Beliefs about Inflation and the Term Structure of Interest Rates

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- Gave us DSGE models used by central bankers & structural asset pricing/term structure models.
- We learned a lot from them including drawbacks/deficiencies.

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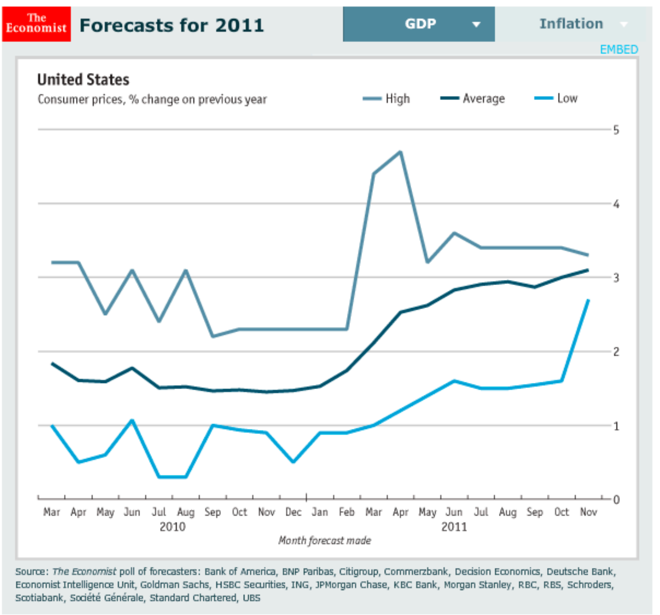
- Our work - How do different beliefs about inflation impact bond prices?

Opinions about Inflation



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- 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?

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    - an income effect dominates,
    - real & nominal short rates rise,
    - the real 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

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- Closed-form bond prices in the quadratic Gaussian class

Model - Output & Inflation

- Uncertainty — a real shock $z_\epsilon(t)$ & a nominal shock $z_\$(t)$
- Real output $\epsilon(t)$ observed by all:

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

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- Expected inflation $x(t)$ unobserved by all:

$$dx(t) = \kappa \left(\bar{x} - x(t)\right) \, dt + \sigma_{x,\epsilon} \, dz_\epsilon(t) + \sigma_{x,\$} \, dz_\$(t),$$

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 $\bar{x}$
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- 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 κ
- Update beliefs via Bayes Rule:

$$x^i(t) = \mathrm{E}^i[x(t) \mid \mathcal{F}_t^{\epsilon,\pi}], \qquad i \in \{0, 1, 2\}$$

- Disagreement about expected inflation implies:

$$dz_\$^i(t) = dz_\$^0(t) + \frac{x^0(t) - x^i(t)}{\sigma_{\pi,\$}} dt$$

Model - How Each Agent Views the World

- Price level under each agent's beliefs:

$$\frac{d\pi(t)}{\pi(t)} = x^i(t)\, dt + \sigma_{\pi,\epsilon}\, dz_\epsilon(t) + \sigma_{\pi,\$}\, dz^i_\$(t)$$

- Unobserved expected inflation under each agent's beliefs:

$$dx^i(t) = \kappa^i \left(\bar{x}^i - x^i(t)\right)\, dt + \sigma_x\, \rho_{x\epsilon}\, dz_\epsilon(t) + \sigma^i_{x,\$}\, dz^i_\$(t)$$

- Volatility $\sigma^i_{x,\$}$
  - Driven by agent i's steady state estimation error which is driven by κ^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:

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- No κ disagreement $\Rightarrow$ $\Delta^i(t)$ & $\Delta(t)$ deterministic

Model - Consumption-Portfolio Choice Problem

- Investors trade in complete markets. Differ in initial wealth & beliefs.
- External habit preferences, $u(c) = \frac{c^{1-\gamma}}{1-\gamma}$, and $\gamma > 0$:

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

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- Standard of living process $X(t)$, a weighted "geometric sum" of past consumption, where δ captures the history dependence

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

$$d\omega(t) = \delta(\bar{\omega} - \omega(t)) \, dt + \sigma_\epsilon \, dz_\epsilon(t)$$

