How much unspanned volatility can different shocks explain?

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Intro

Why should we care about *volatility* in the nominal US yield curve?

1. Hedging of interest-rate derivatives: huge, liquid market with many players;
2. Tightly linked to volatility of holding returns for bonds: portfolio allocation;
3. Risk management of large bond portfolios from institutional investors;

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Do we have good models for yield curve volatility? Yes and no:

- Workhorse: dynamic term structure models (very often affine ones);
- Tractable formulas for yields + arbitrage-free framework + convenient for estimation;
- Model-consistent separation between term premia and expected future short rates;

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- Tractable formulas for yields + arbitrage-free framework + convenient for estimation;
- Model-consistent separation between term premia and expected future short rates;
- Good cross-sectional fit of yields, usually poor time-series dynamics;
- In general: sharp restrictions of how yield curve data should behave;
- Important today: observed volatility in yields should be tightly connected to the cross-section of yields;

Can affine term structure models account for volatility in yields?

Mostly, no. In general, there is more variation than models allow. Some approaches:

- Regress returns from straddles on interest rate changes;
  - Collin-Dufresne & Goldstein (2002); Li & Zhao (2006)
- Regress changes of implied volatility from options/swaptions on interest rate changes;
  - Filipovic et al. (2017); Backwell (2021)
- Likelihood-ratio tests for conditions that connect yield volatility and in yield levels;
  - Bikbov & Chernov (2009)
- State-price density estimation from options data;
  - Li & Zhao (2009)
- Restrictions from high-frequency data that spanning should impose;
  - Andersen & Benzoni (2010)
  - Closest paper to mine, but we deal with jumps and different maturities very differently;

Any room for improvement?

- Jump-diffusion settings are not so common, but jumps are prevalent in bond markets (Piazzesi, 2010);
- What derivatives to use in an empirical test? Results seem dependent on this choice;
  - Swaptions? Caps and floors? Straddles?
  - At the money? Out of the money? In the money?
  - Liquidity and availability of strikes also depend on overall volatility itself...
- Analyses done at the individual maturity levels: too many degrees of freedom;
  - What maturities should we pay attention to?
  - Are any maturities systematically different than the others in any way?
- Crucially: attempts to tie "excessive" volatility to real-world developments are rare;
  - This is where the money is! Super important for derivative hedging!
  - What can explain this "unspanned" volatility? It's probably not just noise...

This project: two contributions

New methodology: a new test for excess volatility with a number of advantages;

- Implications for non-parametric measures of yield volatility within the affine framework;
- Only zero-coupon yields are needed - no need to use data from derivative markets;
- I explicitly allow for jumps and I can measure how “jumpy” yields are over time;
- I don’t analyze specific maturities, focus on a decomposition of the whole curve;
- Characterization of an *unspanned volatility* factor that explains 2/3 of the residual volatility DTSMs cannot account for;

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New empirical results: what can explain this unspanned volatility factor?

- I collect different shocks identified by the literature in monetary policy, fiscal policy, and oil shocks;
- Forward-guidance-type shocks, oil, and fiscal policy shocks help driving this factor;
- But they explain no more than $\approx 12\%$. There is still a lot to explain (and write about!).

Data

- Yield curve data: daily zero-coupon curve from Liu & Wu (2021), from 1973 to 2022;
  - I use maturities from 1 month to 10 years;
  - My methodology requires a balanced panel of yields;
- Monetary policy shocks from Swanson (2021) - monthly frequency;
  - Separation between Fed Funds rate surprises, forward-guidance shocks, and QE-type shocks;
- Oil shocks identified from Känzig (2021) - monthly frequency;
  - These are innovation to the real price of oil;
- Fiscal shocks from different sources - quarterly frequency:
  - Defense spending shocks from Ramey (2011) and Ramey & Zubairy (2018);
  - Tax policy shocks from Romer & Romer (2010);
  - Stock returns from top US government defense contractors Fisher & Peters (2010);

A Flexible Affine Setup

- There are N latent underlying risk factors X_t. The evolution under Q follows:

$$dX_t = K\left(\Theta - X_t\right)dt + \Sigma\sqrt{S_t}dW_t^Q + Z_t d\mathcal{N}_t^Q \tag{1}$$

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- K and Σ are $N \times N$ constant matrices; Θ is an $N \times 1$ vector of long-run means;
- S_t is an $N \times N$ diagonal matrix whose diagonal elements follow:

$$S_{t,[ii]} = s_{0,i} + s_{1,i}' X_t \tag{2}$$

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- $Z_t \sim \nu^Q$ represents a jump size, is independent of both W_t^Q and $\mathcal{N}_t^Q$, with $\mathbb{E}[Z_t Z'_t] = \Omega$;

