Beliefs about Inflation and the Term Structure of Interest Rates

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We learned a lot from them including drawbacks/deficiencies.
Role of Different Beliefs about Inflation?

- Finance has a long tradition of different beliefs models. Macroeconomics is getting more serious too.
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  For example in the period 1975-2000, the wide swings in US fiscal policy could easily have led to differing views about the implications of those swings for future inflation. And in the late 90’s in the US, when unemployment and interest rates stayed persistently low, there were differences of view even among specialist economists about the long term implications for the inflation rate.
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- Our work - How do different beliefs about inflation impact bond prices?
Opinions about Inflation

The Economist
Forecasts for 2011

United States
Consumer prices, % change on previous year

High
Average
Low

Source: The Economist poll of forecasters: Bank of America, BNP Paribas, Citigroup, Commerzbank, Decision Economics, Deutsche Bank, Economist Intelligence Unit, Goldman Sachs, HSBC Securities, ING, JPMorgan Chase, KBC Bank, Morgan Stanley, RBC, RBS, Schroders, Scotiabank, Société Générale, Standard Chartered, UBS
In a dynamic economy with disagreement about expected inflation,

- how do belief differences impact real & nominal yield curves?
Our Work

In a dynamic economy with disagreement about expected inflation,

- how do belief differences impact real & nominal yield curves?
- what belief structure is necessary to capture return predictability & real spillover effects?
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- how do belief differences impact real & nominal yield curves?

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- what is the impact of belief differences when quantitative properties of bonds are fit?
In a dynamic economy with disagreement about expected inflation,

- how do belief differences impact real & nominal yield curves?

- what belief structure is necessary to capture return predictability & real spillover effects?

- what is the impact of belief differences when quantitative properties of bonds are fit?

- empirically, do we find support for how belief differences impact the yield curve?
Results

- Inflation disagreement leads to a real economy spillover effect.
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- With risk aversion $\gamma > 1$ & disagreement $\uparrow$,
  - an income effect dominates,
  - real & nominal short rates rise,
  - the real yield curve and yield volatilities rise,
  - numerically, the nominal yield curve and yield volatilities rise.
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- Expected inflation mean reversion disagreement captures dynamics/predictability.

- Disagreement alone cannot capture the slope of yield curves.
Model - Key Features

- Exchange economy w/ simple dynamics for output & inflation
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- Heterogeneous beliefs about expected inflation
  - Inflation is priced because of speculative trade
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  - Necessary to capture upward sloping yield curves
- Closed-form bond prices in the quadratic Gaussian class
Model - Output & Inflation

- Uncertainty — a real shock $z_\epsilon(t)$ & a nominal shock $z_\$\epsilon(t)$

- Real output $\epsilon(t)$ observed by all:

$$\frac{d\epsilon(t)}{\epsilon(t)} = \mu_\epsilon \ dt + \sigma_\epsilon \ dz_\epsilon(t)$$
Uncertainty — a real shock $z_\epsilon(t)$ & a nominal shock $z_\$ (t)$

Real output $\epsilon(t)$ observed by all:

$$\frac{d\epsilon(t)}{\epsilon(t)} = \mu_\epsilon \ dt + \sigma_\epsilon \ dz_\epsilon(t)$$

Price level $\pi(t)$ observed by all:

$$\frac{d\pi(t)}{\pi(t)} = \chi(t) \ dt + \sigma_{\pi,\epsilon} \ dz_\epsilon(t) + \sigma_{\pi,\$} \ dz_\$(t)$$
Uncertainty — a real shock $z_{\epsilon}(t)$ & a nominal shock $z_\$ (t)$

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Price level $\pi(t)$ observed by all:

$$\frac{d\pi(t)}{\pi(t)} = \chi(t) \ dt + \sigma_{\pi,\epsilon} \ dz_\epsilon(t) + \sigma_{\pi,\$} \ dz_\$(t)$$

Expected inflation $\chi(t)$ unobserved by all:

$$d\chi(t) = \kappa (\bar{\chi} - \chi(t)) \ dt + \sigma_{\chi,\epsilon} \ dz_\epsilon(t) + \sigma_{\chi,\$} \ dz_\$(t),$$
Two investors \((i = 1, 2)\) & an econometrician \((i = 0)\) have different beliefs or models about \(x(t)\) through:

1. the long run mean of expected inflation \(\bar{x}\)
2. the speed of mean reversion of expected inflation \(\kappa\)

Update beliefs via Bayes Rule:

\[ x_i(t) = E_i\left[x(t) | F_{\epsilon,\pi t}\right], i \in \{0, 1, 2\} \]

Disagreement about expected inflation implies:

\[ dz_i(t) = dz_0(t) + x_0(t) - x_i(t) \sigma_{\pi, t} dt \]
Model - Heterogeneous Beliefs about Expected Inflation

- Two investors \((i = 1, 2)\) & an econometrician \((i = 0)\)
- Have different beliefs or models about \(x(t)\) through
  1. the long run mean of expected inflation \(\bar{x}\)
  2. the speed of mean reversion of expected inflation \(\kappa\)

- Update beliefs via Bayes Rule:
  \[
  x^i(t) = \mathbb{E}^i[x(t) \mid \mathcal{F}_{t}^{\epsilon, \pi}], \quad i \in \{0, 1, 2\}
  \]

- Disagreement about expected inflation implies:
  \[
  d z^i_{\$}(t) = d z^0_{\$}(t) + \frac{x^0(t) - x^i(t)}{\sigma_{\pi, \$}} dt
  \]
Model - How Each Agent Views the World

- Price level under each agent’s beliefs:
  \[
  \frac{d\pi(t)}{\pi(t)} = x_i(t) \, dt + \sigma_{\pi,\epsilon} \, d\epsilon(t) + \sigma_{\pi,\$} \, d\$\epsilon(t)
  \]

- Unobserved expected inflation under each agent’s beliefs:
  \[
  dx_i(t) = \kappa_i \left( \bar{x}_i - x_i(t) \right) \, dt + \sigma_x \rho_{x\epsilon} \, d\epsilon(t) + \sigma_{x,\$} \, d\$\epsilon(t)
  \]

- Volatility \( \sigma_{x,\$} \)
  - Driven by agent \( i \)'s steady state estimation error which is driven by \( \kappa_i \)
Model - Disagreement Processes

- $\Delta^i(t)$ — disagreement across the econometrician & investor $i$:
  \[
  \Delta^i(t) = \frac{x^0(t) - x^i(t)}{\sigma_{\pi,$}$}
  \]

- $\Delta(t)$ — disagreement across investors:
  \[
  \Delta(t) = \Delta^1(t) - \Delta^2(t) = \frac{x^2(t) - x^1(t)}{\sigma_{\pi,$}$}
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Model - Disagreement Processes

- $\Delta^i(t)$ — disagreement across the econometrician & investor $i$:

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$$\Delta(t) = \Delta^1(t) - \Delta^2(t) = \frac{x^2(t) - x^1(t)}{\sigma_{\pi,$$}

- No $\kappa$ disagreement $\Rightarrow \Delta^i(t) & \Delta(t)$ deterministic
Investors trade in complete markets. Differ in initial wealth & beliefs.

External habit preferences, \( u(c) = \frac{c^{1-\gamma}}{1-\gamma} \), and \( \gamma > 0 \):

\[
\max_{\{c_i(t)\}} \mathbb{E}^i \left[ \int_0^T e^{-\rho t} u \left( \frac{c_i(t)}{X(t)} \right) \, dt \right], \quad \text{s.t.} \quad \mathbb{E}^i \left[ \int_0^T \xi_i(t)c_i(t) \, dt \right] \leq W^i(0)
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\]

Standard of living process \( X(t) \), a weighted “geometric sum” of past consumption, where \( \delta \) captures the history dependence

Define the business cycle variable \( \omega(t) = \log(\epsilon(t)/X(t)) \):

\[
d\omega(t) = \delta(\bar{\omega} - \omega(t)) \, dt + \sigma_\epsilon \, dz_\epsilon(t)
\]
Econometrician’s real & nominal market prices of risk:

\[ \theta_{\epsilon}(t) = \gamma \sigma_{\epsilon}, \quad \theta_{\$$}(t) = \Delta_1(t) - (1 - f(t)) \Delta(t), \]

\[ \theta_{\$$,\epsilon}(t) = \gamma \sigma_{\epsilon} + \sigma_{\pi} \rho_{\epsilon\pi}, \quad \theta_{\$$,\$$}(t) = \sigma_{\pi,\$$} + \Delta_1(t) - (1 - f(t)) \Delta(t). \]
Equilibrium - Asset Prices