Equilibrium - Asset Prices

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

$$\theta_\epsilon(t) = \gamma\,\sigma_\epsilon, \qquad \theta^0_\$(t) = \Delta_1(t) - (1 - f(t))\,\Delta(t),$$

$$\theta_{\$,\epsilon} = \gamma\sigma_\epsilon + \sigma_\pi\rho_{\epsilon\pi}, \qquad \theta^0_{\$,\$}(t) = \sigma_{\pi,\$} + \Delta_1(t) - (1 - f(t))\,\Delta(t).$$

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- Real & nominal short rates:

$$\begin{aligned} r(t) &= \rho + \mu_\epsilon - \frac{1}{2}(\gamma^2 + 1)\sigma_\epsilon^2 + \delta(\gamma - 1)(\bar{\omega} - \omega(t)) \\ &\quad + \frac{1}{2}\left(1 - \frac{1}{\gamma}\right) f(t)(1 - f(t))(\Delta(t))^2, \\ r_\$(t) &= r(t) + f(t)x^1(t) + (1 - f(t))x^2(t) - \gamma\sigma_\epsilon\sigma_\pi\rho_{\epsilon\pi} - \sigma_\pi^2. \end{aligned}$$

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- Spillover from nominal to real when $\Delta \neq 0$

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  - Short rates rise to counterbalance

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- 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

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- Then when disagreement $\uparrow$, real yields are
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    - unchanged when $\gamma = 1$,
    - and $\downarrow$ when $\gamma < 1$,
- Real bond volatilities also rise with $\uparrow$ disagreement.

Equilibrium - Closed-Form Bond Prices

- When γ is an integer, real & nominal bond prices:

$$
\begin{aligned}
B(t;T') &= \sum_{k=0}^{\gamma} \left(\begin{array}{c} \gamma \\ k \end{array} \right) (1-f(t))^k \, f(t)^{\gamma-k} B_k(t;T') \\
P_{\$}(t;T') &= \sum_{k=0}^{\gamma} \left(\begin{array}{c} \gamma \\ k \end{array} \right) (1-f(t))^k \, f(t)^{\gamma-k} P_{k,\$}(t;T')
\end{aligned}
$$

  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 κ

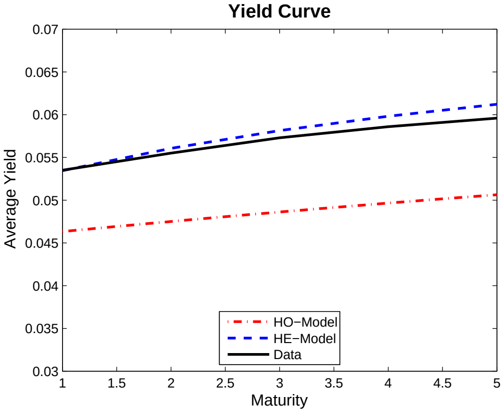
Numerical Results - Parameters

Parameter	Description	Value
Preferences		
ρ	Time Preference Parameter	2.5%
γ	Risk Aversion	7
δ	Habit Parameter	0.07
Consumption	*(Chan & Kogan)*	
μ_ϵ	Expected Consumption Growth	1.72%
σ_ϵ	Volatility of Consumption	3.32%
Inflation	*(Brennan & Xia)*	
σ_π	Inflation Volatility	1.3%
$\bar{x}$	Long Run Mean of Expected Inflation	3%
κ	Mean Reversion of Expected Inflation	0.35
σ_x	Volatility of Expected Inflation	1.4%
$\rho_{\epsilon\pi}$	ρ of Realized Inflation & Real Consumption Growth	-0.2
$\rho_{\pi x}$	ρ of Realized and Expected Inflation	0
$\rho_{x\epsilon}$	ρ of Expected Inflation & Real Consumption Growth	0

Numerical Results - Beliefs

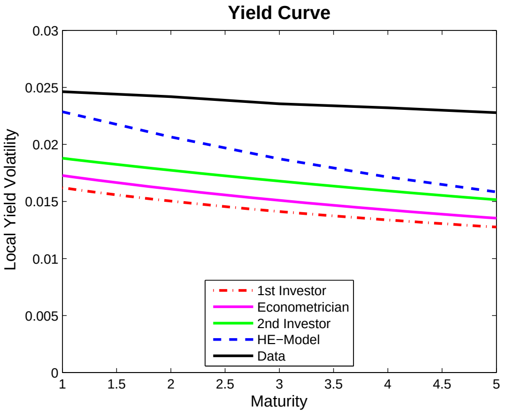
Disagreement		
$\bar{x}_1$	Long run mean of first investor	$\bar{x} - \frac{1}{2}\Delta_{\bar{x}}$
$\bar{x}_2$	Long run mean of second investor	$\bar{x} + \frac{1}{2}\Delta_{\bar{x}}$
κ_1	Mean reversion of first investor	$\kappa - \frac{1}{2}\Delta_{\kappa}$
κ_2	Mean reversion of first investor	$\kappa + \frac{1}{2}\Delta_{\kappa}$

