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 $= \sum E$[short rates] $+$ term premium.
  - Expansionary MP $\Rightarrow$ long rates fall more than $\sum E$[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.

⇒ Quantitatively rationalizes MP effects on real term structure.

⇒ Implications beyond MP: return predictability, price volatility, and declining natural rate.

Related literature

- 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.

- Term structure and "reaching for yield".

  Hanson-Stein (15), Hanson-Lucca-Wright (21).

  Here: investors borrow more when yields fall.

- Macro shocks, heterogeneity, and the price of risk.

  Alvarez-Atkeson-Kehoe (02,09), Caballero-Simsek (20,...), Kekre-Lenel (21,22).

  Here: analysis of bond market in preferred habitat environment.

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

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

Simplified environment and equilibrium

▸ Addt'l results

- First simplify to discrete time, two bonds traded $\tau = \{1, 2\}$.

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- Given $\{r_t, \theta_t, W_t\}$, equilibrium described by six equations:

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

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$$r_{t+1} - \bar{r} = (1 - \kappa_r)(r_t - \bar{r}) + \sigma_r \epsilon_{r,t+1},$$

$$\theta_{t+1} - \bar{\theta} = (1 - \kappa_\theta)\left(\theta_t - \bar{\theta}\right) + \sigma_\theta \epsilon_{\theta,t+1},$$

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

- Next: effects of MP shock; additional results in paper.

Short rate shock with endogenous arb wealth (1/2)

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Short rate shock with endogenous arb wealth (1/2)

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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.

Short rate shock with endogenous arb wealth (2/2)

Proposition

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

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

- 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 $\alpha > 0$.

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  - 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.

Empirical strategy

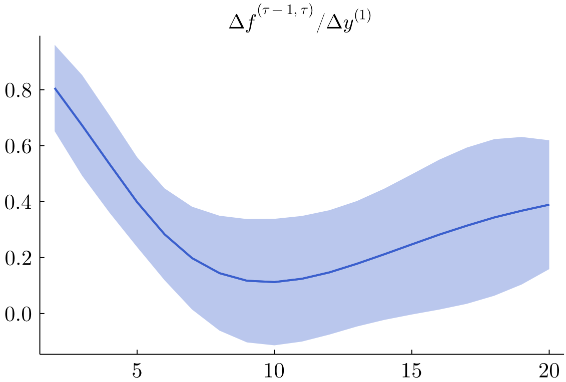
▸ Data

- Regress the change in $\{f_t^{(\tau-1,\tau)}, W_t\}$ on $\Delta y_t^{(1)}$:
    - Δ evaluated around FOMC days between 1/2004 and 12/2016.
    - IV: change in Fed Funds futures in 30 minutes around meeting.
- Following Nakamura-Steinsson (18), focus on high-frequency IV because of other news even on FOMC days.
- Following Jarocinski-Karadi (20), focus on meetings around which $\Delta y_t^{(1)}$ and $\Delta sp500_t$ have opposite signs.
- Robust to all FOMC meetings, excl. 08/09 or LSAP news, IV.

Response of real yield curve

Scatterplot Robustness TIPS Nominal

- Outcome: $f_t^{(\tau-1,\tau)}$ (real forward rates paying τ years ahead).

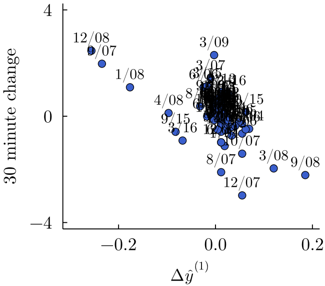


- Bridges Hanson-Stein (15) and Nakamura-Steinsson (18).
- Inconsistent with existing preferred habitat models.

Response of arb wealth

▸ Robustness ▸ State dependent

- Outcome: primary dealer equity index constructed using TAQ.



- 1*pp* increase in 1y yield ⇒ 8.8*pp* decline in dealer equity prices
  - High-freq. response of equity prices needed for power.

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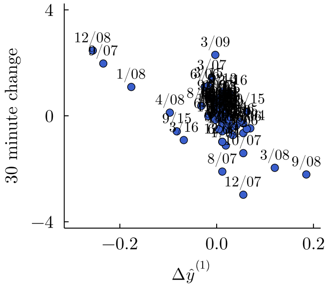


- 1*pp* increase in 1y yield ⇒ 8.8*pp* decline in dealer equity prices
    - High-freq. response of equity prices needed for power.
- Dealer balance sheet data support the duration mechanism.
    - Effects on forwards and equities decreasing in income gap.

