Bond Market Exposures to Macroeconomic and Monetary Policy Risks

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Bond Market Exposures to Macroeconomic and Monetary Policy Risks

Dongho Song

Boston College

July 24, 2015

SEM Conference 2015
Establishing Key Stylized Facts: \text{corr}(\text{stock, bond})

- return on the five-year Treasury bond.
- stock market return (CRSP value-weighted portfolio of stocks).

See Baele, Bekaert, and Inghelbrecht (2010); Campbell, Pflueger, and Viceira (2013); Campbell, Sunderam, and Viceira (2013); David and Veronesi (2013); Burkhardt and Hasseltoft (2012).
Establishing Key Stylized Facts: \( \text{corr}(\Delta c, \pi) \)

\[
\begin{bmatrix}
\Delta c_{t+1} \\
\pi_{t+1}
\end{bmatrix}
= 
\begin{bmatrix}
\mu_c & \mu_{\pi} \\
\rho_{c} & 0
\end{bmatrix}
\begin{bmatrix}
x_{c,t} \\
x_{\pi,t}
\end{bmatrix}
+ 
\begin{bmatrix}
\eta_{c,t+1} & + \text{measurement errors} \\
\eta_{\pi,t+1}
\end{bmatrix}
+ 
\begin{bmatrix}
e_{c,t+1} \\
e_{\pi,t+1}
\end{bmatrix}, \quad e_{t+1} \sim N(0, \Sigma_t)
\]

- use monthly \( \Delta c \) and \( \pi = \text{cpi} \).
Establishing Key Stylized Facts: 1970s - 1990s

- Consumption-Inflation and Stock-Bond correlations

<table>
<thead>
<tr>
<th>Data, Model</th>
<th>corr(Δc, π)</th>
<th>corr(stock,bond)</th>
<th>Yield Curve Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

- See Wachter (2006), Piazzesi and Schneider (2006), Bansal and Shaliastovich (2013)
Establishing Key Stylized Facts: 1960s and 2000s

![Graph showing correlation (corr) between Δc, π, and stock-bond yields over time with shaded areas highlighting specific periods.]

<table>
<thead>
<tr>
<th></th>
<th>corr(Δc, π)</th>
<th>corr(stock, bond)</th>
<th>yield curve slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Model 1</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Model 2</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Why is it important?

- The evidence poses a significant challenge to existing approaches (e.g., Wachter (2006), Piazzesi and Schneider (2006), Bansal and Shaliastovich (2013))

  - $\pi$ is perceived as a carrier of bad good news for future $\Delta c$

  - yet, $\pi$ risks seem to be there: upward sloping yield curve
Why is it important?

- The evidence poses a significant challenge to existing approaches (e.g., Wachter (2006), Piazzesi and Schneider (2006), Bansal and Shaliastovich (2013))
  - $\pi$ is perceived as a carrier of bad good news for future $\Delta c$
  - yet, $\pi$ risks seem to be there

- Need a new model to study the main drivers of $\pi$, bond, stock risks
  - $E(\pi), \sigma(\pi), \rho(\pi)$ dropped significantly
  - the risks properties of stock and bond changed significantly
    - flattening of the yield curve
    - less violation of the Expectations Hypothesis
    - sign change in the stock-bond correlation
    - the slope of the yield curve remains positive
Objective

- Build a regime-switching general equilibrium model that
  - characterizes the monetary and macroeconomic determinants of inflation, asset prices, and bond-stock return correlation
  - reconciles both old and new stylized facts

- Key model features
  - an endowment economy with long-run risks in $\Delta c$, EZ preferences
  - endogenous $\pi$ dynamics implied by the Taylor rule
  - exogenous regime-switching as potential source of risk variations
    1. in the Taylor rule coefficients
    2. in the covariance of $\Delta c$ with $\pi$
Intuition: Inflation Risks in Simplest Form

• Setting “Taylor Rule” = “Fisher” equation yields

\[ \phi \pi_t = r_t + \mathbb{E}_t[\pi_{t+1}] \]

\[ r_t \text{ is the real rate from Euler equation} \]

\[ \pi_t = \begin{cases} 
  f(\phi, \ldots) r_t, & \text{if } |\phi| > 1 \\
  \text{nonstationary, if } |\phi| \leq 1 
\end{cases} \]

