Monetary Policy, Segmentation, and the Term Structure

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Monetary policy and the term structure

- Effect of change in short rates on (real) long rates is central to monetary transmission.
- Transmission operates in part through term premia.
  - Long rate $= \sum E[\text{short rates}] +$ term premium.
  - Expansionary MP $\Rightarrow$ long rates fall more than $\sum E[\text{short rates}]$.

    Cochrane-Piazzesi (02), Gertler-Karadi (15), Hanson-Stein (15), Abrahams-Adrian-Crump-Moench-Yu (16), Hanson-Lucca-Wright (21), ...
- Challenge to rationalize using existing models.
  - Rep. agent: MP shocks have negligible effects on term premia.
  - Preferred habitat: MP easing *raises* term premia.

What we do

Propose a model of term structure consistent with effects of MP.

- As in preferred habitat tradition: habitat investors + arbs.
- As in intermediary AP tradition: arb wealth is state variable.
- Key mechanism: when arbs have positive duration, fall in short rate revalues wealth in arbs' favor and compresses term premia.

⇒ Accounts for effects of MP shock on real term structure.

⇒ State-dependence, price volatility, and trends from declining r^*.

Outline

▸ Related literature

Model (1/2)

Preferred habitat meets intermediary asset pricing.

- Continuous time t.
- Zero coupon bonds with maturities $\tau \in (0, \infty)$.
- Two types of agents:
  - Habitat investors: $Z_t^{(\tau)} = -\alpha(\tau) \log \left(P_t^{(\tau)} \right) - \theta_t(\tau)$.
  - Arbitrageurs born and dying at rate ξ, solving:

$$v_t(w_t) = \max_{\{x_{t+s}^{(\tau)}\}_{\tau,s}} \mathbb{E}_t \int_0^\infty \exp(-\xi s) \log w_{t+s} ds$$

subject to

$$dw_t = r_t w_t dt + \int_0^\infty x_t^{(\tau)} \left(\frac{dP_t^{(\tau)}}{P_t^{(\tau)}} - r_t dt \right) d\tau.$$

Optimal policies linear in w_t. Define $X_t^{(\tau)}$, W_t as aggregates.

Model (2/2)

- Market clearing: $Z_t^{(\tau)} + X_t^{(\tau)} = 0$ at each $\tau \in (0, \infty)$.
- Driving forces:
  - Short rate: $dr_t = \kappa_r \left(\bar{r} - r_t\right) dt + \sigma_r dB_{r,t}$.
  - Habitat demand: $d\beta_t = -\kappa_\beta \beta_t dt + \sigma_\beta dB_{\beta,t}$, where

$$\theta_t(\tau) = \theta_0(\tau) + \theta_1(\tau)\beta_t.$$

- Remarks:
  - Vayanos-Vila (21) + CRRA + perpetual youth.
  - Real interpretation.
  - Monetary shocks as inducing real short rate shocks.

Simplified environment and equilibrium

- First simplify to discrete time, two bonds traded $\tau = \{1, 2\}$.
- Given $\{r_t, \theta_t, W_t\}$, equilibrium described by six equations:

$$r_{t+1}^{(2)} = -r_{t+1} - \log P_t,$$
$$E_t r_{t+1}^{(2)} - r_t + \frac{1}{2}\sigma_r^2 \approx \frac{X_t}{W_t}\sigma_r^2,$$
$$X_t = \alpha \log P_t + \theta_t,$$
$$W_{t+1} = \exp(-\xi)\left[W_t \exp(r_t) + X_t \left(\frac{\exp(-r_{t+1})}{P_t} - \exp(r_t)\right)\right] + (1 - \exp(-\xi))\,\bar{W},$$
$$r_{t+1} - \bar{r} = (1 - \kappa_r)(r_t - \bar{r}) + \sigma_r \epsilon_{r,t+1},$$
$$\theta_{t+1} - \bar{\theta} = (1 - \kappa_\theta)\left(\theta_t - \bar{\theta}\right) + \sigma_\theta \epsilon_{\theta,t+1},$$

  in six unknowns $\{r_{t+1}^{(2)}, P_t, X_t, W_{t+1}, r_{t+1}, \theta_{t+1}\}$.

- Focus on effects of monetary shock $d\epsilon_{r,t}$.

Effect on arb wealth

- For simplicity, focus on responses around stoch. steady-state.

Proposition

In response to a monetary shock

$$d \log W_t = -\exp(-\xi)\omega\sigma_r d\epsilon_{r,t},$$

where ω is the duration of arbitrageurs' wealth and satisfies $\omega \propto \frac{X}{W}$.

- Hence, arbs' wealth is revalued upwards if short rate falls and their portfolio has positive duration.

Effect on yield curve

Proposition

The response of the one-period ahead forward rate to a monetary shock is

$$df_t = \left[\frac{1 - \kappa_r - \frac{1}{W}\alpha\sigma_r^2}{1 + \frac{1}{W}\alpha\sigma_r^2} + \exp(-\xi) \frac{\frac{1}{W} X \sigma_r^2}{1 + \frac{1}{W}\alpha\sigma_r^2} \omega \right] \sigma_r d\epsilon_{r,t},$$

- Yield falls as short rate falls and habitat investors borrow more.
- When $\xi \to \infty$, arbs' wealth is constant at $\bar{W}$.
  - Underreaction: $df_t < (1 - \kappa_r)\sigma_r d\epsilon_{r,t} = dE_t r_{t+1}$ if $\alpha > 0$.
- When ξ finite, arbs' wealth revalued upwards.
  - Overreaction: term premium falls if X/W sufficiently high vs. α.

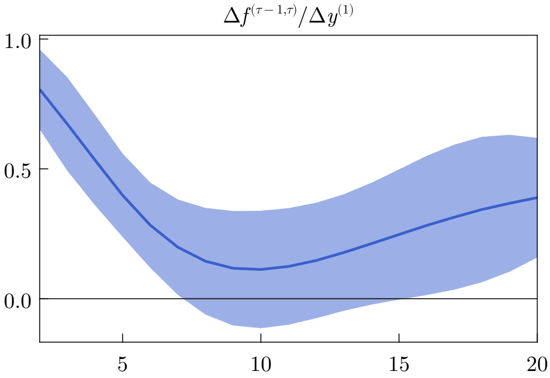
Taking stock and rest of paper

- When $\xi \to \infty$, forward rate underreacts to monetary shock.
- Given finite ξ, forward rate overreacts to monetary shock if portfolio duration is high relative to α.
- Now:
  1. Estimates of monetary shock on yield curve.
  2. Estimates of arb duration.
  3. Assessing whether full model can quantitatively account for #1.
     - Arb duration disciplined by novel evidence in #2.
     - α disciplined by large literature on QE.
  4. Additional implications of endogenous arb wealth for yield curve.

Estimated effects on real yield curve

▸ Details ▸ Scatterplot ▸ Nominal

- $\Delta f_t^{(\tau-1,\tau)}$ on $\Delta y_t^{(1)}$, using high-freq. MP surprise as IV.



- Bridges Hanson-Stein (15) and Nakamura-Steinsson (18).
- Challenge to explain with existing models.

Estimated arb duration

- Who are the arbs?
  - Following literature, broker/dealers and hedge funds.
  - By market clearing, habitat: households, other fin. institutions (pension funds, life insurance), non-financials, govt, and ROW.
- Two approaches to measure dealer + hedge fund duration:
  1. Balance sheets and asset-specific duration. Details
  2. High-freq. response of dealers to MP surprises. Details
- Punchline: duration between 10 and 30.