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- The short rate r_t is given by: $r_t = \delta_0 + \delta'_1 X_t$;

Bond Prices and Bond Yields

- This setup ensures that zero-coupon yields $y_t^{(\tau)}$ are an affine function of state variables;
- If we trade J fixed maturities $(\tau_1, ..., \tau_J)$ we can write for some vector A and matrix B:

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- If B is full column rank (and it is for the US market - Bauer & Rudebusch (2017)):

$$X_t = (B'B)^{-1}B'(Y_t - A) = \tilde{A} + \tilde{B}Y_t \tag{4}$$

- This is a path-by-path condition: movements in yields should reveal movements in X_t;
- It connects the whole distribution of Y_t and X_t;

The Quadratic Variation Process

Definition 1 (Just a fancy variance!)

For a certain class of semimartingales M_t and given a partition $\{t_0 = t, t_1, ..., t_{n-1}, t_n = t+h\}$, we define its Quadratic Variation between t and $t+h$ as

$$QV_M(t, t+h) \equiv \operatorname*{p-lim}_{\delta_n \to 0} \sum_{k=1}^{n} \left(M_{t_k} - M_{t_{k-1}}\right)^2, \quad \delta_n \equiv \sup_{0 \le k \le n} \{t_k - t_{k-1}\} \tag{5}$$

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Proposition 1

For any linear combination of yields $L_t = c' Y_t$, its Quadratic Variation between t and $t+h$ is

$$QV_L(t, t+h) = \tilde{\gamma}_0 + \underbrace{\sum_{j=1}^{J} \tilde{\gamma}_{1,j} \cdot \overline{y}^{(\tau_j)}(t, t+h)}_{\text{Should be spanned by average yields}} + \underbrace{\sum_{k=1}^{\mathcal{N}_{t+h} - \mathcal{N}_t} v' Z_{T_k(t,t+h)} Z'_{T_k(t,t+h)} v}_{\text{No requirement to span the jump-only part!}} \tag{6}$$

where $\overline{y}^{(\tau_j)}(t, t+h) \equiv \frac{1}{h} \int_t^{t+h} y_s^{(\tau_j)} ds$, $\{\tilde{\gamma}_0, \tilde{\gamma}_1\}$ and v depend on parameters;

Identification

- Measuring the QV of stochastic process is usually easy: Realized Variance!
- But here it would incorporate the diffusive (spanned) part and the jump-driven part;
- Can we tease out the diffusive part from the jumps? Yes: Bipower Variation!

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Definition 2 (Barndorff-Nielsen & Shephard (2004, 2006))

For a real-valued process M_t, we define the Bipower Variation process over $[t, t+h]$ as:

$$BPV_M(t, t+h) \equiv \operatorname*{p-lim}_{n \to \infty} \sum_{i=2}^{n} \left| M_{t+i\cdot\frac{h}{n}} - M_{t+(i-1)\cdot\frac{h}{n}} \right| \left| M_{t+(i-1)\cdot\frac{h}{n}} - M_{t+(i-2)\cdot\frac{h}{n}} \right| \tag{7}$$

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Proposition 2

Under this setup, the Bipower Variation of L_t identifies the diffusive part of the QV:

$$BPV_L(t, t+h) = \frac{2}{\pi} \cdot \left[\tilde{\gamma}_0 + \sum_{j=1}^{J} \tilde{\gamma}_{1,j} \cdot \overline{y}^{(\tau_j)}(t, t+h) \right] \tag{8}$$

A Test of Unspanned Volatility

- This condition can be tested:
  - We can approximate both the LHS and RHS;
  - I use daily data to compute these measures at the *monthly* frequency;
- Regressing bipower variation measures on average yields should yield significant coefficients + high R^2;

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But why to focus on linear combinations of yields?...

- US yield curve admits a low-rank representation (Litterman & Scheinkman (1991));
- A common decomposition is the one from Nelson & Siegel (1987);
- Three factors: a long-run factor β_1, a short-run factor β_2, and a medium-run factor β_3;
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SPOILER ALERT: yes.