- Econometrician’s real & nominal market prices of risk:

\[ \theta_\epsilon(t) = \gamma \sigma_\epsilon, \quad \theta_\epsilon^0(t) = \Delta_1(t) - (1 - f(t)) \Delta(t), \]

\[ \theta_{\$\epsilon} = \gamma \sigma_\epsilon + \sigma_\pi \rho_{\epsilon\pi}, \quad \theta_{\$\epsilon}^0(t) = \sigma_\pi \epsilon + \Delta_1(t) - (1 - f(t)) \Delta(t), \]

- Real & nominal short rates:

\[ r(t) = \rho + \mu_\epsilon - \frac{1}{2}(\gamma^2 + 1)\sigma_\epsilon^2 + \delta(\gamma - 1)(\bar{\omega} - \omega(t)) \]

\[ + \frac{1}{2} \left(1 - \frac{1}{\gamma}\right) f(t)(1 - f(t))(\Delta(t))^2, \]

\[ r_{\$}(t) = r(t) + f(t)x^1(t) + (1 - f(t))x^2(t) - \gamma \sigma_\epsilon \sigma_\pi \rho_{\epsilon\pi} - \sigma_\pi^2. \]
Econometrician’s real & nominal market prices of risk:

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Spillover from nominal to real when \( \Delta \neq 0 \)
When $\gamma > 1$, the equilibrium real & nominal short rates rise when $\Delta \uparrow$. 

When $\gamma > 1$, the income effect dominates. Investors want to consume more today by borrowing against future consumption, but cannot as consumption today is fixed. Short rates rise to counterbalance.

When $\gamma < 1$, the substitution effect dominates and the short rates fall to counterbalance.
When $\gamma > 1$, the equilibrium real & nominal short rates rise when $\Delta \uparrow$

- Increased disagreement implies each investor believes he will capture more consumption in the future.

- When $\gamma < 1$, the substitution effect dominates and the short rates fall to counterbalance.
Equilibrium - Impact of Disagreement on the Short Rates

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Assume disagreement is always ↑ in one economy.
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Fix current consumption identical across the two economies.
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Then when disagreement ↑, real yields are

- ↑ when $\gamma > 1$,
- unchanged when $\gamma = 1$,
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- ↑ when \( \gamma > 1 \),
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Real bond volatilities also rise with ↑ disagreement.
Equilibrium - Closed-Form Bond Prices

When $\gamma$ is an integer, real & nominal bond prices:

$$B(t; T') = \sum_{k=0}^{\gamma} \binom{\gamma}{k} (1 - f(t))^k f(t)^{\gamma-k} B_k(t; T')$$

$$P_{\$}(t; T') = \sum_{k=0}^{\gamma} \binom{\gamma}{k} (1 - f(t))^k f(t)^{\gamma-k} P_{k,\$}(t; T')$$

with $B_k(t; T')$ & $P_{k,\$}(t; T')$ fictitious economy $k$ bond prices.

- In economy $k$, $B_k(t; T')$ & $P_{k,\$}(t; T')$ follow
  - Completely affine Gaussian term structure when investors disagree about $\bar{x}$
  - Quadratic Gaussian term structure when investors disagree about $\kappa$
## Numerical Results - Parameters

### Table 1: Parameter Choice for Two Habit Investor Example.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Preferences</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\rho$</td>
<td>Time Preference Parameter</td>
<td>2.5%</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>Risk Aversion</td>
<td>7</td>
</tr>
<tr>
<td>$\delta$</td>
<td>Habit Parameter</td>
<td>0.07</td>
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<tr>
<td><strong>Consumption</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$(\text{Chan } &amp; \text{ Kogan})$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\mu_\epsilon$</td>
<td>Expected Consumption Growth</td>
<td>1.72%</td>
</tr>
<tr>
<td>$\sigma_\epsilon$</td>
<td>Volatility of Consumption</td>
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</tr>
<tr>
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<td></td>
<td></td>
</tr>
<tr>
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<td></td>
</tr>
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<td>$\sigma_\pi$</td>
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</tr>
<tr>
<td>$\bar{x}$</td>
<td>Long Run Mean of Expected Inflation</td>
<td>3%</td>
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</tr>
<tr>
<td>$\rho_\epsilon\pi$</td>
<td>$\rho$ of Realized Inflation &amp; Real Consumption Growth</td>
<td>$-0.2$</td>
</tr>
<tr>
<td>$\rho_{\pi x}$</td>
<td>$\rho$ of Realized and Expected Inflation</td>
<td>0</td>
</tr>
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Numerical Results - Beliefs