Relating yield curve responses and arb duration

Robustness

- Add MP surprise $\times dur_{t-1}$ to high freq. regressions.
- Use 3 proxies for arb duration avail. over sample: Figures

	Proxy for arb duration		
	5-yr fwd, 5-yr TP	Log dealer dur.	$-$Dealer income gap
$\Delta f_t^{(19,20)}$ on $\Delta y_t^{(1)} \times dur_{t-1}$	0.50	0.34	2.0
	(0.25)	(0.15)	(1.7)

- Thus, response of $f_t^{(19,20)}$ to $100bp$ increase in $y_t^{(1)}$ rises by
  - $50bp$ if term premium higher by $1pp$ (SD: $0.4pp$).
  - $0.34bp$ if log dealer dur higher by $1pp$ (SD: $55pp$).
  - $2.0bp$ if dealer income gap lower by $1pp$ (SD: $8pp$).
- Add'l evidence: High freq. dealer return as RHS in first stage
High freq. dealer return amplified when duration high

Returning to full model

- Now: can calibration matching arb duration account for effects of monetary shocks on yield curve?

- Generalizing simple model, equilibrium in full model given by

$$E_t\left(\frac{dP_t^{(\tau)}}{P_t^{(\tau)}}\right) - r_t dt = \frac{1}{W_t}\int_0^\infty X_t^{(s)} Cov_t\left(\frac{dP_t^{(\tau)}}{P_t^{(\tau)}}, \frac{dP_t^{(s)}}{P_t^{(s)}}\right) ds,$$

$$X_t^{(\tau)} = -Z_t^{(\tau)} = \alpha(\tau)\log\left(P_t^{(\tau)}\right) + \theta_0(\tau) + \theta_1(\tau)\beta_t,$$

$$dW_t = W_t r_t dt + \int_0^\infty X_t^{(\tau)}\left[\frac{dP_t^{(\tau)}}{P_t^{(\tau)}} - r_t dt\right] d\tau + \xi(\bar{W} - W_t)dt,$$

and evolution of driving forces.

- Solve numerically (Feynman-Kac & Monte Carlo)

- Assume: $\alpha(\tau) \equiv \alpha \exp^{-\delta\tau}$, $\theta_0(\tau) \equiv \exp^{-\delta\tau}$, $\theta_1(\tau) \equiv \exp^{-\delta\tau}$.

PDE

$$\Bigg[P^{(\tau)}_{r,\,t}\kappa_r\left(\bar{r}-r_t\right)+P^{(\tau)}_{W,\,t}\omega_t+P^{(\tau)}_{\beta,\,t}\kappa_\beta\left(\bar{\beta}-\beta_t\right)-P^{(\tau)}_{\tau,\,t}+\frac{1}{2}P^{(\tau)}_{rr,\,t}\sigma_r^2$$

$$+\frac{1}{2}P^{(\tau)}_{WW,\,t}\left(\eta^2_{r,\,t}+\eta^2_{\beta,\,t}\right)+\frac{1}{2}P^{(\tau)}_{\beta\beta,\,t}\sigma^2_\beta+P^{(\tau)}_{rW,\,t}\sigma_r\eta_{r,\,t}+P^{(\tau)}_{\beta W,\,t}\sigma_\beta\eta_{\beta,\,t}-r_tP^{(\tau)}_t\Bigg]dt$$

$$=\frac{1}{W_t}\Bigg[\left(P^{(\tau)}_{r,\,t}\sigma_r+P^{(\tau)}_{W,\,t}\eta_{r,\,t}\right)\int_0^\infty\left(\alpha(s)\log\left(P^{(s)}_t\right)+\theta_0(s)\right)\frac{1}{P^{(s)}_t}\left(P^{(s)}_{r,\,t}\sigma_r+P^{(s)}_{W,\,t}\eta_{r,\,t}\right)ds$$

$$+\left(P^{(\tau)}_{\beta,\,t}\sigma_\beta+P^{(\tau)}_{W,\,t}\eta_{\beta,\,t}\right)\int_0^\infty\left(\alpha(s)\log\left(P^{(s)}_t\right)+\theta_0(s)\right)\frac{1}{P^{(s)}_t}\left(P^{(s)}_{\beta,\,t}\sigma_\beta+P^{(s)}_{W,\,t}\eta_{\beta,\,t}\right)ds$$

$$+\beta_t\Bigg[\left(P^{(\tau)}_{r,\,t}\sigma_r+P^{(\tau)}_{W,\,t}\eta_{r,\,t}\right)\int_0^\infty\theta_1(s)\frac{1}{P^{(s)}_t}\left(P^{(s)}_{r,\,t}\sigma_r+P^{(s)}_{W,\,t}\eta_{r,\,t}\right)ds$$

$$+\left(P^{(\tau)}_{\beta,\,t}\sigma_\beta+P^{(\tau)}_{W,\,t}\eta_{\beta,\,t}\right)\int_0^\infty\theta_1(s)\frac{1}{P^{(s)}_t}\left(P^{(s)}_{\beta,\,t}\sigma_\beta+P^{(s)}_{W,\,t}\eta_{\beta,\,t}\right)ds\Bigg]\Bigg]dt.$$

PDE

$$\Big[P^{(\tau)}_{r,t}\kappa_r(\bar{r}-r_t)+P^{(\tau)}_{W,t}\omega_t+P^{(\tau)}_{\beta,t}\kappa_\beta\left(\bar{\beta}-\beta_t\right)-P^{(\tau)}_{\tau,t}+\frac{1}{2}P^{(\tau)}_{rr,t}\sigma_r^2$$
$$+\frac{1}{2}P^{(\tau)}_{WW,t}\left(\eta^2_{r,t}+\eta^2_{\beta,t}\right)+\frac{1}{2}P^{(\tau)}_{\beta\beta,t}\sigma^2_\beta+P^{(\tau)}_{rW,t}\sigma_r\eta_{r,t}+P^{(\tau)}_{\beta W,t}\sigma_\beta\eta_{\beta,t}-r_tP^{(\tau)}_t\Big]\,dt$$
$$=\frac{1}{W_t}\Bigg[\left(P^{(\tau)}_{r,t}\sigma_r+P^{(\tau)}_{W,t}\eta_{r,t}\right)\int_0^\infty\left(\alpha(s)\log\left(P^{(s)}_t\right)+\theta_0(s)\right)\frac{1}{P^{(s)}_t}\left(P^{(s)}_{r,t}\sigma_r+P^{(s)}_{W,t}\eta_{r,t}\right)ds$$
$$+\left(P^{(\tau)}_{\beta,t}\sigma_\beta+P^{(\tau)}_{W,t}\eta_{\beta,t}\right)\int_0^\infty\left(\alpha(s)\log\left(P^{(s)}_t\right)+\theta_0(s)\right)\frac{1}{P^{(s)}_t}\left(P^{(s)}_{\beta,t}\sigma_\beta+P^{(s)}_{W,t}\eta_{\beta,t}\right)ds$$
$$+\beta_t\Bigg[\left(P^{(\tau)}_{r,t}\sigma_r+P^{(\tau)}_{W,t}\eta_{r,t}\right)\int_0^\infty\theta_1(s)\frac{1}{P^{(s)}_t}\left(P^{(s)}_{r,t}\sigma_r+P^{(s)}_{W,t}\eta_{r,t}\right)ds$$
$$+\left(P^{(\tau)}_{\beta,t}\sigma_\beta+P^{(\tau)}_{W,t}\eta_{\beta,t}\right)\int_0^\infty\theta_1(s)\frac{1}{P^{(s)}_t}\left(P^{(s)}_{\beta,t}\sigma_\beta+P^{(s)}_{W,t}\eta_{\beta,t}\right)ds\Bigg]\Bigg]\,dt.$$

- Blue terms: Vasicek model
  - How would you solve it numerically?