The Nelson-Siegel Representation

- $y_t^{(\tau)}$: zero-coupon rate at time t and maturity τ;
- $\lambda > 0$: a positive decay parameter;

$$y_t^{(\tau)} = \beta_{1,t} + \beta_{2,t}\left(\frac{1-e^{-\lambda\tau}}{\lambda\tau}\right) + \beta_{3,t}\left(\frac{1-e^{-\lambda\tau}}{\lambda\tau} - e^{-\lambda\tau}\right) \tag{9}$$

- β_1 is a long-run factor: $\lim_{\tau\to\infty} y_t^{(\tau)} = \beta_{1,t}$;
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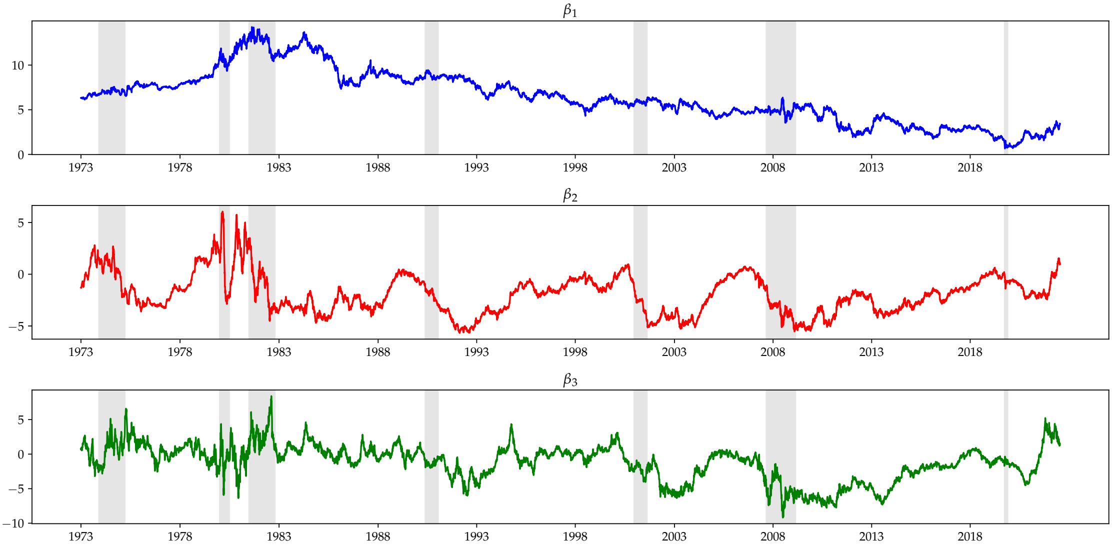
- β_2 is a short-run factor: its absolute loading decreases with τ;
- β_3 is a medium-run factor: its loading is hump-shaped;
- We set $\lambda = 0.0609$ and estimate the model by OLS date by date with $1 \leq \tau \leq 120$;
- Other estimation procedures? NLS, Recursive decay fitting, Kalman Filter...
- Hard to beat OLS in terms of stability of estimates (no numerical methods needed);
- Diebold & Rudebusch (2013) and Freire & Riva (2023) study these in detail;

How to estimate this???

Daily Factors

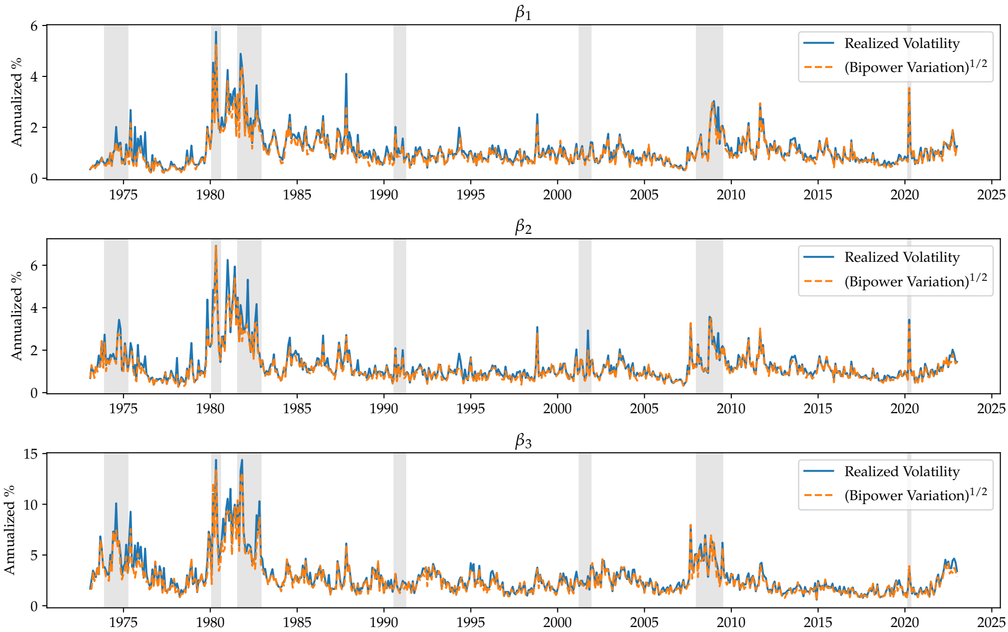


Average daily fitting error over maturities ≈ 5bps;

Fitting error

Variation Measures

Covariances



Running the Test

- If spanning holds, diffusive variation should be an affine function of average yields;
- BPV_i: bipower variation of factor $i \in \{1, 2, 3\}$;
- $BPCov_{i,j}$: bipower covariation between factor i and j;
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(Don't worry! Robustness checks in the paper!)