Numerical Results - Nominal Yield Curve in Steady-State Disagreement



Parameters: $f = 0.5$, $\Delta_{\bar{x}} = 1\%$, and $\Delta_{\kappa} = -0.3$

Numerical Results - Yield Curve Volatility



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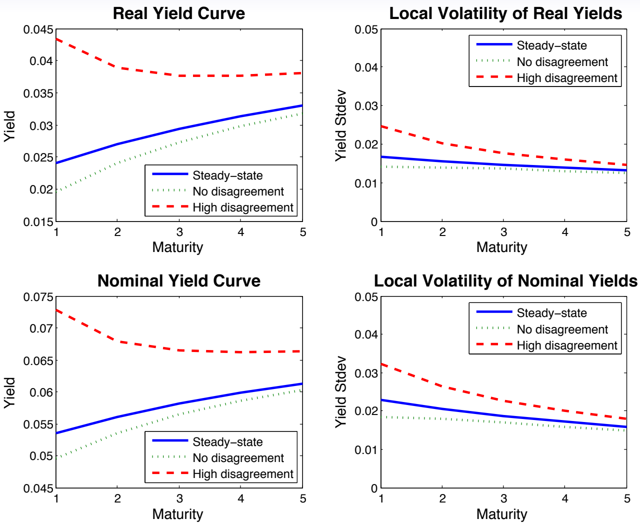
Numerical Results - Impact of Increased Disagreement



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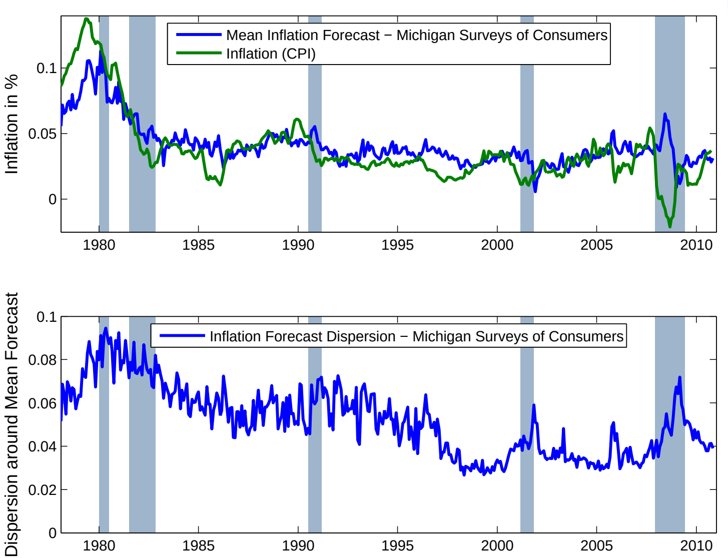
Empirical Work - Inflation Beliefs & Dispersion



Empirical Work - Nominal Yields & Volatilities

	3 Month		1 Year		2 Year		3 Year		5 Year	
Panel A: Yields										
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Intercept	-0.018	-0.022	-0.014	-0.018	-0.011	-0.014	-0.007	-0.009	-0.002	-0.004
t-statistics	-1.919	-2.431	-1.623	-2.020	-1.331	-1.627	-0.944	-1.175	-0.293	-0.497
Dispersion	1.423	0.787	1.429	0.855	1.415	0.956	1.385	1.029	1.342	1.095
t-statistics	7.778	3.458	8.370	3.666	8.881	4.086	9.169	4.465	9.809	5.013
Mean Inflation		0.901		0.812		0.650		0.504		0.351
t-statistics		4.212		3.719		2.887		2.227		1.586
Adj.R2	0.435	0.544	0.442	0.531	0.456	0.516	0.470	0.508	0.497	0.517
N	394	394	394	394	394	394	394	394	394	394
Panel B: Yield Volatilities										
Intercept	-0.016	-0.017	-0.012	-0.013	-0.016	-0.017	-0.015	-0.016	-0.019	-0.020
t-statistics	-2.051	-2.245	-1.712	-1.849	-2.732	-2.838	-2.572	-2.624	-3.976	-3.919
Dispersion	0.824	0.602	0.765	0.598	0.849	0.695	0.807	0.702	0.869	0.789
t-statistics	5.250	3.504	5.358	3.522	6.663	4.245	6.444	4.316	7.816	5.440
Mean Inflation		0.315		0.236		0.218		0.149		0.113
t-statistics		2.208		1.835		1.719		1.162		0.925
Adj.R2	0.313	0.341	0.296	0.312	0.377	0.391	0.361	0.367	0.439	0.442
N	394	394	394	394	394	394	394	394	394	394