PDE

$$
\Big[P^{(\tau)}_{r,\,t}\kappa_r\left(\bar{r}-r_t\right)+P^{(\tau)}_{W,\,t}\omega_t+P^{(\tau)}_{\beta,\,t}\kappa_\beta\left(\bar{\beta}-\beta_t\right)-P^{(\tau)}_{\tau,\,t}+\frac{1}{2}P^{(\tau)}_{rr,\,t}\sigma_r^2
$$

$$
+\frac{1}{2}P^{(\tau)}_{WW,\,t}\left(\eta^2_{r,\,t}+\eta^2_{\beta,\,t}\right)+\frac{1}{2}P^{(\tau)}_{\beta\beta,\,t}\sigma^2_\beta+P^{(\tau)}_{rW,\,t}\sigma_r\eta_{r,\,t}+P^{(\tau)}_{\beta W,\,t}\sigma_\beta\eta_{\beta,\,t}-r_tP^{(\tau)}_t\Big]\,dt
$$

$$
=\frac{1}{W_t}\left[\left(P^{(\tau)}_{r,\,t}\sigma_r+P^{(\tau)}_{W,\,t}\eta_{r,\,t}\right)\int_0^\infty\left(\alpha(s)\log\left(P^{(s)}_t\right)+\theta_0(s)\right)\frac{1}{P^{(s)}_t}\left(P^{(s)}_{r,\,t}\sigma_r+P^{(s)}_{W,\,t}\eta_{r,\,t}\right)ds\right.
$$

$$
+\left(P^{(\tau)}_{\beta,\,t}\sigma_\beta+P^{(\tau)}_{W,\,t}\eta_{\beta,\,t}\right)\int_0^\infty\left(\alpha(s)\log\left(P^{(s)}_t\right)+\theta_0(s)\right)\frac{1}{P^{(s)}_t}\left(P^{(s)}_{\beta,\,t}\sigma_\beta+P^{(s)}_{W,\,t}\eta_{\beta,\,t}\right)ds
$$

$$
+\beta_t\left[\left(P^{(\tau)}_{r,\,t}\sigma_r+P^{(\tau)}_{W,\,t}\eta_{r,\,t}\right)\int_0^\infty\theta_1(s)\frac{1}{P^{(s)}_t}\left(P^{(s)}_{r,\,t}\sigma_r+P^{(s)}_{W,\,t}\eta_{r,\,t}\right)ds\right.
$$

$$
\left.\left.+\left(P^{(\tau)}_{\beta,\,t}\sigma_\beta+P^{(\tau)}_{W,\,t}\eta_{\beta,\,t}\right)\int_0^\infty\theta_1(s)\frac{1}{P^{(s)}_t}\left(P^{(s)}_{\beta,\,t}\sigma_\beta+P^{(s)}_{W,\,t}\eta_{\beta,\,t}\right)ds\right]\right]dt.
$$

- Collect terms multiplying $P^{(\tau)}_{r,t}$, $P^{(\tau)}_{\beta,t}$, $P^{(\tau)}_{W,t}$

PDE

$$P^{(\tau)}_{r,\,t}\mu_{r,t} + P^{(\tau)}_{W,\,t}\mu_{W,t} + P^{(\tau)}_{\beta,\,t}\mu_{\beta,t} - P^{(\tau)}_{\tau,\,t} - r_t P^{(\tau)}_{t}$$
$$+ \frac{1}{2}P^{(\tau)}_{rr,\,t}\sigma_r^2 + \frac{1}{2}P^{(\tau)}_{WW,\,t}\left(\eta^2_{r,\,t} + \eta^2_{\beta,\,t}\right) + \frac{1}{2}P^{(\tau)}_{\beta\beta,\,t}\sigma_\beta^2 + P^{(\tau)}_{rW,\,t}\sigma_r\eta_{r,\,t} + P^{(\tau)}_{\beta W,\,t}\sigma_\beta\eta_{\beta,\,t} = 0.$$

PDE

$$
\begin{aligned}
&P^{(\tau)}_{r,\,t}\mu_{r,t} + P^{(\tau)}_{W,\,t}\mu_{W,t} + P^{(\tau)}_{\beta,\,t}\mu_{\beta,t} - P^{(\tau)}_{\tau,\,t} - r_t P^{(\tau)}_t \\
&+ \frac{1}{2}P^{(\tau)}_{rr,\,t}\sigma_r^2 + \frac{1}{2}P^{(\tau)}_{WW,\,t}\left(\eta^2_{r,\,t} + \eta^2_{\beta,\,t}\right) + \frac{1}{2}P^{(\tau)}_{\beta\beta,\,t}\sigma_\beta^2 + P^{(\tau)}_{rW,\,t}\sigma_r\eta_{r,\,t} + P^{(\tau)}_{\beta W,\,t}\sigma_\beta\eta_{\beta,\,t} = 0.
\end{aligned}
$$

- Feynman-Kac: Solution is $P^{(\tau)}_t = \mathbb{E}^Q_t\left[e^{-\int_0^\tau r_{t+s}ds}\right]$

  where processes of r_t, β_t and W_t under Q

$$
\begin{aligned}
dr_t &= \mu_r(r_t, \beta_t, W_t)dt + \sigma_r dB_{r,t}, \\
d\beta_t &= \mu_\beta(r_t, \beta_t, W_t)dt + \sigma_\beta dB_{\beta,t}, \\
dW_t &= \mu_W(r_t, \beta_t, W_t)dt + \eta_r(r_t, \beta_t, W_t)dB_{r,t} + \eta_\beta(r_t, \beta_t, W_t)dB_{\beta,t}.
\end{aligned}
$$

Solution algorithm

1. Create tensor grid of r, β, and W values.
2. Initialize $\mu_r(r,\beta,W)$, $\mu_\beta(r,\beta,W)$, $\mu_W(r,\beta,W)$, $\omega(r,\beta,W)$, $\eta_r(r,\beta,W)$, and $\eta_\beta(r,\beta,W)$ at each grid point.
3. Use cubic splines to approximate $\mu_r(r,\beta,W)$, $\mu_\beta(r,\beta,W)$, $\mu_W(r,\beta,W)$, $\omega(r,\beta,W)$, $\eta_r(r,\beta,W)$, and $\eta_\beta(r,\beta,W)$ outside of the grid.
4. Approximate $\mathbb{E}^Q[\cdot]$ using Monte Carlo simulation.
5. Update the values for $\mu_r(r,\beta,W)$, $\mu_\beta(r,\beta,W)$, $\mu_W(r,\beta,W)$, $\omega(r,\beta,W)$, $\eta_r(r,\beta,W)$, and $\eta_\beta(r,\beta,W)$.
6. If values in step 5 are sufficiently close to guess in step 2, stop. Otherwise, return to step 2 using values in step 5.

Calibration: key parameters and targets

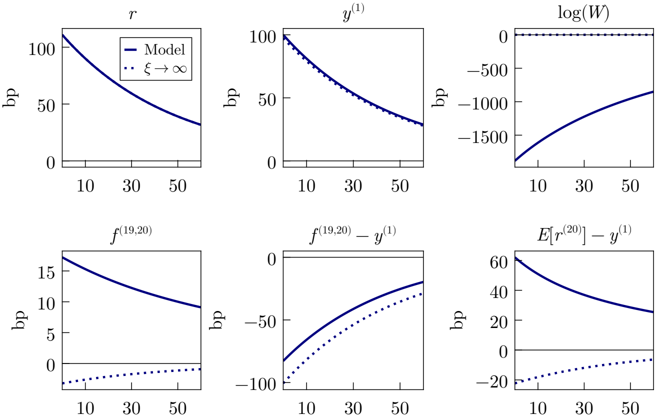
All calibrated parameters

- δ (shape habitat demand): asset duration of arbs.
- $\bar{W}$ (arb endowment): wealth duration of arbs.
- α (habtat price elast.), ξ (persist. arb wealth): QE responses.
  - Simplified environment provides intuition: $\frac{d \log P_t}{d\theta_t} = -\frac{1}{\alpha + \frac{W_t}{\sigma_r^2}}$.
  - Focus on 3/18/09 announcement: purchase \$300bn Treasuries; increase agency debt and MBS purchases by \$100bn, \$750bn.
  - Translate each security-level purchase through 3/31/10 into purchase of ZCBs and feed into model.
  - Initialize W_0 at 1/3 below average W, consistent with data.