Equilibrium and solution ▸ PDE

- Generalizing simple model, equilibrium in full model given by

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

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

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

and evolution of driving forces.

- Solve numerically on discretized grid (τ, r, β, W).

- Following VV (21): $\alpha(\tau) \equiv \alpha \exp^{-\delta_\alpha \tau}$,

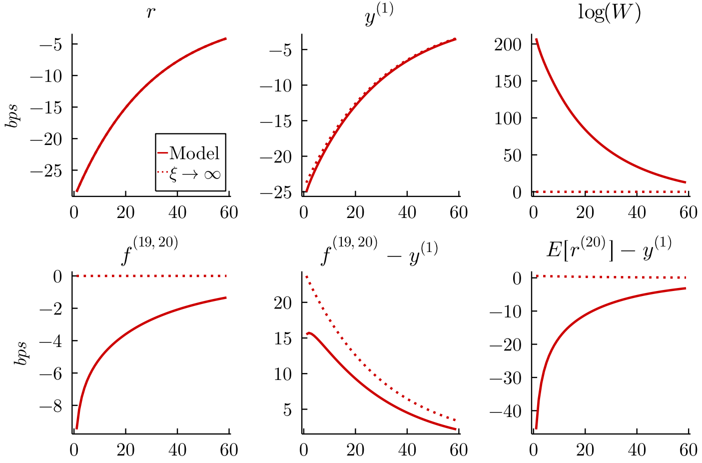
$$\theta_0(\tau) \equiv \exp^{-\delta_\alpha \tau} - \exp^{-\delta_\theta \tau},$$
$$\theta_1(\tau) \equiv \exp^{-\delta_\alpha \tau} - \exp^{-\delta_\theta \tau}.$$

Calibration

	Description	Value	Moment	Target	Model
Unconditional moments of yields and volumes					
$\bar{r}$	mean short rate	-0.001	$y_t^{(1)}$	0.06%	0.06%
κ_r	mean rev. short rate	0.4	$\sigma(y_t^{(1)})$	1.66%	1.51%
σ_r	std. dev. short rate	0.02	$\sigma(\Delta y_{t+1}^{(1)})$	1.75%	1.53%
ξ	persistence arb. wealth	0.15	$y_t^{(20)} - y_t^{(1)}$	1.54%	1.61%
κ_β	mean rev. demand	0.05	$\frac{1}{20}\sum_{\tau=1}^{20} \sigma(y_t^{(\tau)})$	1.01%	1.36%
σ_β	std. dev. demand	0.55	$\frac{1}{20}\sum_{\tau=1}^{20} \sigma(\Delta y_{t+1}^{(\tau)})$	0.78%	1.29%
α	level price elast.	0.4	$\frac{1}{20}\sum_{\tau=1}^{20} \rho(\Delta y_{t+1}^{(1)}, \Delta y_{t+1}^{(\tau)})$	0.57	0.68
δ_α	sens. price elast. to τ	0.38	$\sum_{\tau=1}^{2} \Delta X_t^\tau / \sum_\tau \Delta X_t^\tau$	0.20	0.20
δ_θ	sens. demand to τ	0.42	$\sum_{\tau>11} \Delta X_t^\tau / \sum_\tau \Delta X_t^\tau$	0.09	0.09
Impact effects of monetary shock					
$\bar{W}$	arb. endowment	0.005	$dW_t/dy_t^{(1)}$	-8.8	-8.3

Monetary shock (1/2)

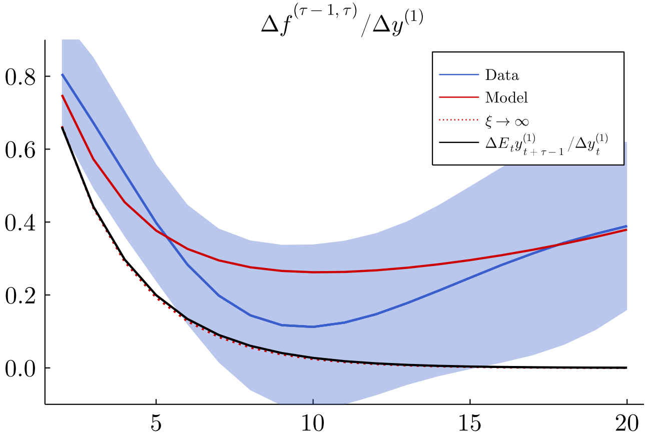
CP (08) decomposition



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

Monetary shock (2/2)

▸ Forwards, ex. returns ▸ Applying CP (08) ▸ State dep.



