Business Cycle Anatomy

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Motivation and Contribution

"One is led by the facts to conclude that, with respect to the qualitative behavior of co-movements among series, business cycles are all alike. To theoretically inclined economists, this conclusion should be attractive and challenging, for it suggests the possibility of a unified explanation of business cycles." *(Lucas 1977)*

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  i.e., multiple triggers but a dominant propagation mechanism

- This paper's contribution: provide an empirical template of it

What We Do

- Estimate a VAR (or VECM) on a few key variables
- Recover shock that has max contribution to volatility of U over BC frequencies
- Repeat exercise by targeting other variables (e.g., TFP) or other frequencies (e.g, LR)

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$\Longrightarrow$ "**Business Cycle Anatomy**" = large collection of one-dimensional cuts of the data

= rich set of restrictions on models of any size and type

Main Findings and their Use

- Establish existence of a "main business cycle (MBC) shock"
    - shocks that target u, Y, h, I, and C over BC frequencies produce similar IRFs
    - supports hypothesis of common propagation mechanism
- Document its properties
    - transitory
    - disconnected from TFP at all horizons
    - orthogonal to shock that targets inflation
    - ...
- Use its properties and overall anatomy to guide theory
    - parsimonious, semi-structural perspective
    - fully structural DSGE models

Lessons for Theory

- Good news for parsimonious theories with a dominant shock/propagation mechanism
- Bad news for the following candidates
  - technology shocks

    RBC model
  - financial, uncertainty, or other shocks that map to TFP fluctuations

    Benhabib and Farmer (1992), Bloom et al (2016)
  - news about future TFP

    Beaudry and Portier (2006), Lorenzoni (2009)
  - inflationary demand shocks of the textbook type
  - propagation mechanisms in state-of-the-art DSGE models

    Smets & Wouters, Justiniano, Primiceri & Tambalott, Christiano, Motto & Rostagno

Lessons for Theory

- What fits the MBC template best?
- Non-inflationary, non-specialized, demand shocks
- Perhaps they exist (even) outside realm of sticky prices and Philips curves?

  example: our earlier Ecma paper (ACD 2018)

  Bai, Ros-Rull & Storesletten (2017), Beaudry & Portier (2018), Benhabib, Wang & Wen (2015), Huo & Takayama (2015), Ilut & Saijo (2018); older literature on coordination failures

Outline

- Empirical Analysis
- Main Findings and Lessons
- Application to Three DSGE Models

Empirical Analysis

Baseline VAR

- Quarterly U.S data: 1955Q1-2017Q4
  - Macro Quantities: Unemployment, GDP, Hours, Invest. (inclusive of durables), Cons.
  - Productivity: util-adjust TFP, NFB labor productivity;
  - Nominal: Inflation (GDP Delator), Federal Fund Rate, Labor Share
- Bayesian VAR, 2 Lags (robust to 4 or 6 lags and VECM)

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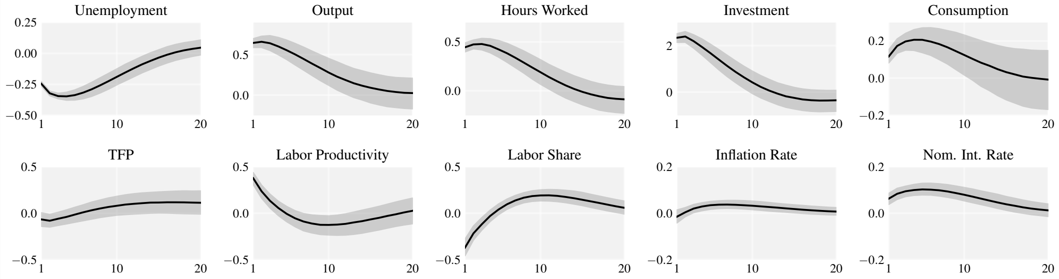
  - Productivity: util-adjust TFP, NFB labor productivity;
  - Nominal: Inflation (GDP Delator), Federal Fund Rate, Labor Share
- Bayesian VAR, 2 Lags (robust to 4 or 6 lags and VECM)
- What next? Construct the "shock to variable X"

  Linear combination of the VAR residuals that has the maximal contribution to the volatility of a variable X at the business-cycle frequencies, 6-32 quarters.

Technicalities

Main Business Cycle Shock: Targeting Unemployment

Impulse Response Functions

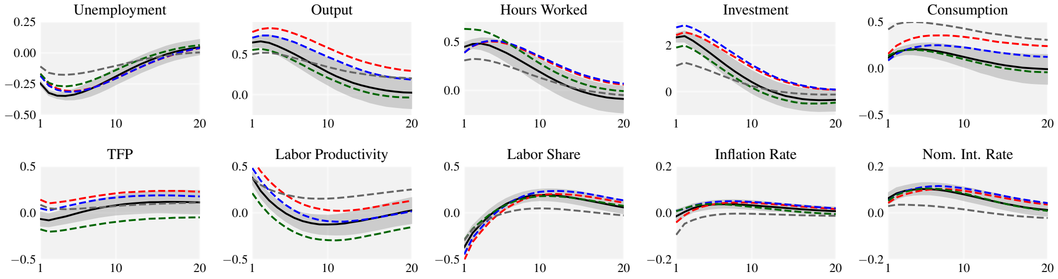


Variance Contributions, Business-Cycle Frequencies

u	Y	h	I	C	TFP	Y/h	Wh/Y	π	R
73.71	58.51	47.72	62.09	20.38	5.86	23.91	27.02	6.96	22.27

Main Business Cycle Shock: Alternative Targets

Interchangeable facets of the same shock!