Test - Full Sample (1973-2022)

Table: Full Sample (1973-2022)

	BPV_1	BPV_2	BPV_3	$BPCov_{21}$	$BPCov_{31}$	$BPCov_{32}$
Average β_1	0.341***	0.561***	2.897***	-0.141**	-0.562**	0.136
	(0.112)	(0.175)	(0.863)	(0.065)	(0.220)	(0.099)
Average β_2	0.340*	0.874***	3.770***	-0.152	-0.639**	0.038
	(0.174)	(0.318)	(1.382)	(0.106)	(0.303)	(0.100)
Average β_3	-0.248**	-0.537***	-1.679*	0.194**	0.253	0.028
	(0.116)	(0.206)	(0.880)	(0.076)	(0.168)	(0.078)
N	600	600	600	600	600	600
R^2	0.18	0.31	0.27	0.08	0.18	0.02

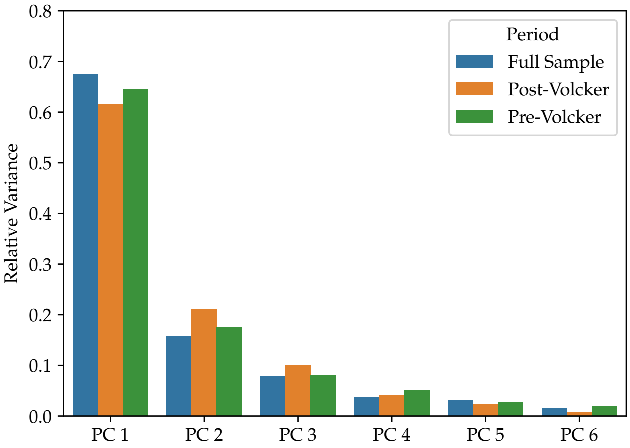
Test - Post-Volcker Sample

Table: Post-Volcker Sample (September, 1987 - December, 2022)

	BPV_1	BPV_2	BPV_3	$BPCov_{21}$	$BPCov_{31}$	$BPCov_{32}$
Average β_1	-0.026	-0.006	0.364	0.059	0.015	-0.044
	(0.044)	(0.051)	(0.296)	(0.038)	(0.055)	(0.055)
Average β_2	-0.054	-0.026	-0.558	0.077	-0.037	0.001
	(0.069)	(0.084)	(0.516)	(0.060)	(0.103)	(0.123)
Average β_3	-0.100	-0.145	-0.206	0.106	0.119	-0.069
	(0.082)	(0.090)	(0.517)	(0.071)	(0.105)	(0.083)
N	424	424	424	424	424	424
R^2	0.07	0.08	0.06	0.13	0.02	0.01

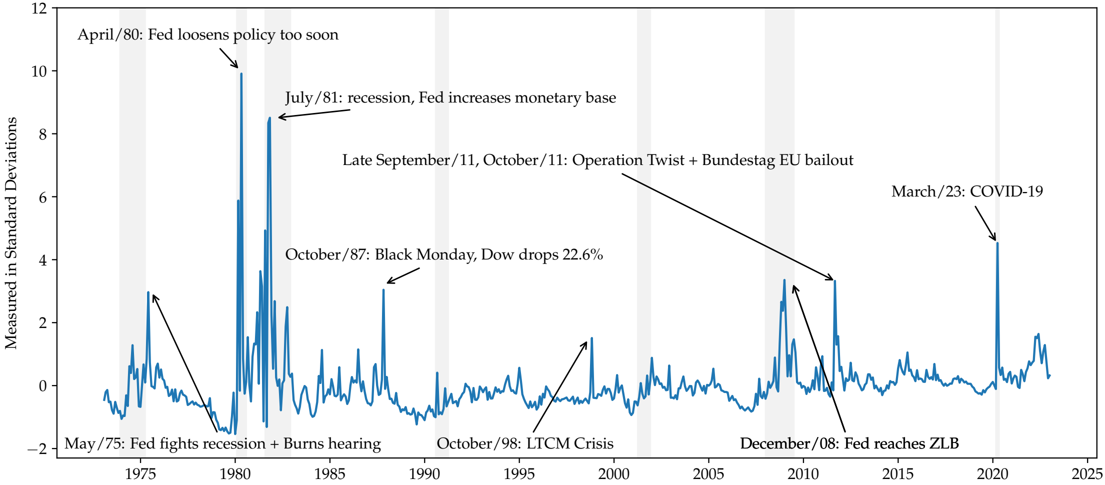
Is everything just noise?