- Response of forward rates consistent with data, unlike $\xi \to \infty$.
- *U*-shape reflects EH vs. term premia as τ increases.

Implications beyond monetary policy

- Bond return predictability ▸ Details
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- Bond price volatility ▸ Details
  - Endog. arb wealth accounts for $>1/2$ of long-term price vol.
  - When $\xi \to \infty$ slope of yield curve falls by $3/4$.
- Secular decline in natural rate ▸ Details
  - Decline in $\bar{r}$ increases arbs' wealth, lowers term premia by 12 bp.
  - Complements explanations focused on changing comovements.

Summary

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.

⇒ Quantitatively rationalizes MP effects on real term structure.

⇒ Implications beyond MP: return predictability, price volatility, and declining natural rate.

Outlook: Heterogeneity, risk premia, and macro

How do heterogeneous portfolios affect transmission of macro shocks and comovements with asset prices?

- Monetary Policy, Redistribution and Risk Premia (ECMA)
  - het. in households' marginal propensity to take risk (MPR)
  - expansionary monetary policy redistributes to high MPR
  - ⇒ lowers risk premia and amplifies transmission mechanism
- The Flight to Safety and International Risk Sharing (WP)
  - two country model w. time varying demand for safe dollar bonds
  - heterogeneous exposure to "global financial cycle"
- Monetary Policy, Segmentation and the Term Structure (WP)
- ...

APPENDIX

Slope of yield curve and return predictability

Back

- Monetary easing implies steep yield curve and (if X/W is sufficiently high vs. α) low future excess returns.
- But Fama-Bliss (87) and Campbell-Shiller (91) find that steep yield curve predicts high excess returns.

Proposition

Consider estimating the FB (87) and CS (91) regressions

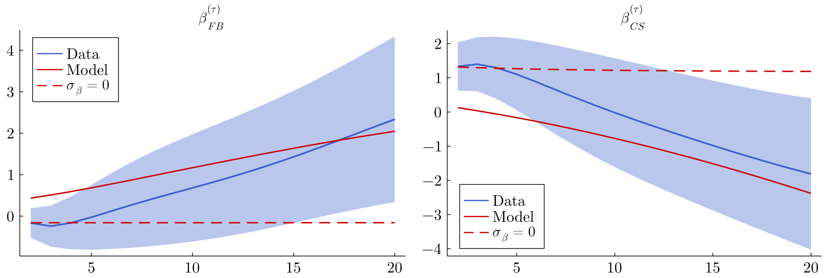
$$r^{(2)}_{t+1} - r_t = \alpha_{FB} + \beta_{FB}\left(f_t - r_t\right) + \epsilon_{FB,t+1},$$
$$r_{t+1} - y_t = \alpha_{CS} + \beta_{CS}\left(y_t - r_t\right) + \epsilon_{CS,t+1}$$

on model-generated data. As $\sigma_\theta \to \infty$, $\beta_{FB} \to 1$ and $\beta_{CS} \to -1$.

- Intuition: θ shocks only affect yields through term premia.

Bond return predictability

▸ Back ▸ Demand shock



- Model also consistent with FB (87), CS (91) evidence

$$r^{(\tau)}_{t+1} - y^{(1)}_t = \alpha^{(\tau)}_{FB} + \beta^{(\tau)}_{FB}\left(f^{(\tau-1,\tau)}_t - y^{(1)}_t\right) + \epsilon^{(\tau)}_{FB,t+1}$$

$$y^{(\tau-1)}_{t+1} - y^{(\tau)}_t = \alpha^{(\tau)}_{CS} + \beta^{(\tau)}_{CS}\frac{1}{\tau-1}\left(y^{(\tau)}_t - y^{(1)}_t\right) + \epsilon^{(\tau)}_{CS,t+1}$$

