standard deviation of term premium: 0.2 bp
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- exogenous process for inflation

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Intuition: in a DSGE model, households can self-insure by varying labor supply
Possible solution:

- add labor market frictions to prevent households from self-insuring

Explore three classes of labor market frictions:

- households pay an adjustment cost: \( \kappa (\log l_t - \log l_{t-1})^2 \)
- staggered nominal wage contracting
- real wage rigidities (Nash bargaining)
Campbell-Cochrane Habits with Adjustment Costs

Figure 1: Mean Term Premium

- Blue line: mean term premium, no C-C habits
- Red line: mean term premium, with C-C habits

Output Cost of 1% Change in Labor

Mean Term Premium (basis points)
### Table 6: Unconditional Moments

<table>
<thead>
<tr>
<th>Variable</th>
<th>Baseline</th>
<th>Campbell-Cochrane</th>
<th>C-C with quadratic adj. costs to labor</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean[$\psi$]</td>
<td>2.0</td>
<td>3.7</td>
<td>79.7</td>
</tr>
<tr>
<td>sd[C]</td>
<td>1.24</td>
<td>0.99</td>
<td>1.07</td>
</tr>
<tr>
<td>sd[Y]</td>
<td>0.79</td>
<td>0.64</td>
<td>0.70</td>
</tr>
<tr>
<td>sd[L]</td>
<td>2.40</td>
<td>2.57</td>
<td>3.72</td>
</tr>
<tr>
<td>sd[w']</td>
<td>1.89</td>
<td>1.80</td>
<td>224.2</td>
</tr>
<tr>
<td>sd[\pi]</td>
<td>2.20</td>
<td>2.14</td>
<td>19.7</td>
</tr>
<tr>
<td>sd[i]</td>
<td>209</td>
<td>218</td>
<td>907</td>
</tr>
<tr>
<td>sd[ytm]</td>
<td>53</td>
<td>56</td>
<td>134</td>
</tr>
<tr>
<td>sd[\psi]</td>
<td>0.1</td>
<td>0.2</td>
<td>12.7</td>
</tr>
</tbody>
</table>
### Table 6: Unconditional Moments

<table>
<thead>
<tr>
<th>Variable</th>
<th>Baseline</th>
<th>Campbell-Cochrane</th>
<th>C-C with quadratic adj. costs to labor</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean[$\psi$]</td>
<td>2.0</td>
<td>3.7</td>
<td>79.7</td>
</tr>
<tr>
<td>sd[C]</td>
<td>1.24</td>
<td>0.99</td>
<td>1.07</td>
</tr>
<tr>
<td>sd[Y]</td>
<td>0.79</td>
<td>0.64</td>
<td>0.70</td>
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<tr>
<td>sd[L]</td>
<td>2.40</td>
<td>2.57</td>
<td>3.72</td>
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<tr>
<td>sd[$w'$]</td>
<td>1.89</td>
<td>1.80</td>
<td>224.2</td>
</tr>
<tr>
<td>sd[$\pi$]</td>
<td>2.20</td>
<td>2.14</td>
<td>19.7</td>
</tr>
<tr>
<td>sd[$r$]</td>
<td>209</td>
<td>218</td>
<td>907</td>
</tr>
<tr>
<td>sd[ytm]</td>
<td>53</td>
<td>56</td>
<td>134</td>
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<tr>
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</tr>
</tbody>
</table>
Staggered Nominal Wage Contracts

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Note: to make the model tractable, assume complete markets
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With Campbell-Cochrane habits and nominal wage contracts, term premium in the model decreases to 1.3bp
Staggered Nominal Wage Contracts


Note: to make the model tractable, assume **complete markets**

With Campbell-Cochrane habits and nominal wage contracts, term premium in the model *decreases* to 1.3bp

Intuition: complete markets provide households with insurance, more than offsets the costs of the wage friction
Real Wage Rigidities

Following Blanchard and Galí (2005), model real wage bargaining rigidity as:

\[
\log w_t^{r} = (1 - \mu)(\log w_t^{r*} + \omega) + \mu \log w_{t-1}^{r}
\]
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With Campbell-Cochrane habits and $\mu = .99$, term premium in the model is just 4.2bp

With Campbell-Cochrane habits and $\mu = .999$, term premium in the model is 4.7bp
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With Campbell-Cochrane habits and \(\mu = .99\), term premium in the model is just 4.2bp.

With Campbell-Cochrane habits and \(\mu = .999\), term premium in the model is 4.7bp.

Intuition: wage friction increases volatility of MRS, but decreases volatility of inflation, interest rates.
Additional Robustness Checks

- CEE model
- models with investment
- time-varying $\pi_t^*$

None of these have helped to fit the term premium
Conclusions

The bond premium puzzle remains:
1. The term premium in standard NK DSGE models is very small, even more stable.
2. To match the term premium in the NK DSGE framework, need high curvature together with labor frictions (not wage frictions).
3. However, matching the term premium destroys the model's ability to fit macro variables, particularly the real wage.
4. There appears to be no easy way to fix this in the standard, habit-based NK DSGE framework.
5. Future work: Epstein-Zin preferences?
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5. Future work: Epstein-Zin preferences?
Slow-Moving Habits

Brief intuition:

\[
R_t = \frac{1}{\mathbb{E}_t m^r_{t+1}} = \frac{(c_t - h_t)^{-\gamma}}{\beta \mathbb{E}_t(c_{t+1} - h_{t+1})^{-\gamma}}
\]

\[
\hat{R}_t \approx -\beta + \frac{\gamma}{\bar{c} - \bar{h}} \left[ \bar{c}(E_t \hat{c}_{t+1} - \hat{c}_t) - \bar{h}(E_t \hat{h}_{t+1} - \hat{h}_t) \right]
\]

\[
\approx -\beta - \frac{\gamma \bar{h}}{\bar{c} - \bar{h}} (\hat{h}_{t+1} - \hat{h}_t)
\]

Slow-moving habits can keep risk-free rate volatility down even if \(\bar{h} \approx \bar{c}\)
Campbell-Cochrane Habits with Adjustment Costs

Intuition for why real wages are so volatile:

\[
w_t^r = \frac{\chi_0 l_t^\chi}{(c_t - h_t)^{-\gamma}}
\]

\[
\hat{w}_t^r \approx \chi \hat{l}_t + \frac{\gamma}{\bar{c} - \bar{h}} (\bar{c} \hat{c}_t - \bar{h} \hat{h}_t)
\]

Note:
- \(\bar{h} \approx \bar{c}\)
- \(h_t\) and \(c_t\) do not covary strongly (because habits are slow-moving)

So the real wage is very volatile.
Impulse Responses: Baseline Model
Impulse Responses: Campbell-Cochrane

- Consumption
- Labor
- Real Wage
- Inflation
- Interest Rate
- Term Premium
Impulse Responses: Camp-Coch w/ RW Rigidity

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