Figure: Spectral decomposition of residuals



- The first principal component of residuals commands 2/3 of the unexplained variation;
- If the failure of the previous tests were due to pure noise, we wouldn't see such a dominant factor;

How does this factor look like?



- Realizations are skewed, spiking up during recessions and major events;
- It's hard to make the case this is pure noise;

What can explain this factor?

- Much of the yield curve volatility is not accounted by affine term structure models;
- Spikes in the unspanned volatility seem related to monetary policy;
- How much of this factor can monetary policy explain?

$$USV_t = \alpha + \theta \cdot |\text{Shock}_t| + u_t \tag{12}$$

- Three types of monetary policy shocks from Swanson (2021);
  - Pure Fed Funds rate surprise, a forward-guidance shock, and a QE-type shock;
  - Identified using Fed Funds + Eurodollar futures (1991-2019);

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  - Identified using Fed Funds + Eurodollar futures (1991-2019);
- What about oil price shocks? $\uparrow$ inflation, $\uparrow$ inflation expectations (Känzig, 2021);
  - Monthly frequency, identified with daily oil futures prices (1975-2022);
- This is about the US sovereign debt... can fiscal policy help explaining volatility? (Fisher & Peters, 2010; Romer & Romer, 2010; Ramey, 2011; Ramey & Zubairy, 2018);

Monetary Policy

	First PC of Residuals				Second PC of Residuals			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
FFR	0.10		0.04		0.16*		0.15	
	(0.10)		(0.09)		(0.09)		(0.09)	
FG		0.17**	0.16**	0.30*		0.09	0.04	-0.03
		(0.08)	(0.07)	(0.17)		(0.07)	(0.07)	(0.18)
LSAP				-0.05				0.02
				(0.09)				(0.07)
Sample	1991-2019			2009-2016	1991-2019			2009-2016
N	336	336	336	96	336	336	336	96
R^2	0.01	0.03	0.03	0.08	0.03	0.01	0.03	0.00

- 1 sd of FG $\approx \uparrow$ 6 bps on future Fed Funds 1 year ahead; Shocks Time Series
- Back of envelope: 25 bps worth of FG $\approx \uparrow$ 0.64 standard deviations in unspanned vol;

How Jumpy Are The Factors?

- How much variation is coming from the diffusive part? How much from the jumps?
- Surprisingly stable over factors and over time!

$$JV_i(t) \equiv \max\{RCov_{ii}(t) - BPV_i(t), 0\}, \qquad JR_i(t) \equiv \frac{JV_i(t)}{RCov_{ii}(t)} \tag{13}$$

Table: Average jumpiness of Nelson-Siegel factors

	JR_1	JR_2	JR_3
Whole Sample (1973-2022)	0.172	0.158	0.170
No FOMC Meeting	0.146	0.145	0.161
FOMC Meeting	0.150	0.149	0.157
p-value	0.799	0.808	0.812

Oil Price Shocks + Monetary Policy

Table: Projecting Jump-Robust Unspanned Vol

	(1)	(2)	(3)	(4)
Oil Shock	0.42***	0.43**	0.43**	0.43**
	(0.15)	(0.18)	(0.18)	(0.18)
FFR		0.05		0.02
		(0.06)		(0.05)
FG			0.11**	0.10**
			(0.05)	(0.05)
Sample	1975-2022	1991-2019		
N	576	336	336	336
R^2	0.02	0.09	0.12	0.13

- 20% oil price increase $\approx \uparrow 0.42$ standard deviations of USV;
- Oil price shock identified through an external instrument - futures price changes around OPEC meetings
- Oil shock + monetary policy explain at most 13% of the unspanned volatility factor;

Oil Shock Time Series

Fiscal Policy

Table: Projecting Unspanned Vol on Fiscal Policy Shocks

	(1)	(2)	(3)	(4)
Tax Changes	0.67*			0.70*
(Romer & Romer, 2010)	(0.39)			(0.39)
Defense Spending Shocks		0.04		-0.01
(Ramey & Zubairy, 2018)		(0.07)		(0.08)
Defense Contractors Returns			0.03*	0.02
(Fisher & Peters, 2010)			(0.02)	(0.02)
End of sample (quarterly data)	2007	2015	2008	2007
N	140	172	144	140
R^2	0.02	0.00	0.02	0.04

- A tax change worth 1% of GDP $\implies \uparrow$ 0.7 standard deviations of USV; Shocks Time Series

Wrap Up

Main takeaways:

- I provide a jump-robust test for the presence of unspanned volatlity;
- I show that there is unspanned volatility steaming from the entire maturity spectrum;
- Unspanned volatility can be characterized by a single factor, which I formally characterize;
- This factor is partially driven by monetary policy, fiscal policy, and oil shocks;
- Still a lot to explain!