- Relies on sufficiently volatile demand shocks in calibration

Bond price volatility

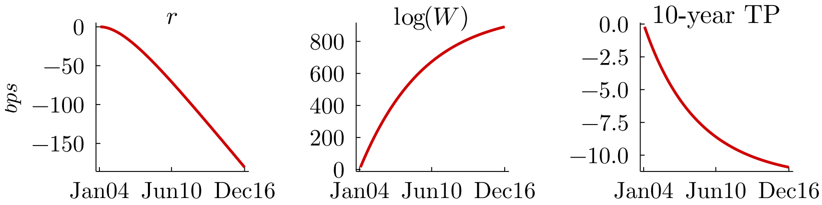
Back

Moment	Model	$\xi \to \infty$
$y_t^{(1)}$	0.06%	0.00%
$y_t^{(20)} - y_t^{(1)}$	1.61%	0.40%
$\sigma(y_t^{(1)})$	1.51%	1.44%
$\sigma(\Delta y_{t+1}^{(1)})$	1.53%	1.45%
$\frac{1}{20}\sum_{\tau=1}^{20}\sigma(y_t^{(\tau)})$	1.36%	0.63%
$\frac{1}{20}\sum_{\tau=1}^{20}\sigma(\Delta y_{t+1}^{(\tau)})$	1.29%	0.61%
$\frac{1}{20}\sum_{\tau=1}^{20}\rho(\Delta y_{t+1}^{(1)}, \Delta y_{t+1}^{(\tau)})$	0.68	0.92

- Unconditional yield curve moments in model vs. $\xi \to \infty$
  - lower yield curve vol. and slope when arb wealth constant

Secular decline in natural rate

Back



- Decline in $\bar{r}$ from Laubach and Williams (2003) / FRB NY
  - decline recapitalizes arbs' wealth, compresses term premia
  - lower term premia without changes in macro comovements.

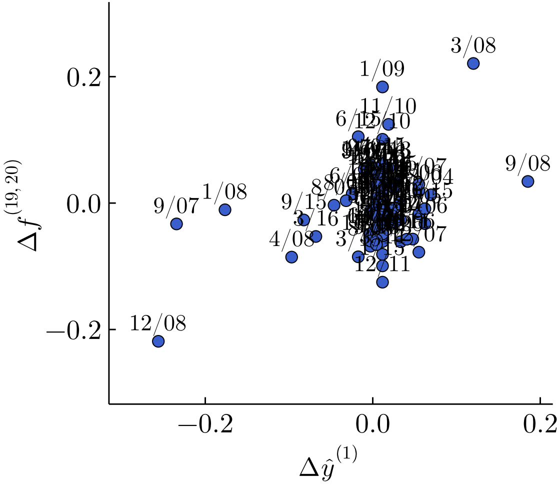
Data

▸ Back

Series	Source
High-frequency FF surprise and S&P 500	Jarocinski-Karadi (20)
Nominal and real yields and forwards	Gurkaynak-Sack-Wright (06,08)
List of primary dealers	New York Fed
Dealer daily closing prices and market caps	CRSP
Dealer dealer intraday prices	TAQ
FOMC meetings with LSAP news	Cieslak-Schrimpf (19)
Alternative high-frequency IV	Nakamura-Steinsson (18)

Response of yield curve (1/2)

Back



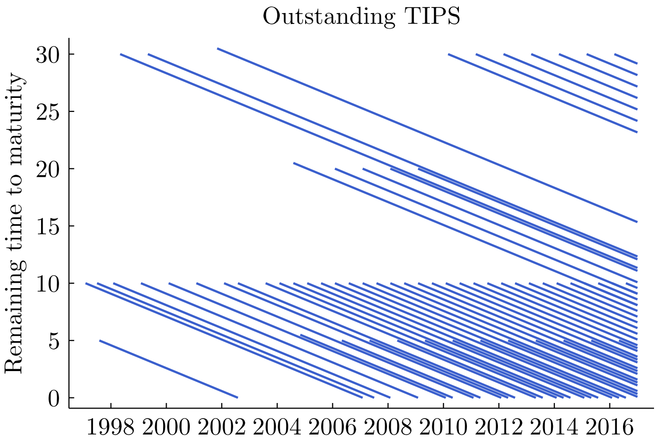
Response of yield curve (2/2)