Data: Monthly, January 1978 - October 2010

Empirical Work - Real Yields & Volatilities

	3 Month		1 Year		2 Year		3 Year		5 Year	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Panel A: Yields										
Intercept	0.015	0.015	0.017	0.016	0.009	0.010	0.012	0.013	0.013	0.014
t-statistics	1.174	1.170	1.524	1.542	1.058	1.234	1.430	1.710	1.761	2.215
Dispersion	0.221	0.327	0.187	0.321	0.280	0.423	0.251	0.413	0.244	0.432
t-statistics	0.909	0.993	0.877	1.148	1.550	2.128	1.485	2.309	1.590	2.792
Mean Inflation		-0.126		-0.160		-0.198		-0.224		-0.259
t-statistics		-0.516		-0.766		-1.308		-1.577		-1.969
Adj.R2	0.019	0.015	0.019	0.022	0.074	0.093	0.071	0.106	0.088	0.149
N	100	100	100	100	127	127	127	127	131	131
Panel B: Yield Volatilities										
Intercept	0.002	0.002	0.001	0.001	0.002	0.002	0.001	0.001	-0.001	-0.001
t-statistics	0.417	0.370	0.270	0.205	0.535	0.635	0.223	0.280	-0.338	-0.338
Dispersion	0.268	0.400	0.242	0.347	0.202	0.247	0.198	0.223	0.191	0.194
t-statistics	2.698	3.216	2.956	3.256	3.356	3.080	3.909	3.142	4.713	3.139
Mean Inflation		-0.158		-0.126		-0.062		-0.034		-0.004
t-statistics		-1.805		-1.669		-1.169		-0.710		-0.082
Adj.R2	0.150	0.177	0.166	0.188	0.168	0.173	0.197	0.195	0.231	0.225
N	100	100	100	100	127	127	127	127	131	131

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,
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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
  - Affine - Dai & Singleton (2000, 2002, 2003), Duffee (2002)
  - Quadratic - Ahn, Dittmar, and Gallant (2002)
- Latent + Macro Variables - Ang & Piazzesi (2003), Ang, Dong, & Piazzesi (2007), Adrian & Wu (2009), Ang, Bekaert, & Wei (2008)

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Structural Models

- Exogenous inflation - Wachter (2006), Piazzesi & Schneider (2006)
- Endogenous Inflation - Gallmeyer, Hollifield, & Zin (2005), Buraschi & Jiltsov (2007), Gallmeyer, Hollifield, Palomino, & Zin (2007), Bekaert, Cho, & Moreno (2010), Palomino (2010)

Related Work on Yield Curve Economics

Reduced Form No Arbitrage Models

- Latent state variables
  - Affine - Dai & Singleton (2000, 2002, 2003), Duffee (2002)
  - Quadratic - Ahn, Dittmar, and Gallant (2002)
- Latent + Macro Variables - Ang & Piazzesi (2003), Ang, Dong, & Piazzesi (2007), Adrian & Wu (2009), Ang, Bekaert, & Wei (2008)

Structural Models

- Exogenous inflation - Wachter (2006), Piazzesi & Schneider (2006)
- Endogenous Inflation - Gallmeyer, Hollifield, & Zin (2005), Buraschi & Jiltsov (2007), Gallmeyer, Hollifield, Palomino, & Zin (2007), Bekaert, Cho, & Moreno (2010), Palomino (2010)

Subjective Beliefs/Survey Data & Yield Curves

- Ang, Bekaert & Wei (2007), Buraschi & Whelan (2010), Chernov & Mueller (2008), Gürkaynak & Wright (2010), Xiong & Yan (2010)