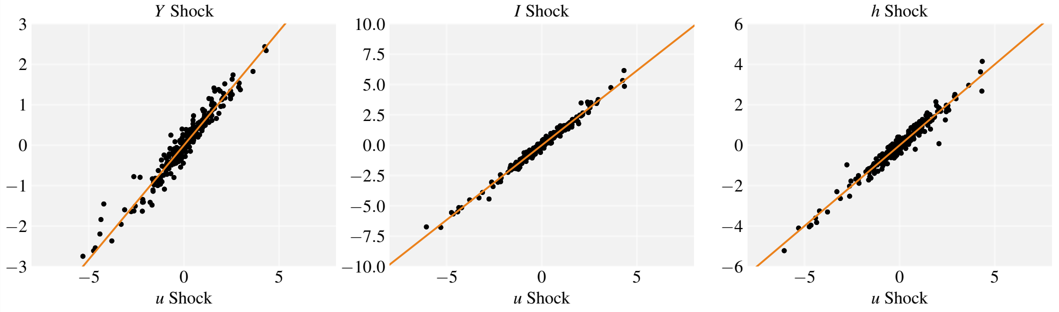


u shock; Y shock; I shock; h shock; C shock; Shaded area: 68% HPDI.

Main Business Cycle Shock: Alternative Targets

	u	Y	h	I	C	TFP	Y/h	Wh/Y	π	R
u	73.71	58.51	47.72	62.09	20.38	5.86	23.91	27.02	6.96	22.27
Y	56.24	80.13	44.73	67.13	33.03	4.24	41.31	40.20	10.47	16.89
h	49.84	47.54	70.45	47.99	21.78	11.62	22.61	19.47	7.23	22.38
I	59.03	66.60	45.20	80.29	19.01	3.81	33.74	36.44	7.69	21.51
C	19.19	31.59	20.15	17.10	68.30	1.57	12.93	10.31	9.93	4.50

The Main Business Cycle Shock: Alternative Targets



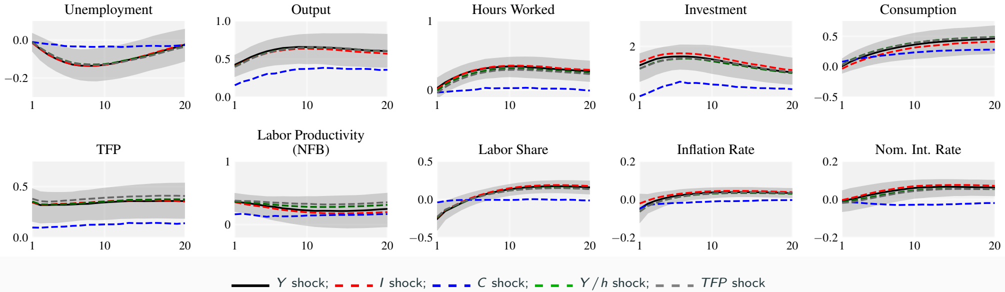
PCA on Business Cycle Frequencies

First Principal Component, Business Cycle Frequencies

	u	Y	h	I	C	TFP	Y/h	wh/Y	π	R
Raw Data	75.33	92.26	81.24	99.80	60.19	6.10	17.73	3.02	2.33	12.27
VAR-Based	63.31	87.33	62.47	99.72	26.67	1.22	29.19	14.16	0.68	8.10

- Similar message about variance contributions: MBC $\approx$ 1st PC
- But our approach adds info about (i) IRFs and (ii) footprint on other frequencies

The Main Long-Run Shock

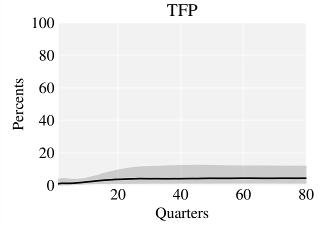


Target	Y	I	C	TFP	Y/h
Y	99.59	95.94	99.47	95.66	97.82
I	96.88	97.83	96.41	91.62	93.02
C	99.34	95.63	99.53	95.39	97.59
TFP	97.39	92.55	97.40	98.43	98.46
Y/h	98.52	93.36	98.67	97.70	99.25