Back

Specification	$\Delta f_t^{(5)}$	$\Delta f_t^{(10)}$	$\Delta f_t^{(15)}$	$\Delta f_t^{(20)}$
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)
Excluding 7/08-6/09	0.46	-0.26	0.21	0.50
	(0.22)	(0.30)	(0.21)	(0.29)
Excluding announcements with LSAP news	0.28	-0.12	0.07	0.30
	(0.12)	(0.17)	(0.14)	(0.19)
Nakamura-Steinsson (18) IV	0.64	0.27	0.35	0.40
	(0.15)	(0.13)	(0.11)	(0.13)
Nakamura-Steinsson (18) IV, ex. 7/08-6/09	0.72	-0.07	0.13	0.29
	(0.32)	(0.26)	(0.19)	(0.26)

Outstanding TIPS

Back



List of dealers (1/2)

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	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	7/10/2006-12/30/2016	2797498	2004Q1-2004Q3
Credit Suisse	CS	9/25/2006-12/30/2016	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	11/15/2013-12/30/2016	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)

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	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	1/17/2006-12/30/2016	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

Response of nominal yields (1/3)

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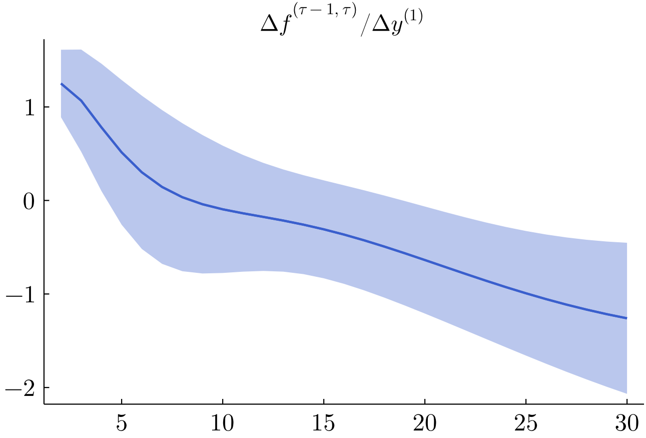

Response of nominal yields (2/3)

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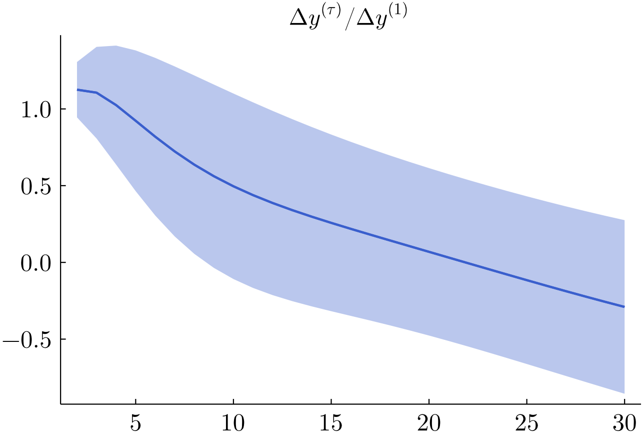

Response of nominal yields (3/3)

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Specification	$\Delta f_t^{(5)}$	$\Delta f_t^{(10)}$	$\Delta f_t^{(15)}$	$\Delta f_t^{(20)}$
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)
Excluding 7/08-6/09	0.10	-0.49	-0.59	-0.84
	(0.34)	(0.33)	(0.43)	(0.51)
Excluding announcements with LSAP news	-0.02	-0.52	-0.51	-0.74
	(0.30)	(0.27)	(0.35)	(0.40)
Nakamura-Steinsson (18) IV	0.91	0.27	-0.12	-0.48
	(0.46)	(0.40)	(0.28)	(0.33)
Nakamura-Steinsson (18) IV, ex. 7/08-6/09	0.27	-0.29	-0.37	-0.66
	(0.29)	(0.29)	(0.32)	(0.41)

Response of arb wealth

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Specification	30 minute change	One day change
Baseline	-8.8	-8.1
	(2.7)	(9.4)
All FOMC announcements	-3.0	-2.8
	(4.2)	(7.8)
Excluding 7/08-6/09	-15.5	-3.9
	(8.7)	(19.5)
Excluding announcements with LSAP news	-10.5	3.0
	(4.7)	(9.9)
Nakamura-Steinsson (18) IV	-12.2	-21.0
	(4.0)	(6.4)
Nakamura-Steinsson (18) IV, ex. 7/08-6/09	-24.1	-21.5
	(9.9)	(17.3)