• Inflation risks depend on the joint determination of

  monetary policy aggressiveness: \( \phi \in \{|\phi| > 1, |\phi| \leq 1\} \)

  macroeconomic shocks: \( \text{corr}(\pi_t, r_t) \simeq \text{corr}(\pi_t, \Delta c_t) \in \{+, -\} \)
Risk Characterization

| Active  | $|\phi| > 1$  | Countercyclical | $\text{corr}(\pi_t, \Delta c_t) < 0$ |
|---------|-------------|-----------------|------------------|
| Passive | $|\phi| \leq 1$ | Procyclical     | $\text{corr}(\pi_t, \Delta c_t) > 0$ |

- Key risks in the economy can be characterized by

- Agents in the model know the probability of moving across regimes

Regime uncertainties reflected in today’s bond market prices
Findings

- Estimate the model using asset prices and macroeconomic data
- Quantify the risks: the **darker** the **riskier**

Monetary Policy

- Upward sloping yield curve in all regimes
- Negative stock-bond correlation in procyclical inflation regime
Findings

- Account for several other features of the bond market
  - time varying risk premiums
  - bond return predictability
  - violation of the expectations hypothesis

- Provide the timeline of the regimes (the **darker** the **riskier**)

![Timeline of regimes](image)
Model Details

- **Real consumption dynamics**
  \[ \Delta c_t = \mu_c + x_{c,t} + \eta_{c,t} \]
  \[ x_{c,t} = \rho_c x_{c,t-1} + e_{c,t} + \beta(S_t)e_{\pi,t}, \quad e_{j,t} \sim N(0, \sigma_{j,t-1}^2) \]
  \[ \sigma_{j,t}^2 \sim \text{independent AR}(1) \]

- **Taylor Rule**
  \[ i_t = \mu_i(S_t) + \phi_c(S_t)(\Delta c_t - \mu_c) + \phi_{\pi}(S_t)(\pi_t - \mu_{\pi} - x_{\pi,t}) + x_{\pi,t} + x_{m,t} \]
  \[ x_{\pi,t}, x_{m,t} \sim \text{AR}(1) \]

- **Stochastic discount factor from EZ preferences, \( \Delta c_t \)**
  \[ m_t = m(\Theta, x_{j,t}, \sigma_{j,t}^2, \beta(S_t), ...) \]

- **Inflation from Taylor rule**
  \[ i_t^{\text{Taylor rule}} = i_t^{\text{Fisher}}(m_t, \Delta c_t, E_t[\pi_{t+1}], ...) \]
  \[ \pi_t = \pi(\Theta, \phi_c(S_t), \phi_{\pi}(S_t), \beta(S_t), x_{j,t}, \sigma_{j,t}^2, \mathbb{P}, ...) \]
Intuition: Term Structure

- Nominal bond yields (ignoring monetary policy shock)

\[ y_{n,t}^\$ = \frac{1}{n} \left( B_{n,0}^\$ + B_{n,1,c}^\$ x_{c,t} + B_{n,1,\pi}^\$ x_{\pi,t} + B_{n,2,c}^\$ \sigma_{c,t}^2 + B_{n,2,\pi}^\$ \sigma_{\pi,t}^2 \right) \]

- If nominal vol dominates, then risk increases with maturity
  \( \rightarrow \) upward sloping yield curve

- Their relative magnitudes determined by
  1. stochastic volatilities
  2. monetary policy regimes
  3. macroeconomic shock regimes
Intuition: Term Structure

- Nominal bond yields (ignoring monetary policy shock)

\[ y_{n,t}^\$ = \frac{1}{n} \left( B_{n,0}^\$ + B_{n,1,c}^\$ x_{c,t} + B_{n,1,\pi}^\$ x_{\pi,t} + B_{n,2,c}^\$ \sigma_{c,t}^2 + B_{n,2,\pi}^\$ \sigma_{\pi,t}^2 \right) \]