Purchases in data | Price impact in data | Arb wealth Q407–Q109 | Simulating QE in model

Monetary shock: impulse responses

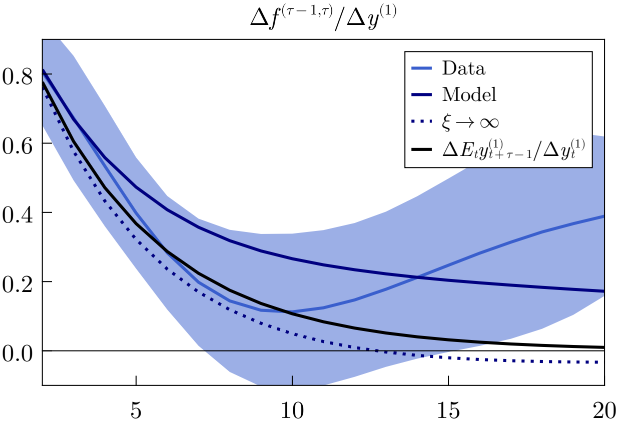
β shock



- Arbs' wealth rises and lowers term premia, unlike $\xi \to \infty$.

Monetary shock: model vs. data

▸ More transitory shock ▸ CP (08) decomp.



- Account for roughly half of $f^{(19,20)}$, unlike $\xi \to \infty$...
- ...and all of $f^{(19,20)}$ given higher duration/lower α. ▸ Details

Monetary shock: state-dependence

	Proxy for arb duration		
	5-yr fwd, 5-yr TP	Log dealer dur.	−Dealer income gap
Data	[0.09,0.91]	[0.09,0.59]	[-0.8,4.8]
Model	0.19	0.16	0.4

- As in data, higher arb duration implies larger response of $f^{(19,20)}$ to monetary tightening.
- If anything, model understates effects of changes in arb wealth.

Additional implications of endogenous arb wealth

...beyond conditional response to monetary shocks.

1. State-dependent effects of QE. ▸ Details
   - If arb wealth was W before 3/18/09 announcement, response of long-dated yields and forwards dampened by $20-30\%$.
   - Reflects more elastic demand and lower duration at higher W_0.
2. Bond price volatility. ▸ Details
   - Endog. arb wealth induces endogenous, stochastic yield vol
   - Average slope of yield curve flattens by 1/3 in its absence.
3. Secular decline in natural rate. ▸ Details
   - Decline in $\bar{r}$ accounts for $> 30\%$ of decline in real term premia.
   - Complements explanations focused on changing comovements.

Conclusion

Propose a model of term structure consistent with effects of MP.

- As in preferred habitat tradition: habitat investors + arbs.
- As in intermediary AP tradition: arb wealth is state variable.
- Key mechanism: when arbs have positive duration, fall in short rate revalues wealth in arbs' favor and compresses term premia.

⇒ Accounts for effects of MP shock on real term structure.

⇒ State-dependence, stochastic vol., and trends from declining r^*.

APPENDIX

Related literature

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- Preferred habitat models of term structure.

  Vayanos-Vila (21), Greenwood-Hanson-Stein (10), Guibaud-Nosbusch-Vayanos (13), Gourinchas-Ray-Vayanos (21), Greenwood-Hanson-Stein-Sunderam (20), Ray (21), ...

  Here: resolve counterfactual responses to short rate.

- Intermediary asset pricing and financial accelerator.

  Bernanke-Gertler-Gilchrist (99), He-Krishnamurthy (13), Brunnermeier-Sannikov (14), Haddad-Sraer (20), He-Nagel-Song (22), Schneider (22), ...

  Here: application to term structure and monetary transmission.

- "Reaching for yield" or changing policy rules.

  Hanson-Stein (15), Bianchi-Lettau-Ludvisgon (21), Hanson-Lucca-Wright (21), Bianchi-Ludvigson-Ma (22), Bauer-Pflueger-Sunderam (22), ...

  Here: wealth revaluation channel with distinct predictions.

- Our prior work on macro, wealth distribution, and price of risk.

Estimated effects on real yield curve

▸ Outstanding TIPS ▸ Back

- We regress $\Delta f_t^{(\tau-1,\tau)}$ on $\Delta y_t^{(1)}$:
  - Δ is one-day change around FOMC meetings 2004–2016.
  - IV: high freq. change in FF future (Jarocinski-Karadi (20)).
- Following Nakamura-Steinsson (18), use high freq. IV because of other news even on FOMC days. ▸ Comparing FOMC vs. non-FOMC days
- Following Jarocinski-Karadi (20), focus on meetings around which IV and S&P 500 return have opposite signs.
- Robustness: ▸ Details
  - Sample: all FOMC meetings, excl. 7/2008–6/2009, excl. LSAP news (Cieslak-Schrimpf (19)).
  - IV: Bauer-Swanson(22), Nakamura-Steinsson(18), Swanson(21).

Outstanding TIPS

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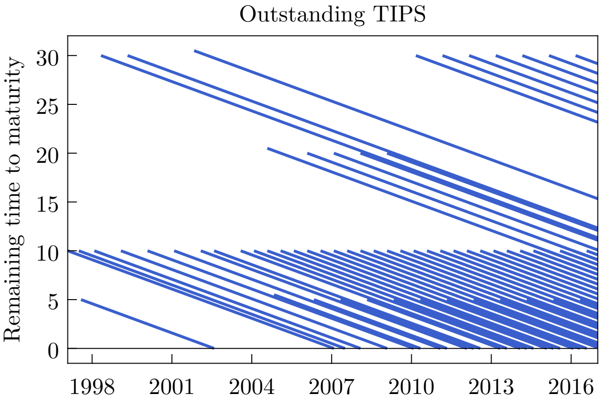
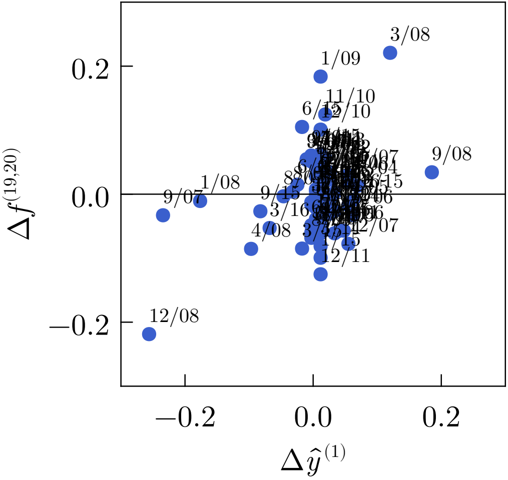


Estimated effects on real yield curve (1/2)

Back



Estimated effects on real yield curve (2/2)

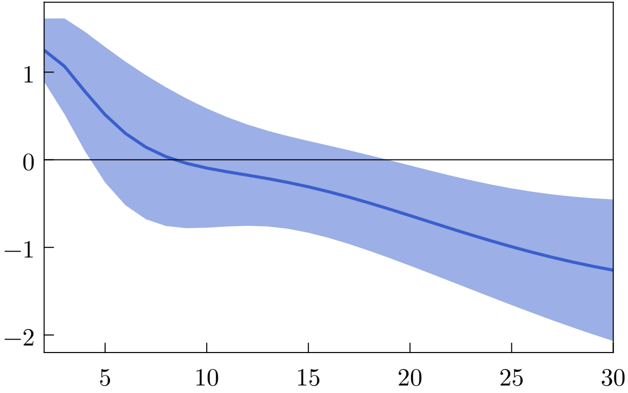
▸ Back

Specification	$\Delta f_t^{(4,5)}$	$\Delta f_t^{(9,10)}$	$\Delta f_t^{(14,15)}$	$\Delta f_t^{(19,20)}$
Baseline	0.40	0.11	0.25	0.39
	(0.10)	(0.14)	(0.15)	(0.14)
All FOMC announcements	0.38	0.11	0.13	0.27
	(0.10)	(0.11)	(0.15)	(0.13)
Excl. 7/08-6/09	0.46	-0.26	0.21	0.50
	(0.22)	(0.30)	(0.21)	(0.29)
Excl. announcements with LSAP news	0.28	-0.12	0.07	0.30
	(0.12)	(0.17)	(0.14)	(0.19)
Swanson (21) Fed funds IV	0.31	0.15	0.30	0.41
	(0.13)	(0.13)	(0.16)	(0.17)
Swanson (21) forward guidance IV	1.05	0.44	0.25	0.23
	(0.23)	(0.13)	(0.13)	(0.12)
Bauer-Swanson (22) IV	0.64	0.27	0.17	0.23
	(0.14)	(0.11)	(0.14)	(0.13)
Nakamura-Steinsson (18) IV	0.64	0.27	0.35	0.40
	(0.15)	(0.13)	(0.11)	(0.13)
NS (18) IV, excl. 7/08-6/09	0.72	-0.07	0.13	0.29
	(0.32)	(0.26)	(0.19)	(0.26)