State-dependent effects of MP

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Specification	$\Delta f_t^{(15)}$	$\Delta f_t^{(20)}$	30 minute change in dealer price
Baseline	-2.3	-2.9	13.8
	(1.2)	(1.4)	(7.5)
All FOMC announcements	-0.3	-2.2	2.5
	(1.6)	(1.9)	(8.7)
Excluding 7/08-6/09	-3.9	-5.9	53.9
	(2.7)	(5.2)	(24.4)
Excluding announcements with LSAP news	-1.4	-2.5	23.6
	(1.3)	(1.9)	(10.9)
Nakamura-Steinsson (18) IV	-6.3	-10.1	10.1
	(3.2)	(5.0)	(10.1)
Nakamura-Steinsson (18) IV, ex. 7/08-6/09	-6.2	-9.0	26.3
	(3.3)	(5.8)	(21.5)

Coefficients on $\Delta y_t^{(1)} \times incgap_t$ and $\Delta y_t^{(1)} \times incgap_{dt}$

State-dependent effects of MP

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	$\Delta f_t^{(15)}$	$\Delta f_t^{(20)}$	30 minute change in dealer price
Data	[-4.3,-0.4]	[-5.3,-0.5]	[1.5,25.1]
Model	-0.3	-0.4	24.9

Coefficients on $\Delta y_t^{(1)} \times incgap_t$ given MP shock

Cochrane-Piazzesi decomposition

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- 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

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

Forward curve and excess returns

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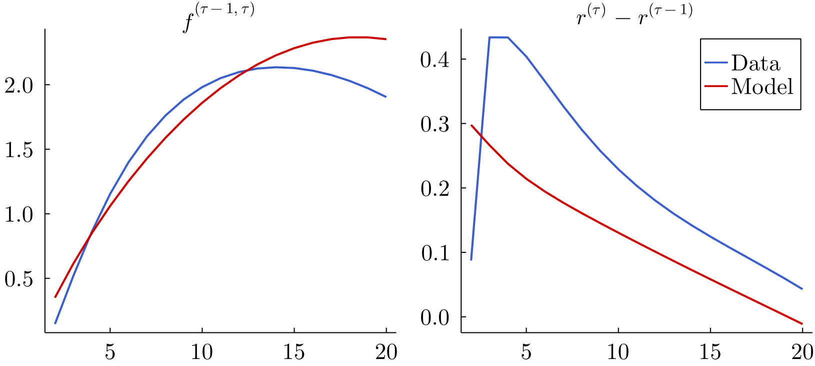

Decomposing forward rate response

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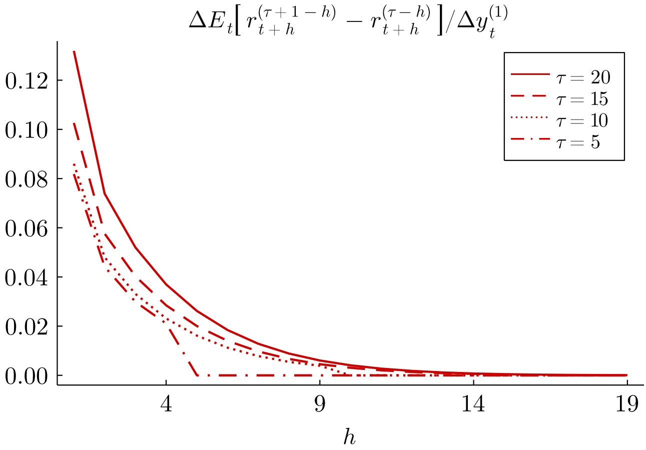