<table>
<thead>
<tr>
<th>bond price</th>
<th>state</th>
</tr>
</thead>
<tbody>
<tr>
<td>↑</td>
<td>↑</td>
</tr>
<tr>
<td>↓</td>
<td>↓</td>
</tr>
<tr>
<td>↑</td>
<td>↓</td>
</tr>
<tr>
<td>↓</td>
<td>↑</td>
</tr>
</tbody>
</table>

- If real vol dominates, then long-term yields fall in bad times → downward sloping yield curve

- Their relative magnitudes determined by
  1. stochastic volatilities
  2. monetary policy regimes
  3. macroeconomic shock regimes
Intuition: Stock-Bond Correlation

- Log price-dividend ratio

\[
\log{\text{pd}_t} = D_0 + D_{1,c} x_{c,t} + D_{1,\pi} x_{\pi,t} + D_{2,c} \sigma_{c,t}^2 + D_{2,\pi} \sigma_{\pi,t}^2
\]

- Correlation between stock and bond returns: \( \text{corr}_t[r_{t+1}^m, r_{n,t+1}^s] \)

\[
= \ldots - B_{n,1,c}^s D_{1,c} \sigma_{c,t}^2 - B_{n,1,\pi}^s D_{1,\pi} \sigma_{\pi,t}^2
\]

<table>
<thead>
<tr>
<th>price</th>
<th>state</th>
</tr>
</thead>
<tbody>
<tr>
<td>stock ↓</td>
<td>( x_{c,t} ) ↓ ( x_{\pi,t} ) ↑ ( \sigma_{c,t}^2 ) ↑ ( \sigma_{\pi,t}^2 ) ↑</td>
</tr>
<tr>
<td>bond ↓</td>
<td></td>
</tr>
</tbody>
</table>

stock-bond correlation is (+) if nominal vol dominates
Intuition: Stock-Bond Correlation

- Log price-dividend ratio

\[ pd_t = D_0 + D_{1,c} x_{c,t} + D_{1,\pi} x_{\pi,t} + D_{2,c} \sigma_{c,t}^2 + D_{2,\pi} \sigma_{\pi,t}^2 \]

mildly–/+ 

- Correlation between stock and bond returns: \( \text{corr}_t[r_{t+1}^m, r_{n,t+1}^s] \)

\[ = \ldots - B_{n,1,c}^s D_{1,c} \sigma_{c,t}^2 - B_{n,1,\pi}^s D_{1,\pi} \sigma_{\pi,t}^2 + \text{mildly–/+} \]

<table>
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<th>state</th>
</tr>
</thead>
<tbody>
<tr>
<td>stock ↓</td>
<td>( x_{c,t} ) ↓ ( x_{\pi,t} ) ↑ ( \sigma_{c,t}^2 ) ↑ ( \sigma_{\pi,t}^2 ) ↑</td>
</tr>
<tr>
<td>bond ↑</td>
<td></td>
</tr>
</tbody>
</table>

stock-bond correlation is (–) if real vol dominates
Identification and Estimation

• Apply nonlinear Bayesian method
  • Particle filter + MCMC

• Estimation sample: 1959-2011
  • Quarterly SPF, monthly macroeconomic data
  • monthly stock price, Treasury bond yields data

• Use mixed-frequency data to pin down the key state variables and identify macroeconomic/monetary policy regime shifts
  • regime-switching coefficients: $\phi_c(S_t), \phi_\pi(S_t), \beta(S_t)$
  • stochastic volatilities: $\sigma^2_{c,t}, \sigma^2_{\pi,t}$
  • latent long-run growth, inflation target, monetary policy shock: $x_{c,t}, x_{\pi,t}, x_{m,t}$
Estimated Regime Transition Probabilities

<table>
<thead>
<tr>
<th></th>
<th>Continuation</th>
<th>Half-life</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \mathbb{P} ) Countercyclical Inflation</td>
<td>99.2 %</td>
<td>7.5 years</td>
</tr>
<tr>
<td>( \mathbb{P} ) Procyclical Inflation</td>
<td>94.1 %</td>
<td>1 years</td>
</tr>
<tr>
<td>( \mathbb{P} ) Active Monetary Policy</td>
<td>99.0 %</td>
<td>6 years</td>
</tr>
<tr>
<td>( \mathbb{P} ) Passive Monetary Policy</td>
<td>97.5 %</td>
<td>2.5 years</td>
</tr>
</tbody>
</table>