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- Allow for more general dynamics between the unspanned vol factor and shocks? VARs?
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Thank you!

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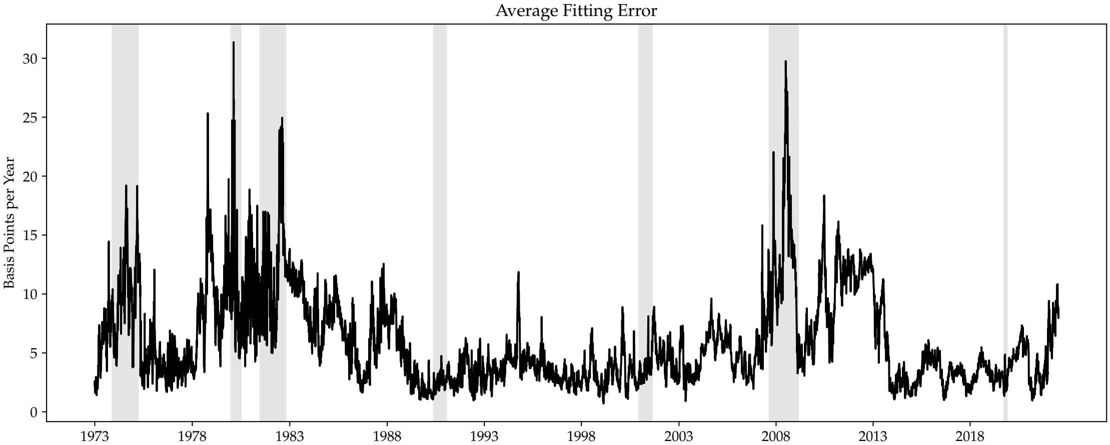
Thank you! (I'll be on the job market this year... got a spot for me? Let me know!)

Appendix

Figures

Fitting Error



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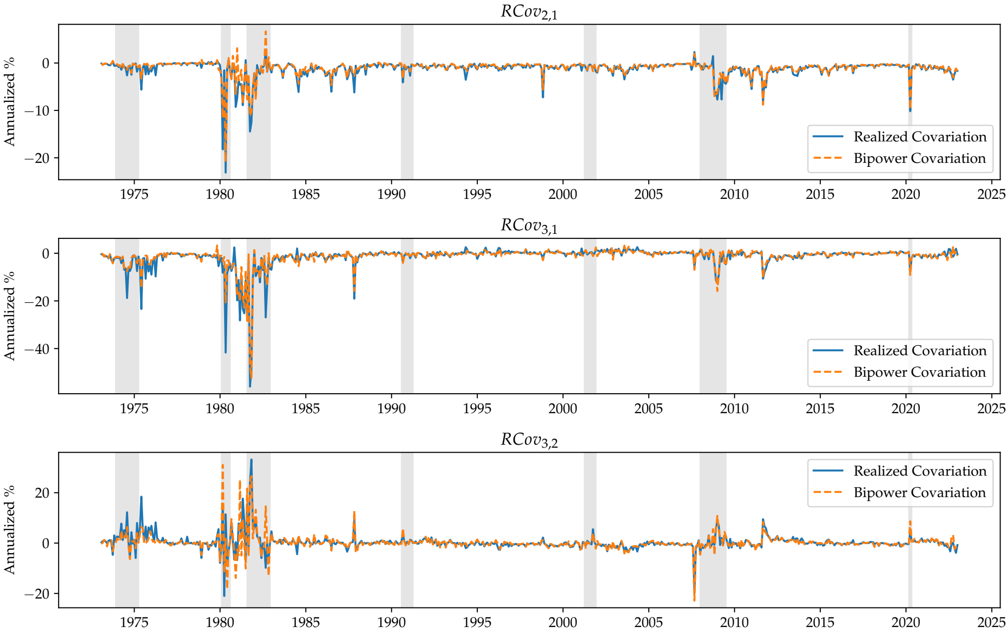
Realized Covariances