Effects of habitat demand shock

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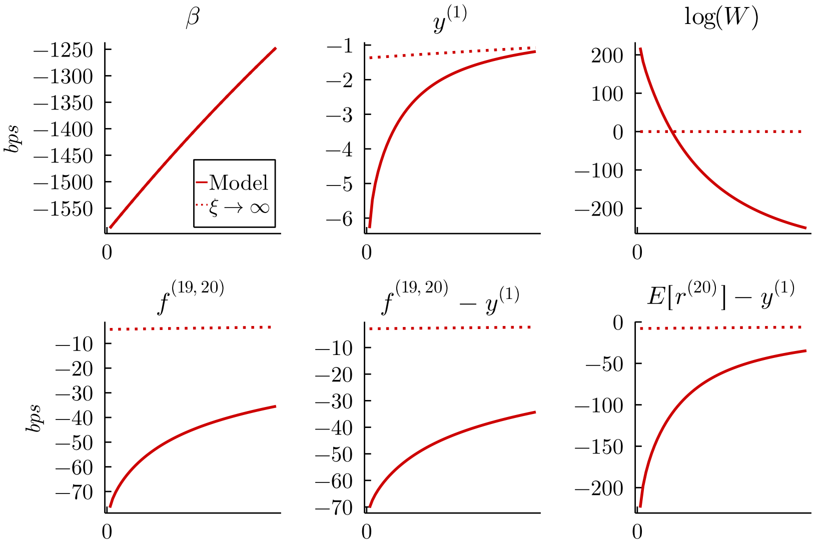

Effects of $\bar{r}$ shock

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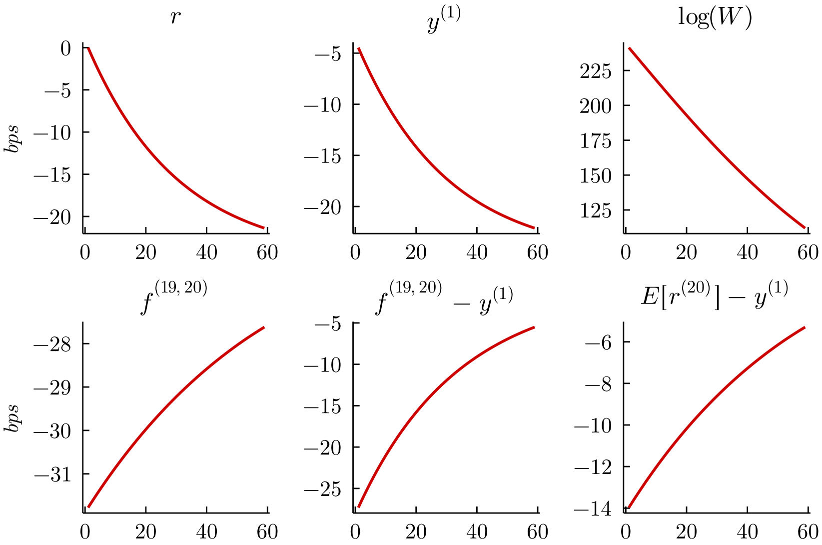

PDE

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

Wealth process

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

where

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

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

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

PDE when $\xi \to \infty$ Back

$$\left[P_{r,\,t}^{(\tau)}\kappa_r\left(\bar{r}-r_t\right)+P_{\beta,\,t}^{(\tau)}\kappa_\beta\left(\bar{\beta}-\beta_t\right)-P_{\tau,\,t}^{(\tau)}+\frac{1}{2}P_{rr,\,t}^{(\tau)}\sigma_r^2+\frac{1}{2}P_{\beta\beta,\,t}^{(\tau)}\sigma_\beta^2-r_tP_t^{(\tau)}\right]dt$$
$$= P_{r,\,t}^{(\tau)}\frac{1}{W_t}\sigma_r\int_0^\infty\left(\alpha(s)\log\left(P_t^{(s)}\right)+\theta_0(s)+\beta_t\theta_1(s)\right)\frac{1}{P_t^{(s)}}P_{r,\,t}^{(s)}\sigma_r ds$$
$$+P_{\beta,\,t}^{(\tau)}\frac{1}{W_t}\sigma_\beta\int_0^\infty\left(\alpha(s)\log\left(P_t^{(s)}\right)+\theta_0(s)+\beta_t\theta_1(s)\right)\frac{1}{P_t^{(s)}}P_{\beta,\,t}^{(s)}\sigma_\beta ds$$

with

$$dr_t=\kappa_r(\bar{r}-r_t)dt+\sigma_r dB_{r,t},$$
$$d\beta_t=-\kappa_\beta\beta_t dt+\sigma_\beta dB_{\beta,t}.$$