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<td>$\rho_{\bar{x},\epsilon}$ of Expected Inflation &amp; Real Consumption Growth</td>
<td>0</td>
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</table>

Disagreement

<table>
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<th>Value</th>
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<tbody>
<tr>
<td>$\bar{x}_1$</td>
<td>Long run mean of first investor</td>
<td>$\bar{x} - \frac{1}{2} \Delta \bar{x}$</td>
</tr>
<tr>
<td>$\bar{x}_2$</td>
<td>Long run mean of second investor</td>
<td>$\bar{x} + \frac{1}{2} \Delta \bar{x}$</td>
</tr>
<tr>
<td>$\kappa_1$</td>
<td>Mean reversion of first investor</td>
<td>$\kappa - \frac{1}{2} \Delta \kappa$</td>
</tr>
<tr>
<td>$\kappa_2$</td>
<td>Mean reversion of first investor</td>
<td>$\kappa + \frac{1}{2} \Delta \kappa$</td>
</tr>
</tbody>
</table>
Numerical Results - Nominal Yield Curve in Steady-State Disagreement

Parameters: $f = 0.5$, $\Delta \bar{\rho} = 1\%$, and $\Delta \kappa = -0.3$
Parameters: \( f = 0.5 \), \( \Delta \bar{X} = 1 \% \), and \( \Delta \kappa = -0.3 \)
Numerical Results - Impact of Increased Disagreement

Parameters: $f = 0.5$, $\Delta \bar{X} = 1\%$, and $\Delta \kappa = -0.3$
Empirical Work - Inflation Beliefs & Dispersion

Beliefs about Inflation - Empirical Work

Mean Inflation Forecast – Michigan Surveys of Consumers
Inflation (CPI)

Inflation Forecast Dispersion – Michigan Surveys of Consumers
Empirical Work - Nominal Yields & Volatilities

Table 2: Inflation Beliefs Dispersion and Nominal Yields

The table reports results from OLS regressions of the determinants of nominal yields (Panel A) and volatilities of nominal yields (Panel B). The dependent variables are from the Fama-Bliss Discount Bond Files (1, 2, 3, and 5 year yields) and from "The U.S. Treasury Yield Curve: 1961 to the Present," Gurkaynak, Sack, and Wright available at https://www.federalreserve.gov/econresdata/researchdata.htm (3 month and 10 year yields). Yield volatilities are estimated by a GARCH(1,1). Explanatory variables include inflation beliefs dispersion (Dispersion) and the mean of the inflation forecasts (Mean Inflation). The t-statistics are Newey-West corrected. The mean and dispersion of inflation forecasts are computed from raw data obtained from Thomson Reuters / University of Michigan. Sample: January 1978 - October 2010.

### Panel A: Yields

<table>
<thead>
<tr>
<th></th>
<th>3 Month</th>
<th>1 Year</th>
<th>2 Year</th>
<th>3 Year</th>
<th>5 Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>Model 1</td>
<td>-0.018</td>
<td>-0.014</td>
<td>-0.018</td>
<td>-0.011</td>
</tr>
<tr>
<td></td>
<td>Model 2</td>
<td>-0.022</td>
<td>-0.014</td>
<td>-0.018</td>
<td>-0.011</td>
</tr>
<tr>
<td>t-statistics</td>
<td>Model 1</td>
<td>-1.919</td>
<td>-1.623</td>
<td>-2.020</td>
<td>-1.331</td>
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<tr>
<td></td>
<td>Model 2</td>
<td>-2.431</td>
<td>-1.429</td>
<td>0.855</td>
<td>1.415</td>
</tr>
<tr>
<td>Dispersion</td>
<td>Model 1</td>
<td>1.423</td>
<td>0.787</td>
<td>1.429</td>
<td>0.855</td>
</tr>
<tr>
<td></td>
<td>Model 2</td>
<td>0.787</td>
<td>1.429</td>
<td>0.855</td>
<td>1.415</td>
</tr>
<tr>
<td>Mean Inflation</td>
<td>Model 1</td>
<td>0.901</td>
<td>0.812</td>
<td>0.531</td>
<td>0.456</td>
</tr>
<tr>
<td></td>
<td>Model 2</td>
<td>0.812</td>
<td>0.901</td>
<td>0.531</td>
<td>0.456</td>
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### Panel B: Yield Volatilities