- Most of the time, \( \pi \) shock is large and countercyclical
  - inflation risk premium is positive
  - stock and bond return correlation is positive
- The long-run Taylor principle holds (by construction)
  - the regime in which passive policy is realized is short-lived
  - ensures stationary inflation dynamics
Model-Implied Correlation between $\Delta c$ and $\pi$

<table>
<thead>
<tr>
<th>Regime</th>
<th>Data $\text{corr}(\Delta c_t, \pi_t)$</th>
<th>Model $\text{corr}(\Delta c_t, \pi_t)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA : Countercyclical Inf, Active MP</td>
<td>-0.49</td>
<td>-0.51  [-0.75, -0.28]</td>
</tr>
<tr>
<td>CP : Countercyclical Inf, Passive MP</td>
<td>-0.20</td>
<td>-0.10  [-0.49, 0.35]</td>
</tr>
<tr>
<td>PA : Procyclical Inf, Active MP</td>
<td>0.12  0.02 [-0.09, 0.11]</td>
<td></td>
</tr>
<tr>
<td>PP : Procyclical Inf, Passive MP</td>
<td>0.14  0.02 [-0.12, 0.16]</td>
<td></td>
</tr>
</tbody>
</table>

- When inflation shock is procyclical $\pi$, $\Delta c$ positively comove
- Monetary policy alone cannot change the sign
- Passive monetary policy creates more dispersion
Model-Implied Yield Spread $y_n - y_{3m}, \ n \in \{1y \sim 5y, 10y\}$

$corr(\pi, \Delta c) < 0, \ \text{Active MP}$

$corr(\pi, \Delta c) > 0, \ \text{Active MP}$

$corr(\pi, \Delta c) < 0, \ \text{Passive MP}$

$corr(\pi, \Delta c) > 0, \ \text{Passive MP}$

- regime-switching NOT allowed
- counter-/procyclicality amplified in passive monetary policy regime
Model-Implied Yield Spread $y_n - y_{3m}, \ n \in \{1y \sim 5y, 10y\}$

$\text{corr}(\pi, \Delta c) < 0$, Active MP

$\text{corr}(\pi, \Delta c) < 0$, Passive MP

$\text{corr}(\pi, \Delta c) > 0$, Active MP

$\text{corr}(\pi, \Delta c) > 0$, Passive MP

- upward sloping yield curve due to regime uncertainties
- shifts in monetary policy affect the variance of the yield curve
Model-Implied Stock-Bond Return Correlation

\[ \text{corr}(\pi, \Delta c) < 0, \text{ Active MP} \]

\[ \text{corr}(\pi, \Delta c) > 0, \text{ Active MP} \]

\[ \text{corr}(\pi, \Delta c) < 0, \text{ Passive MP} \]

\[ \text{corr}(\pi, \Delta c) > 0, \text{ Passive MP} \]

- procyclical \( \pi \) shock generates negative stock-bond return correlation
- monetary policy alone cannot change the sign
Conclusion

- I estimate an equilibrium asset pricing model that allows for shifts in
  1. the aggressiveness of the central bank to inflation fluctuations
  2. the covariance between the long-run growth and inflation target

- My Bayesian estimation provides strong evidence of regime changes
  - passive monetary policy: 1970s
  - countercyclical inflation shocks: 1970s - mid1990s

- Main findings
  - upward sloping yield curve due to regime uncertainties
  - positive bond-stock return correlation when $\pi$ shock is procyclical
  - policy shifts affect the 2nd moment of $\pi$ and yield curve

- Future research: extension to the production economy
Appendix: Piazzesi and Schneider (2006) Revisited

- Structural shift for all coefficients

\[ z_t = \mu + s_{t-1} + \epsilon_t, \quad z_t = [\pi_t, \Delta c_t]' \]
\[ s_t = \phi s_{t-1} + \phi K \epsilon_t, \quad \epsilon_t \sim \mathcal{N}(0, \Omega). \]