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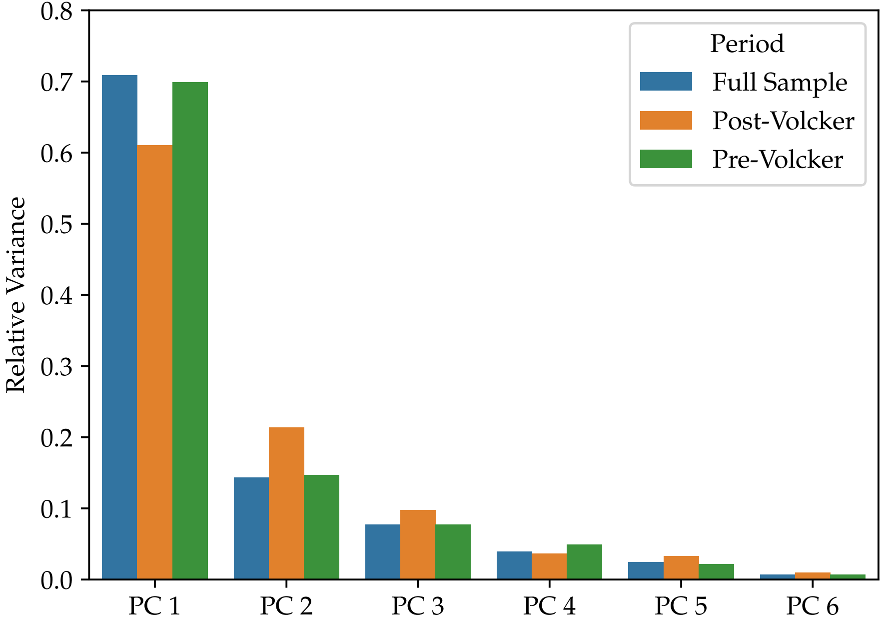
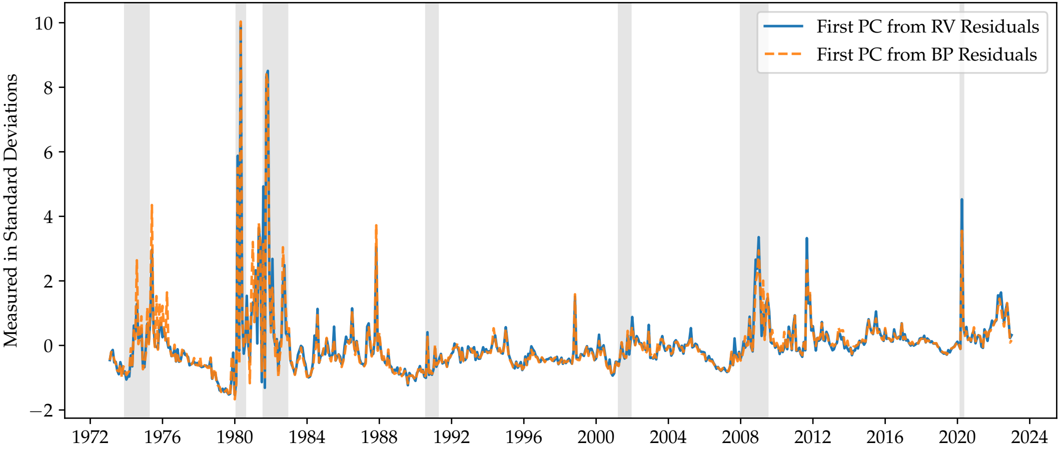
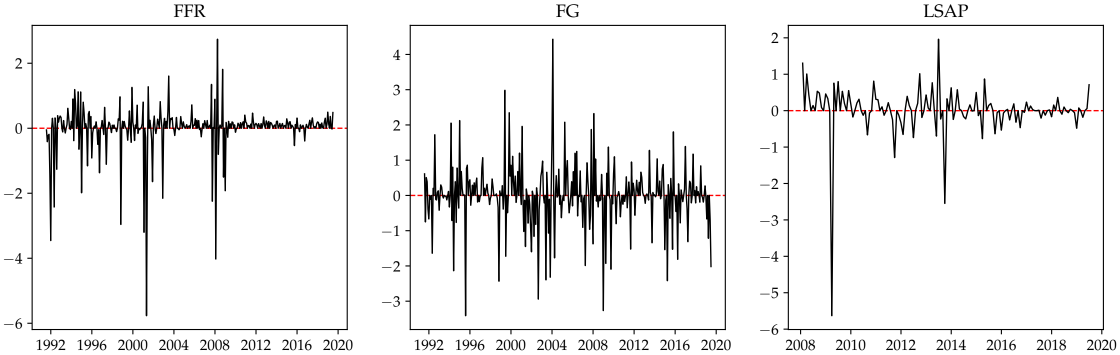
Spectral Decomposition of RV Residuals



Unspanned Factors: RV vs BP



Monetary Policy Shocks from Swanson (2021)