Estimated effects on nominal yield curve (1/3)

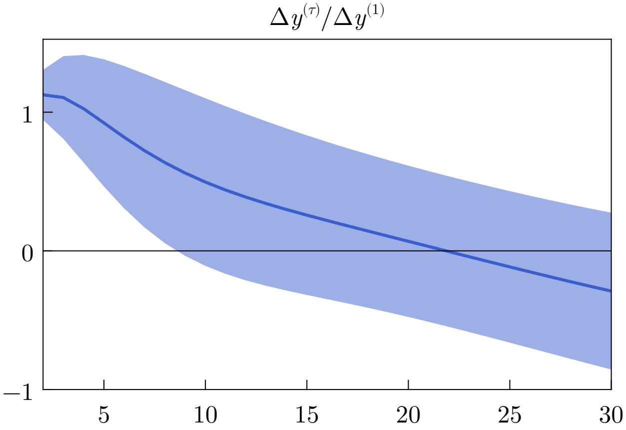
Back

$\Delta f^{(\tau-1,\tau)}/\Delta y^{(1)}$



Estimated effects on nominal yield curve (2/3)

Back



Estimated effects on nominal yield curve (3/3)

▸ Back

Specification	$\Delta f_t^{(4,5)}$	$\Delta f_t^{(9,10)}$	$\Delta f_t^{(14,15)}$	$\Delta f_t^{(19,20)}$
Baseline	0.51	-0.09	-0.31	-0.64
	(0.47)	(0.41)	(0.31)	(0.34)
All FOMC announcements	0.42	-0.09	-0.23	-0.42
	(0.26)	(0.23)	(0.17)	(0.19)
Excl. 7/08-6/09	0.10	-0.49	-0.59	-0.84
	(0.34)	(0.33)	(0.43)	(0.51)
Excl. announcements with LSAP news	-0.02	-0.52	-0.51	-0.74
	(0.30)	(0.27)	(0.35)	(0.40)
Swanson (21) Fed funds IV	0.41	0.00	-0.18	-0.64
	(0.57)	(0.47)	(0.35)	(0.46)
Swanson (21) forward guidance IV	2.30	0.87	0.09	-0.20
	(0.94)	(0.48)	(0.23)	(0.29)
Bauer-Swanson (22) IV	0.87	0.15	-0.20	-0.50
	(0.36)	(0.30)	(0.22)	(0.28)
Nakamura-Steinsson (18) IV	0.91	0.27	-0.12	-0.48
	(0.46)	(0.40)	(0.28)	(0.33)
NS (18) IV, excl. 7/08-6/09	0.27	-0.29	-0.37	-0.66
	(0.29)	(0.29)	(0.32)	(0.41)

Estimated arb duration

Back

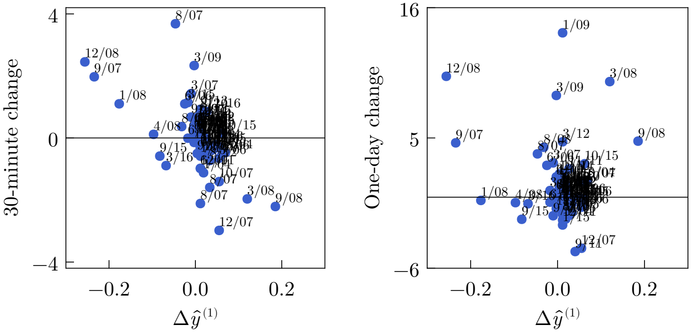
- Dealer balance sheets from FA, hedge funds from Form PF.
- Duration from Bloomberg indices and Greenwald et al (22).
- Estimate duration with/without corporate equities.

	Q4 2012 balance sheet ($bn)			
	Broker/ dealers	Hedge funds	Sum	Duration (years)
Cash, deposits, MMFs	128	553	681	0.25
Repo and other short-term loans*	-448	-1,231	-1,679	0.083
Treasuries	185	654	839	5.4
Corporate and foreign bonds	40	994	1,034	7.2
Other debt securities†	302	61	363	3.2
Loans	-35	133	99	5
Corporate equities	127	1,148	1,275	46.5
Wealth	299	2,313	2,612	27.9
Only fixed income	172	1,164	1,336	10.1

Estimated arb duration

▸ List of dealers ▸ Robustness ▸ Back

- Complementary approach: high freq. response of publicly traded dealer stock prices to monetary shocks.



- 1*pp* increase in 1y yield ⇒ 9.8*pp* decline in dealer equity prices.

- High freq. window needed for power.

List of dealers (1/2) ▸ Back

	CRSP/TAQ		FR Y9-C	
Dealer	Ticker	Availability	RSSD	Availability
Bank of America	BAC	1/2/2004-12/30/2016	1073757	2004Q1-2016Q4
Barclays	BCS	1/2/2004-12/30/2016	2914521	2004Q4-2010Q3*
BMO	BMO	1/2/2004-12/30/2016	1245415	2004Q1-2016Q4
Bank of Novia Scotia	BNS	1/2/2004-12/30/2016	1238967	
Bear Stearns	BSC	1/2/2004-5/30/2008	1573257	
Citigroup	C	1/2/2004-12/30/2016	1951350	2004Q1-2016Q4
CIBC	CM	1/2/2004-12/30/2016	2797498	2004Q1-2004Q3
Credit Suisse	CS	1/2/2004-12/30/2016	1574834	2016Q3-2016Q4
Deutsche Bank	DB	1/2/2004-12/30/2016	1032473	2004Q1-2016Q4*
Goldman Sachs	GS	1/2/2004-12/30/2016	2380443	2009Q1-2016Q4
HSBC	HSBC	1/2/2004-12/30/2016	3232316	2004Q1-2016Q4
Jefferies	JEF	1/2/2004-2/28/2013	2046020	
JP Morgan	JPM	1/2/2004-12/30/2016	1039502	2004Q1-2016Q4
Lehman Brothers	LEH	1/2/2004-9/17/2008	2380144	

List of dealers (2/2)

Back

	CRSP/TAQ		FR Y9-C	
Dealer	Ticker	Availability	RSSD	Availability
Merrill Lynch	MER	1/2/2004-12/31/2008		
MF Global	MF	7/19/2007-10/28/2011	4236731	2016Q3-2016Q4
Mizuho	MFG	11/8/2006-12/30/2016	5034792	2016Q3-2016Q4
Morgan Stanley	MS	1/2/2004-12/30/2016	2162966	2009Q1-2016Q4
Nomura	NMR	1/2/2004-12/30/2016	1445345	
Banc One	ONE	1/2/2004-6/30/2004	1068294	2004Q1-2004Q2
Prudential	PRU	1/2/2004-12/30/2016	2441728	
RBS	RBS	10/18/2007-12/30/2016	1851106	
RBC	RY	1/2/2004-12/30/2016	3226762	2010Q4-2016Q4*
TD	TD	1/2/2004-12/30/2016	3606542	2015Q3-2016Q4
UBS	UBS	1/2/2004-12/30/2016	4846998	2016Q3-2016Q4
Wells Fargo	WFC	1/2/2004-12/30/2016	1120754	2004Q1-2016Q4
Zions First National	ZION	1/2/2004-12/30/2016	1027004	2004Q1-2016Q4