1. 1970-1990s:

\[
S_t = \begin{bmatrix}
0.96 & 0.14 \\
-0.06 & 0.52 \\
[-0.10, -0.02] & [0.10, 0.12]
\end{bmatrix}
S_{t-1} + \epsilon_t, \quad \text{var}(\phi K \epsilon_t) = \begin{bmatrix}
1.06 & -0.14 \\
-0.14 & 0.32 \\
[-0.26, 0.52] & [0.32, 0.55]
\end{bmatrix}
\]

2. 2000s:

\[
S_t = \begin{bmatrix}
0.41 & 0.26 \\
0.07 & 0.83 \\
[-0.03, 0.18] & [0.30, 0.55]
\end{bmatrix}
S_{t-1} + \epsilon_t, \quad \text{var}(\phi K \epsilon_t) = \begin{bmatrix}
0.78 & 0.29 \\
0.29 & 0.55 \\
[0.01, 2.28] & [0.55, 1.28]
\end{bmatrix}
\]

Drop in \( E(\pi), \sigma(\pi), \rho(\pi) \) and sign switch in covariance
Appendix: Shifts in the Slope of the Phillips Curve

Panel A: Sample Split in mid-1980s, Backward-Looking PC

Panel B: Sample Split in mid-1980s, Forward-Looking PC

- Coibon and Gorodnichenko (2013): Is The Phillips Curve Alive and Well After All?
Appendix: Term Premium

\[ t_{t,n} = y_{t,n} - \frac{1}{n} \sum_{i=0}^{n-1} E_t(y_{t+i,1}) \]

corr(\pi, \Delta c) < 0, Active MP

corr(\pi, \Delta c) < 0, Passive MP

corr(\pi, \Delta c) > 0, Active MP

corr(\pi, \Delta c) > 0, Passive MP

- term premium more important in the Active MP regime
Appendix: CP Excess Return Predictive Regression

$corr(\pi, \Delta c) < 0$, Active MP

$corr(\pi, \Delta c) < 0$, Passive MP

$corr(\pi, \Delta c) > 0$, Active MP

$corr(\pi, \Delta c) > 0$, Passive MP

- higher $R^2$ when Active MP and $corr(\pi, \Delta c) < 0$
Appendix: Expectations Hypothesis (EH) Slope Coefficient

$\text{corr}(\pi, \Delta c) < 0, \text{ Active MP}$

$\text{corr}(\pi, \Delta c) > 0, \text{ Active MP}$

$\text{corr}(\pi, \Delta c) < 0, \text{ Passive MP}$

$\text{corr}(\pi, \Delta c) > 0, \text{ Passive MP}$

- Passive MP decreases the degree of violation of EH
Appendix: (EH) Slope Coefficient

\[ y_{t+1,n-1} - y_{t,n} = \alpha_n + \beta_n \left( (y_{t,n} - y_{t,1}) \frac{1}{n - 1} \right) + \epsilon_{t+1} \]

- Slope coefficient \( \beta_n = 1 - \frac{\text{cov}(E_t r_{t+1,n}, y_{t,n} - y_{t,1})}{\text{var}(y_{t,n} - y_{t,1})} \rightarrow 1 \)

1. \( \text{cov}(E_t r_{t+1,n}, y_{t,n} - y_{t,1}) \downarrow \)
   term spread contains less information about expected excess bond returns

2. \( \text{var}(y_{t,n} - y_{t,1}) \uparrow \)
   variance of the term spread increases

- Passive MP raises \( \text{var}(y_{t,n} - y_{t,1}) \uparrow \)
Appendix: Equilibrium Bond Yield Loadings

- Active MP: loadings on level factors are nearly flat across maturities
- Passive MP: loadings on level factors decrease over maturities
Appendix: U.K. Real Bond Yields, $\Delta c$, $\pi$

Real Consumption Per Capita and CPI Inflation

Real Yields

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Appendix: U.K. Real Bond Yields, $\Delta c, \pi$

Rolling Window 2 Years: $\text{corr}(\pi, \Delta c)$

Real Yield Spread: $y_{t,n} - y_{t,5y}, n \in \{6y, ..., 15y\}$
Consumption Reaction to 1 % Point Inflation Surprises