<table>
<thead>
<tr>
<th></th>
<th>3 Month</th>
<th>1 Year</th>
<th>2 Year</th>
<th>3 Year</th>
<th>5 Year</th>
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</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>Model 1</td>
<td>-0.016</td>
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<td>0.218</td>
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<td>0.237</td>
<td>0.218</td>
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<td>Adj.R2</td>
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<td>Model 2</td>
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</tr>
</tbody>
</table>

Data: Monthly, January 1978 - October 2010
Table 3: Inflation Beliefs Dispersion and Real Yields

The table reports results from OLS regressions of the determinants of real yields (Panel A) and volatilities of nominal yields (Panel B). The dependent variables are from "The Term Structure of Inflation Expectations," Chernov and Mueller (Q3 1971 to Q4 2002) and from "The TIPS Yield Curve and Inflation Compensation," Gurkaynak, Sack, and Wright available at https://www.federalreserve.gov/econresdata/researchdata.htm (3 month and 10 year yields). Yield volatilities are estimated by a GARCH(1,1). Explanatory variables include inflation beliefs dispersion (Dispersion) and the mean of the inflation forecasts (Mean Inflation). The t-statistics are Newey-West corrected. The mean and dispersion of inflation forecasts are computed from raw data obtained from Thomson Reuters / University of Michigan. Sample: Q3 1971 - Q3 2010.

### Panel A: Yields

<table>
<thead>
<tr>
<th></th>
<th>3 Month</th>
<th>1 Year</th>
<th>2 Year</th>
<th>3 Year</th>
<th>5 Year</th>
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<tbody>
<tr>
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<td>Model 1</td>
<td>Model 2</td>
<td>Model 1</td>
<td>Model 2</td>
<td>Model 1</td>
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<tr>
<td>Intercept</td>
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<td>0.015</td>
<td>0.017</td>
<td>0.016</td>
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<td>t-statistics</td>
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<td>Dispersion</td>
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<td>0.327</td>
<td>0.187</td>
<td>0.321</td>
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<td>t-statistics</td>
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<td>0.993</td>
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<td>-0.160</td>
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### Panel B: Yield Volatilities

<table>
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<th>2 Year</th>
<th>3 Year</th>
<th>5 Year</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Model 1</td>
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<td>Model 1</td>
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<td>Model 1</td>
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<td>Dispersion</td>
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<td>0.168</td>
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<td>127</td>
</tr>
</tbody>
</table>

Data: Quarterly, Q3 1978 - Q3 2010
Conclusion

Key Results

- Inflation disagreement induces a real economy spillover effect.
- When common relative risk aversion $\gamma > 1$ and disagreement increases,
  - an income effect dominates implying real & nominal short rates rise,
  - the real yield curve and yield volatilities rise,
  - numerically, the nominal yield curve and yield volatilities rise.
- Empirically, we find support for these predictions.
Conclusion

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- When common relative risk aversion $\gamma > 1$ and disagreement increases,
  - an income effect dominates implying real & nominal short rates rise,
  - the real yield curve and yield volatilities rise,
  - numerically, the nominal yield curve and yield volatilities rise.

- Empirically, we find support for these predictions.

More Work …

- Explore the risk/term premia
- Explore predictability (Wachter (2006), Xiong & Yan (2010))
  - Preliminary results - Tension between predictability & first two yield curve moments
- More complete calibration
Related Work on Yield Curve Economics

Reduced Form No Arbitrage Models

- Latent state variables

Related Work on Yield Curve Economics

Reduced Form No Arbitrage Models

- Latent state variables


Structural Models


Beliefs about Inflation - Future work
Related Work on Yield Curve Economics

Reduced Form - No Arbitrage Models

- Latent state variables


Structural Models


Subjective Beliefs/Survey Data & Yield Curves


Beliefs about Inflation - Future work