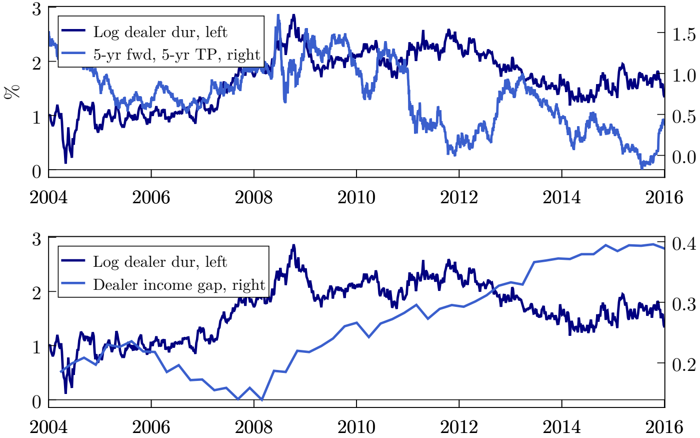
High frequency response of dealer equities

Back

Specification	30 minute change	One day change
Baseline	-9.8	-8.0
	(3.2)	(9.9)
All FOMC announcements	-1.4	-2.7
	(4.5)	(8.2)
Excl. 7/08-6/09	-19.4	-2.6
	(11.2)	(20.0)
Excl. announcements with LSAP news	-12.4	4.0
	(5.8)	(10.1)
Swanson (21) Fed funds IV	-10.0	-4.2
	(3.6)	(10.5)
Swanson (21) forward guidance IV	-11.4	-13.1
	(5.0)	(5.3)
Bauer-Swanson (22) IV	-7.7	-14.8
	(3.2)	(6.7)
Nakamura-Steinsson (18) IV	-12.2	-21.3
	(4.0)	(6.6)
NS (18) IV, excl. 7/08-6/09	-24.2	-20.6
	(10.0)	(17.6)

Comparing measures of arb duration

Back



Relating yield curve responses and arb duration ▸ Back

Specification	5-yr fwd, 5-yr TP	Log dealer dur.	−Dealer income gap
Baseline	0.50	0.34	2.0
	(0.25)	(0.15)	(1.7)
All FOMC announcements	0.11	0.20	1.4
	(0.43)	(0.21)	(1.7)
Excl. 7/08-6/09	1.08	1.08	6.5
	(0.63)	(0.66)	(5.7)
Excl. announcements with LSAP news	0.43	0.52	1.6
	(0.38)	(0.38)	(1.6)
[?] Fed funds IV	0.70	0.14	2.1
	(0.42)	(0.23)	(2.7)
[?] forward guidance IV	0.08	0.05	1.4
	(0.20)	(0.18)	(1.7)
[?] IV	0.65	0.20	2.1
	(0.73)	(0.19)	(2.2)
[?] IV	0.56	0.10	16.2
	(0.55)	(0.19)	(10.2)
NS (2018) IV, excl. 7/08-6/09	1.11	0.64	14.2
	(0.70)	(0.90)	(9.5)

High frequency dealer return in first stage

▸ Back

Specification	$\Delta f_t^{(4,5)}$	$\Delta f_t^{(9,10)}$	$\Delta f_t^{(14,15)}$	$\Delta f_t^{(19,20)}$
Baseline	-0.041	-0.011	-0.025	-0.040
	(0.018)	(0.016)	(0.017)	(0.016)
All FOMC announcements	-0.275	-0.082	-0.094	-0.199
	(0.915)	(0.269)	(0.262)	(0.608)
Excl. 7/08-6/09	-0.024	0.013	-0.011	-0.025
	(0.020)	(0.010)	(0.012)	(0.017)
Excl. announcements with LSAP news	-0.023	0.010	-0.006	-0.025
	(0.016)	(0.010)	(0.011)	(0.013)
Swanson (21) Fed funds IV	-0.031	-0.015	-0.030	-0.041
	(0.019)	(0.016)	(0.016)	(0.017)
Swanson (21) forward guidance IV	-0.092	-0.038	-0.022	-0.020
	(0.034)	(0.019)	(0.012)	(0.012)
Bauer-Swanson (22) IV	-0.084	-0.035	-0.022	-0.030
	(0.036)	(0.021)	(0.020)	(0.021)
Nakamura-Steinsson (18) IV	-0.052	-0.022	-0.029	-0.033
	(0.018)	(0.017)	(0.016)	(0.017)
NS (18) IV, excl. 7/08-6/09	-0.030	0.003	-0.005	-0.012
	(0.017)	(0.010)	(0.009)	(0.011)

High frequency dealer return and duration (1/2) ▸ Back

Specification	5-yr fwd, 5-yr TP	Log dealer dur.	−Dealer income gap
Baseline	-6.3	-9.4	-75.3
	(7.8)	(7.0)	(37.2)
All FOMC announcements	1.6	8.5	-6.9
	(13.3)	(9.1)	(51.8)
Excl. 7/08-6/09	-33.2	-81.1	-257.8
	(29.7)	(194.3)	(289.4)
Excl. announcements with LSAP news	-13.4	-17.9	-81.6
	(10.4)	(14.7)	(51.2)
Swanson (21) Fed funds IV	0.6	-9.4	-74.9
	(9.8)	(5.9)	(51.3)
Swanson (21) forward guidance IV	-5.0	-9.0	-132.7
	(8.5)	(10.9)	(113.1)
Bauer-Swanson (22) IV	-9.5	0.0	-51.2
	(8.5)	(6.9)	(44.2)
Nakamura-Steinsson (18) IV	17.5	-0.0	-282.2
	(11.2)	(8.0)	(257.9)
NS (18) IV, excl. 7/08-6/09	1.0	-89.1	-296.1
	(14.6)	(232.1)	(365.7)

High frequency dealer return and duration (2/2) ▸ Back

Specification	−Income gap
Baseline	-11.8
	(7.9)
All FOMC announcements	1.4
	(10.4)
Excl. 7/08-6/09	-60.8
	(30.4)
Excl. announcements with LSAP news	-24.6
	(13.4)
Swanson (21) Fed funds IV	-5.0
	(9.4)
Swanson (21) forward guidance IV	-22.5
	(12.2)
Bauer-Swanson (22) IV	-3.8
	(7.0)
Nakamura-Steinsson (18) IV	-4.0
	(9.1)
NS (18) IV, excl. 7/08-6/09	-22.6
	(22.2)

Quarterly dealer returns and income gap

Back

	Dealer return	Dealer return	Dealer return	Dealer return
Ex. 5-10 year bond return	-0.69	1.55	-0.69	1.55
	(2.31)	(1.24)	(2.34)	(1.24)
Lagged income gap	81.6	-6.58	72.9	-1.35
	(82.23)	(63.61)	(144.74)	(104.62)
Ex. 5-10 year bond return × lagged income gap	-5.99	-9.51	-6.02	-9.49
	(7.12)	(4.10)	(7.22)	(4.10)
Ex. S&P 500 return		1.35		1.35
		(0.23)		(0.24)
3-month Treasury return			-0.64	0.39
			(5.76)	(3.76)
N	52	52	52	52
R^2	0.35	0.67	0.35	0.67