1959–1997

1998–2011

Horizon

Horizon
Inflation Reaction to 1 % Point Inflation Surprises

1959–1997

1998–2011

Horizon

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<table>
<thead>
<tr>
<th></th>
<th>70s, 80s, 90s</th>
<th>00s</th>
<th>Full Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Correlation between Stock and Bond Return</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\text{Corr}(r_m, r_{2y})$</td>
<td>0.16</td>
<td>-0.13</td>
<td>0.09</td>
</tr>
<tr>
<td><strong>Correlation between Spread and Growth</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\text{Corr}(y_{5y}-y_{3m}, \Delta c)$</td>
<td>0.33</td>
<td>-0.19</td>
<td>0.20</td>
</tr>
<tr>
<td><strong>Excess Bond Return Predictability, $R^2$</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$r_{x_{2y},t+1y}$ onto forward$_t$</td>
<td>34.34</td>
<td>13.60</td>
<td>20.68</td>
</tr>
<tr>
<td><strong>Term Spread Regression, Slope Coefficient</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$r_{2y,t+1y}$ onto $y_{2y,t}-y_{1y,t}$</td>
<td>-0.95</td>
<td>0.89</td>
<td>-0.62</td>
</tr>
</tbody>
</table>
Calibration I: Neutral Inflation

\[
\begin{bmatrix}
\Delta c_{t+1} \\
\pi_{t+1}
\end{bmatrix} =
\begin{bmatrix}
\mu_c \\
\mu_\pi
\end{bmatrix} +
\begin{bmatrix}
x_{c,t} \\
x_{\pi,t}
\end{bmatrix} +
\begin{bmatrix}
\bar{\sigma}_c \eta_{c,t+1} \\
\bar{\sigma}_\pi \eta_{\pi,t+1}
\end{bmatrix}
\]

\[
\begin{bmatrix}
x_{c,t+1} \\
x_{\pi,t+1}
\end{bmatrix} =
\begin{bmatrix}
\rho_c & 0 \\
0 & \rho_\pi
\end{bmatrix}
\begin{bmatrix}
x_{c,t} \\
x_{\pi,t}
\end{bmatrix} +
\begin{bmatrix}
1 & \chi_{c,\pi}
\end{bmatrix}
\begin{bmatrix}
\sigma_{c,t} e_{c,t+1} \\
\sigma_{\pi,t} e_{\pi,t+1}
\end{bmatrix}
\]

\[
\begin{bmatrix}
\sigma_{c,t+1}^2 \\
\sigma_{\pi,t+1}^2
\end{bmatrix} =
\begin{bmatrix}
(0.01)\sigma_{c,t}^2 \\
(0.01)\sigma_{\pi,t}^2
\end{bmatrix} +
\begin{bmatrix}
0.99\sigma_{c,t}^2 \\
0.99\sigma_{\pi,t}^2
\end{bmatrix} +
\begin{bmatrix}
\sigma_{w,c} w_{c,t+1} \\
\sigma_{w,\pi} w_{\pi,t+1}
\end{bmatrix}
\]

- regime 1: \( \rho_c = 0.99, \rho_\pi = 0.998 \) and \( \chi_{c,\pi} = 0 \)

- regime 2: \( \rho_c = 0.99, \rho_\pi = 0.6 \) and \( \chi_{c,\pi} = 0 \)

\[P = \begin{bmatrix}
0.97 & 0.03 \\
0.04 & 0.96
\end{bmatrix}\]
Yield Curve, Stock-Bond Correlation: Calibration I

yield curve

stock-bond correlation

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Calibration II: Non-Neutral Inflation

\[
\begin{bmatrix}
\Delta c_{t+1} \\
\pi_{t+1}
\end{bmatrix}
= \begin{bmatrix}
\mu_c \\
\mu_\pi
\end{bmatrix} + \begin{bmatrix}
\chi_{c,t} \\
\chi_{\pi,t}
\end{bmatrix} + \begin{bmatrix}
\bar{\sigma}_c \eta_{c,t+1} \\
\bar{\sigma}_\pi \eta_{\pi,t+1}
\end{bmatrix}
\]