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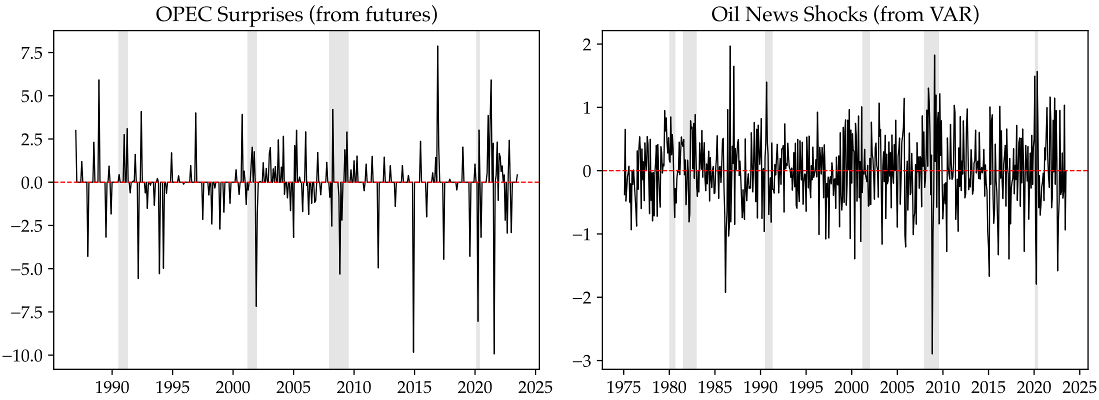
Oil Shocks from Känzig (2021)



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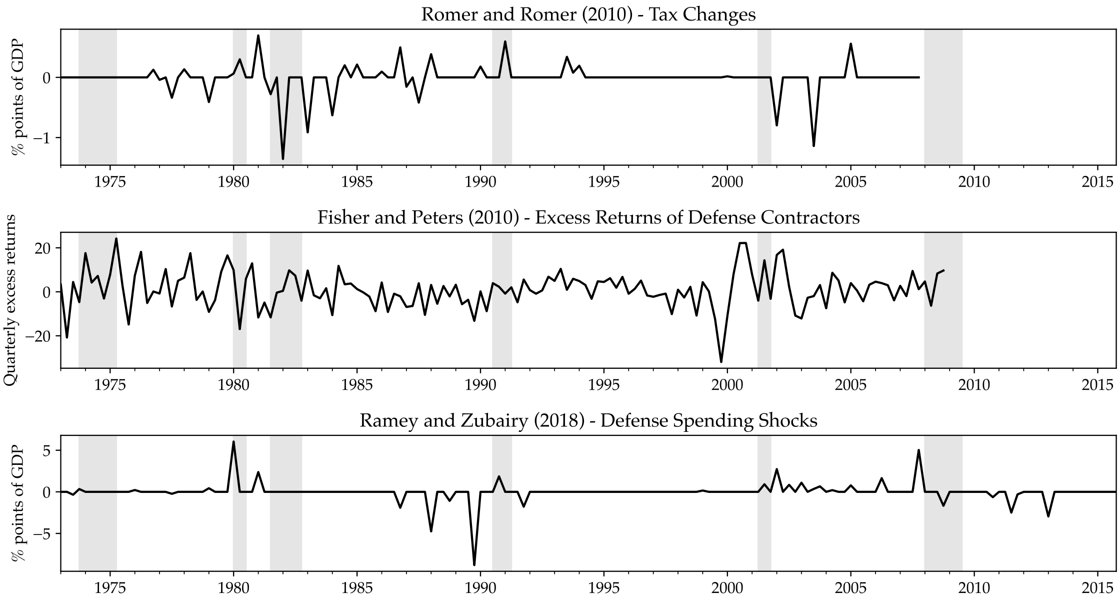
Fiscal Shocks



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Math and Tables

Estimating Nelson-Siegel Factors with OLS

- We estimate the factors using OLS: regress yields on coefficients;
- $\lambda > 0$ is fixed;
- No need of numerical solutions!

$$\begin{bmatrix} \widehat{\beta}_{1,t} \\ \widehat{\beta}_{2,t} \\ \widehat{\beta}_{3,t} \end{bmatrix} = \left(M'M\right)^{-1} M'Y_t, \qquad M \equiv \begin{bmatrix} 1 & \frac{1-e^{-\lambda\tau_1}}{\lambda\tau_1} & \frac{1-e^{\lambda\tau_1}}{\lambda\tau_1} - e^{-\lambda\tau_1} \\ 1 & \frac{1-e^{-\lambda\tau_2}}{\lambda\tau_2} & \frac{1-e^{\lambda\tau_2}}{\lambda\tau_2} - e^{-\lambda\tau_2} \\ \vdots & \vdots & \vdots \\ 1 & \frac{1-e^{-\lambda\tau_J}}{\lambda\tau_J} & \frac{1-e^{\lambda\tau_J}}{\lambda\tau_J} - e^{-\lambda\tau_J} \end{bmatrix}.$$

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