Wealth process

Back

$$dW_t = \omega(r_t, \beta_t, W_t)dt + \eta_r(r_t, \beta_t, W_t)dB_{r,\,t} + \eta_\beta(r_t, \beta_t, W_t)dB_{\beta,\,t}$$

where

$$\omega_t = \xi\left(\bar{W} - W_t\right) + W_t r_t + \int_0^\infty \left(\alpha(\tau)\log\left(P_t^{(\tau)}\right) + \theta_0(\tau) + \theta_1(\tau)\beta_t\right)\left(\mu_t^{(\tau)} - r_t\right)d\tau$$

$$\eta_{r,\,t} = \int_0^\infty \left(\alpha(\tau)\log\left(P_t^{(\tau)}\right) + \theta_0(\tau) + \theta_1(\tau)\beta_t\right)\frac{1}{P_t^{(\tau)}}\left(P_{r,\,t}^{(\tau)}\sigma_r + P_{W,\,t}^{(\tau)}\eta_{r,\,t}\right)d\tau$$

$$\eta_{\beta,\,t} = \int_0^\infty \left(\alpha(\tau)\log\left(P_t^{(\tau)}\right) + \theta_0(\tau) + \theta_1(\tau)\beta_t\right)\frac{1}{P_t^{(\tau)}}\left(P_{\beta,\,t}^{(\tau)}\sigma_\beta + P_{W,\,t}^{(\tau)}\eta_{\beta,\,t}\right)d\tau.$$

QE purchases in data (1/2)

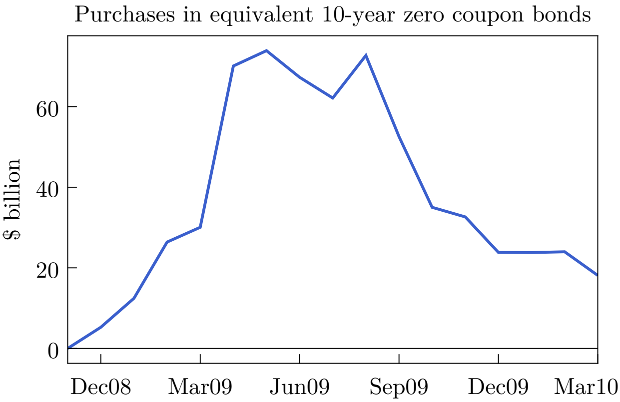
Back

- CUSIP-level Treasuries and agency debt purchases from SOMA, agency MBS purchases from Fed Board.
- Transform purchases into panel dataset of purchases of ZCBs purchased at each maturity $\tau \in (0, 30]$ on each date t:
  - Treasuries and agency debt: strip and compute market values using ZCB yield curve.
  - MBS: assume ZCB with maturity = effective duration of Bloomberg MBS index.

$\Rightarrow$ Over $600bn in ten-year equivalent ZCBs purchased in QE1.

QE purchases in data (2/2)

Back



QE price impact in data

▸ Back

	$\Delta y_t^{(10)}$	$\Delta y_t^{(20)}$	$\Delta f_t^{(10)}$	$\Delta f_t^{(20)}$
11/25/2008	-39	-19	-48	22
12/1/2008	-34	-39	-10	-98
12/16/2008	-58	-39	-31	-17
1/28/2009	9	14	16	21
3/18/2009	-61	-41	-46	-25
Sum to date	-183	-124	-119	-98
8/12/2009	-0	-0	-1	-1
9/23/2009	-1	1	1	4
11/4/2009	-3	-6	2	-6
Sum to date	-188	-129	-117	-100

Arb wealth from Q407 to Q109

▸ Back

	Q4 2007	Q1 2009	Percent change
Broker/dealers	285	293	3
Hedge funds: distressed securities	176	69	-61
Hedge funds: fixed income	160	69	-57
Hedge funds: macro	91	61	-33
Broker/dealers + core FI hedge funds	712	492	-31
Hedge funds: convertible arbitrage	42	11	-74
Hedge funds: emerging markets	353	125	-65
Hedge funds: equity strategies	538	303	-44
Hedge funds: event-driven	162	57	-65
Hedge funds: merger arbitrage	39	5	-87
Hedge funds: multistrategy	224	122	-46
Hedge funds: other	61	20	-67
Hedge funds: sector specific	130	58	-55
Broker/dealers + hedge funds	2,261	1,193	-47

Simulating QE in model

Back

- Focus on 3/18/09 surprise: all Treasuries, \$100bn agency debt, \$750bn MBS.
- Translate purchases into model scale:
  - Over 2012-16, arb wealth 9% of GDP (next slide).

  $\Rightarrow$ In month 0, agents learn $\theta_t(\tau)$ will fall by

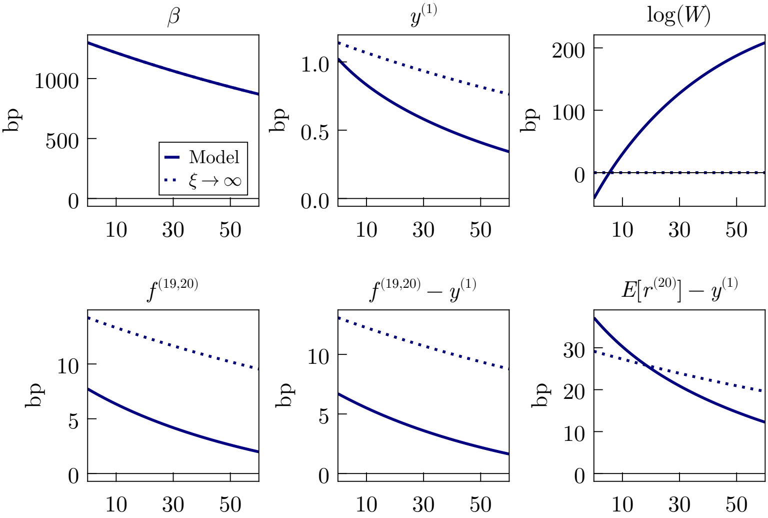
$$\frac{\text{purchases}(\tau)_t}{\text{gdp}_{2007}} \frac{W}{0.09},$$

  where purchases$(\tau)_t$ is t months after 4/09, gdp$_{2007}$ is annual GDP prior to crisis, and W is average value of arbitrageur wealth in model.

- Simulate in model starting from $\{r = \bar{r}, \beta = 0, W_0 = 0.6W\}$.

Habitat demand shock

Back



Calibration: details

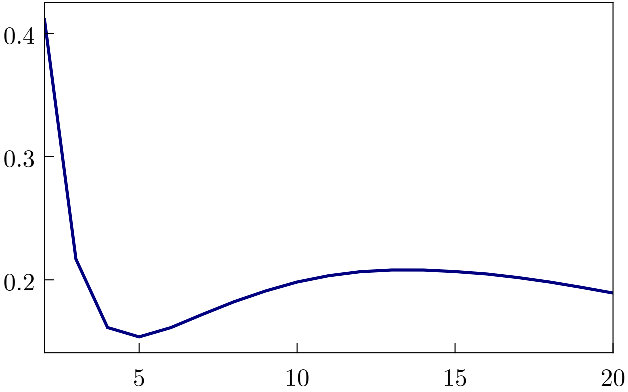
Back

	Description	Value	Moment	Target	Model
Unconditional moments of yields					
$\bar{r}$	mean short rate	-0.0004	$y_t^{(1)}$	0.06%	0.06%
γ	arb. risk aversion	2	$y_t^{(20)} - y_t^{(1)}$	1.54%	1.53%
σ_r	std. dev. short rate	0.007	$\sigma(y_t^{(20)})$	0.74%	0.74%
κ_r	mean rev. short rate	0.03	$\sigma(\Delta y_t^{(20)})$	0.56%	0.57%
σ_β	std. dev. demand	0.45	$\beta_{FB}^{(10)}$	0.68	0.69
Duration of arbitrageurs					
$\bar{W}$	arb. endowment	0.002	duration	20	20
κ_β	mean rev. demand	0.08	$\sigma(\log(\text{duration}))$	0.5	0.5
Yield curve responses to QE announcement on March 18, 2009					
α	habitat price elast.	5	$df_t^{(9,10)}$	-0.46%	-0.53%
ξ	persistence arb. wealth	0.05	$df_t^{(19,20)}$	-0.25%	-0.25%

More persistent short rate shock

Back

$\Delta f^{(\tau-1,\tau)}/\Delta y^{(1)}$



- Set $\kappa_m = 1.0$: more transitory monetary shock.
- U-Shape: transitory effect on short rate, term premia effect