\[
\begin{bmatrix}
\chi_{c,t+1} \\
\chi_{\pi,t+1}
\end{bmatrix}
= \begin{bmatrix}
\rho_c & 0 \\
0 & \rho_\pi
\end{bmatrix} \begin{bmatrix}
\chi_{c,t} \\
\chi_{\pi,t}
\end{bmatrix} + \begin{bmatrix}
1 & \chi_{c,\pi}
\end{bmatrix} \begin{bmatrix}
\sigma_{c,t} e_{c,t+1} \\
\sigma_{\pi,t} e_{\pi,t+1}
\end{bmatrix}
\]

\[
\begin{bmatrix}
\sigma^2_{c,t+1} \\
\sigma^2_{\pi,t+1}
\end{bmatrix}
= \begin{bmatrix}
(0.01)\sigma^2_c \\
(0.01)\sigma^2_\pi
\end{bmatrix} + \begin{bmatrix}
0.99\sigma^2_{c,t} \\
0.99\sigma^2_{\pi,t}
\end{bmatrix} + \begin{bmatrix}
\sigma_{w,c} w_{c,t+1} \\
\sigma_{w,\pi} w_{\pi,t+1}
\end{bmatrix}
\]

- regime 1: \( \rho_c = 0.99, \rho_\pi = 0.998 \) and \( \chi_{c,\pi} = -0.3 \)

- regime 2: \( \rho_c = 0.99, \rho_\pi = 0.6 \) and \( \chi_{c,\pi} = -0.05 \)

\[
P = \begin{bmatrix}
0.97 & 0.03 \\
0.04 & 0.96
\end{bmatrix}
\]

Bond Market Exposures to Macroeconomic and Monetary Policy Risks

Dongho Song
Yield Curve, Stock-Bond Correlation: Calibration II

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Dongho Song
Calibration III: Non-Neutral Inflation

\[
\begin{align*}
\begin{bmatrix}
\Delta c_{t+1} \\
\pi_{t+1}
\end{bmatrix} &= 
\begin{bmatrix}
\mu_c \\
\mu_\pi
\end{bmatrix} + 
\begin{bmatrix}
x_{c,t} \\
x_{\pi,t}
\end{bmatrix} + 
\begin{bmatrix}
\bar{\sigma}_c \eta_{c,t+1} \\
\bar{\sigma}_\pi \eta_{\pi,t+1}
\end{bmatrix} \\
\begin{bmatrix}
x_{c,t+1} \\
x_{\pi,t+1}
\end{bmatrix} &= 
\begin{bmatrix}
\rho_c & 0 \\
0 & \rho_\pi
\end{bmatrix} 
\begin{bmatrix}
x_{c,t} \\
x_{\pi,t}
\end{bmatrix} + 
\begin{bmatrix}
1 & \chi_{c,\pi} \\
0 & 1
\end{bmatrix} 
\begin{bmatrix}
\sigma_{c,t} e_{c,t+1} \\
\sigma_{\pi,t} e_{\pi,t+1}
\end{bmatrix} \\
\begin{bmatrix}
\sigma^2_{c,t+1} \\
\sigma^2_{\pi,t+1}
\end{bmatrix} &= 
\begin{bmatrix}
(0.01)\sigma^2_c \\
(0.01)\sigma^2_\pi
\end{bmatrix} + 
\begin{bmatrix}
0.99\sigma^2_{c,t} \\
0.99\sigma^2_{\pi,t}
\end{bmatrix} + 
\begin{bmatrix}
\sigma_{w,c} w_{c,t+1} \\
\sigma_{w,\pi} w_{\pi,t+1}
\end{bmatrix}
\end{align*}
\]

- regime 1: \( \rho_c = 0.99, \rho_\pi = 0.998 \) and \( \chi_{c,\pi} = -0.3 \)

- regime 2: \( \rho_c = 0.99, \rho_\pi = 0.6 \) and \( \chi_{c,\pi} = 0.1 \)

\[
P = 
\begin{bmatrix}
0.97 & 0.03 \\
0.04 & 0.96
\end{bmatrix}
\]
Bond Market Exposures to Macroeconomic and Monetary Policy Risks

Dongho Song