Cochrane-Piazzesi decomposition

Back

- As derived in Cochrane-Piazzesi (08),

$$f_t^{(\tau-1,\tau)} - y_{t+\tau-1}^{(1)} =$$
$$\left[r_{t+1}^{(\tau)} - r_{t+1}^{(\tau-1)}\right] + \left[r_{t+2}^{(\tau-1)} - r_{t+2}^{(\tau-2)}\right] + \ldots + \left[r_{t+\tau-1}^{(2)} - y_{t+\tau-2}^{(1)}\right],$$

where

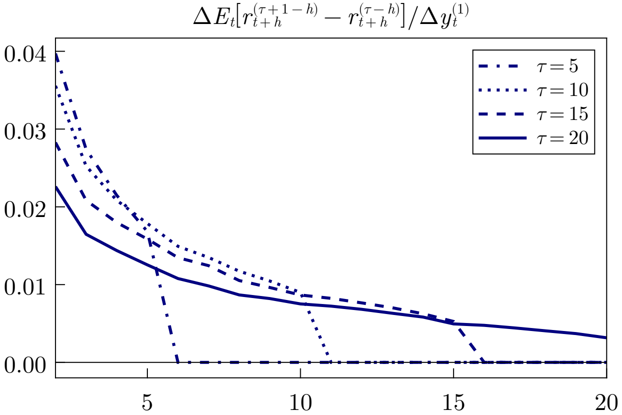
$$r_{t+1}^{(\tau)} \equiv \log P_{t+1}^{(\tau-1)} - \log P_t^{(\tau)}.$$

- Ex-ante, this implies

$$f_t^{(\tau-1,\tau)} - E_t y_{t+\tau-1}^{(1)} =$$
$$E_t\left[r_{t+1}^{(\tau)} - r_{t+1}^{(\tau-1)}\right] + E_t\left[r_{t+2}^{(\tau-1)} - r_{t+2}^{(\tau-2)}\right] + \ldots + E_t\left[r_{t+\tau-1}^{(2)} - y_{t+\tau-2}^{(1)}\right].$$

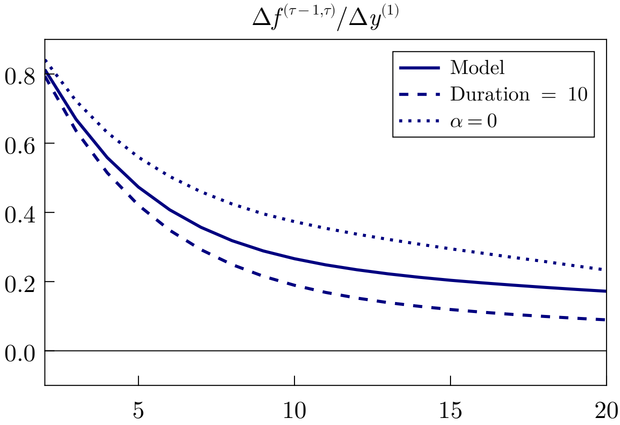
Decomposing forward rate response

Back



Monetary shock: sensitivity

Back

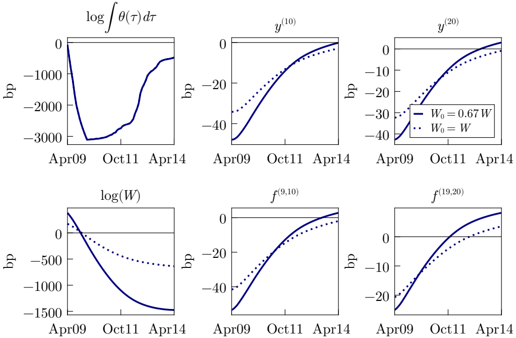


- Fully account for $f^{(19,20)}$ given higher duration and/or lower α.
- "Reach for yield" suggests lower α conditional on r shock.

State-dependent effects of QE

Back

- Reconsider 3/18/09 announcement but set W_0 to avg level:



- Long-dated yields, forwards fall by 20 − 30% less:
  - More elastic demand (recall $\frac{d\log P_t}{d\theta_t} = -\frac{1}{\alpha + \frac{W_t}{\sigma_r^2}}$).
  - Lower duration and thus recapitalization from QE.

Bond price volatility

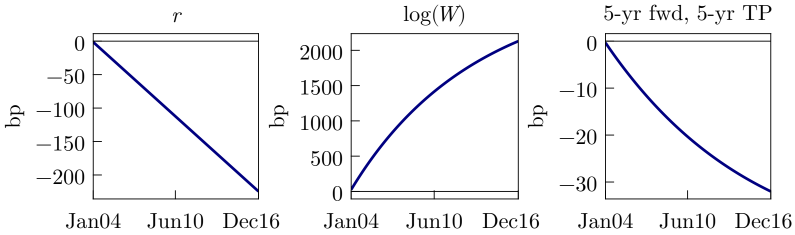
Back

Moment	Model	$\xi \to \infty$
$\sigma(y_t^{(20)})$	0.74%	0.73%
$\sigma(\sigma_{t-1}(y_t^{(20)}))$	0.23%	0.00%
$y_t^{(20)} - y_t^{(1)}$	1.53%	1.00%

- Setting $\xi \to \infty$ while recalibrating $\bar{W}$ to match average W:
  - no endogenous, stochastic bond price volatility: slope of the yield curve falls by $1/3$

Secular decline in natural rate

▸ Back



- Decline in $\bar{r}$ from Laubach-Williams (2003) / FRB NY.
- Decline recapitalizes arbs and accounts for 20% – 30% of decline in term premium from D'Amico-Kim-Wei (2018) / Fed Board.
- Complements explanations focused on changing comovements.

Comparing FOMC vs. non-FOMC days (1/3) ▸ Back

- Alternative approach to studying effects of monetary policy on yield curve considered in literature:

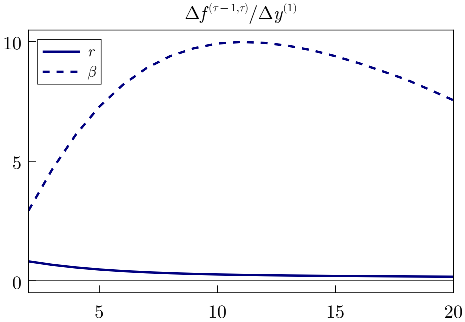
	$\Delta f_t^{(4,5)}$	$\Delta f_t^{(9,10)}$	$\Delta f_t^{(14,15)}$	$\Delta f_t^{(19,20)}$
$\Delta y_t^{(1)}$	0.11	-0.01	0.01	0.11
	(0.02)	(0.02)	(0.02)	(0.02)
$FOMC_t$	-0.01	-0.00	-0.00	-0.00
	(0.01)	(0.01)	(0.01)	(0.01)
$\Delta y_t^{(1)} \times FOMC_t$	0.25	0.14	0.00	-0.04
	(0.14)	(0.11)	(0.08)	(0.06)
N	3,252	3,252	3,252	3,252
R^2	0.07	0.00	0.00	0.03

- Small (even negative) interaction coefficients suggest monetary tightening does not raise (and may reduce) long forward rates.

Comparing FOMC vs. non-FOMC days (2/3) ▸ Back

- Model clarifies two reasons why this is incorrect.
- Underlying reason: β shocks have small effect on short yields.

1. Estimated interaction coefficients will be *negative* even though monetary tightening raises term premia:



Comparing FOMC vs. non-FOMC days (3/3)

▸ Back

2. Estimated interaction coefficients will be *small* unless proportion of r vs. β shocks change massively on FOMC days:

σ_r	$\Delta f_t^{(4,5)}$	$\Delta f_t^{(9,10)}$	$\Delta f_t^{(14,15)}$	$\Delta f_t^{(19,20)}$
Baseline	0.37	0.23	0.22	0.24
1.2 $\times$ Baseline	0.35	0.21	0.19	0.20