Disconnect Between the Short Run and the Long Run

	u	Y	h	I	C	TFP	Y/h
MBC shock $\rightarrow$ Long Run	20.83	4.64	5.45	5.16	4.13	4.09	3.88
LR TFP shock $\rightarrow$ Short Run	9.63	24.78	11.01	17.56	15.58	22.01	21.89

MBC shock $\rightarrow$ TFP at different horizons



MBC Shock: Main Properties and Prelim Lessons

- Explains bulk of BC volatility in key quantities
- Realistic business cycle, with u, h, Y, I, C moving in tandem
- Interchangeability: same IRFs regardless of target
  - support for parsimonious theories
- ≈ 0 comovement with TFP at BC frequencies
  - rules out technology and financial, uncertainty or other shocks that map to TFP fluctuations
- ≈ 0 footprint on the Long Run (and conversely LR has small footprint on BC)
  - echoes Blanchard & Quad (1989), Gal (1999)
  - hard to reconcile with Beaudry & Portier (2006)
- Disconnect from inflation (coming soon)

More on News Shocks: a Semi-structural Exercise

- Could it be that disconnect between SR and LR reflects offsetting effects of (i) expansionary news shocks and (ii) contractionary unanticipated shocks?
- Semi-structural exercise using our anatomy:
  recover these two shocks from reduced-form shocks that drive TFP in SR and LR
- Explore sensitivity to VAR size

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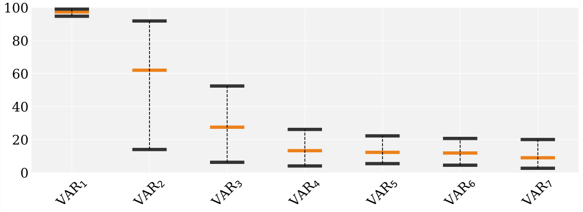
Variance Contribution of News Shock to Unemployment



$\text{VAR}_1 = \{u, \text{TFP}\}$, $\text{VAR}_2 = \text{VAR}_1 \cup \{I\}$, $\text{VAR}_3 = \text{VAR}_2 \cup \{Y, C, h\}$, $\text{VAR}_4 = \text{Baseline VAR}$,
$\text{VAR}_5 = \text{VAR}_4 \cup \{SP500\}$, $\text{VAR}_6 = \text{VAR}_5 \cup \{\text{utilization}\}$, $\text{VAR}_7 = \text{VAR}_6 \cup \{\text{credit spread}\}$.

MBC Shock: Robustness

Robust to

- More lags, VECM
- Varying the sample: Post vs Pre-Volcker era, w/o Great Recession/ZLB ...
- Adding variables: SP, $P^{\mathrm{I}}/P^{\mathrm{C}}$, financial variables ...
- ...
- Shifting to time domain rather than frequency domain

MBC Shock: Robustness

Short-Run Variance Contributions

	u	Y	h	I	C	TFP	Y/h	Wh/Y	π	R
[1] Benchmark	73.71	58.51	47.72	62.09	20.38	5.86	23.91	27.02	6.96	22.27
[2] 4 lags	74.49	58.23	49.16	62.42	21.20	6.28	23.10	27.87	6.91	24.75
[3] VECM(1)	62.43	50.27	48.81	53.39	34.88	18.13	23.80	24.11	10.46	33.37
[4] VECM(2)	64.85	54.99	48.82	53.78	44.93	12.17	19.51	29.71	11.29	19.51
[5] 1948-2017	78.98	65.32	49.61	63.76	19.52	6.14	26.53	29.62	5.16	16.94
[6] 1960-2007	68.15	59.93	55.99	65.02	20.67	6.02	25.04	29.96	10.70	27.03
[7] pre-Volcker	74.23	56.75	43.21	61.50	23.43	6.82	30.69	28.43	17.45	27.60
[8] post-Volcker	73.39	50.37	50.65	58.44	20.23	7.94	18.46	23.01	4.65	15.05
[9] Extended	59.33	50.61	45.50	52.91	21.83	4.81	26.69	27.82	12.12	28.99
[10] Financial	68.57	57.56	46.84	59.95	25.94	7.04	27.20	26.86	8.42	26.59
[11] Chained-Type C&I	81.41	59.04	45.96	61.52	17.36	4.03	20.35	20.19	5.82	23.17

MBC Shock: Robustness

Long-Run Variance Contributions

	u	Y	h	I	C	TFP	Y/h	Wh/Y	π	R
[1] Benchmark	20.83	4.64	5.45	5.16	4.13	4.09	3.88	3.12	5.77	9.12
[2] 4 lags	18.22	4.39	5.19	4.94	3.98	3.66	3.67	2.93	5.44	9.81
[3] VECM(1)	12.97	14.07	8.06	14.07	14.07	14.07	14.07	13.91	7.50	13.82
[4] VECM(2)	23.29	16.70	9.22	16.70	16.70	16.70	16.70	10.55	8.66	8.66
[5] 1948-2017	31.82	7.44	4.43	7.80	6.66	7.20	6.72	4.85	3.37	4.91
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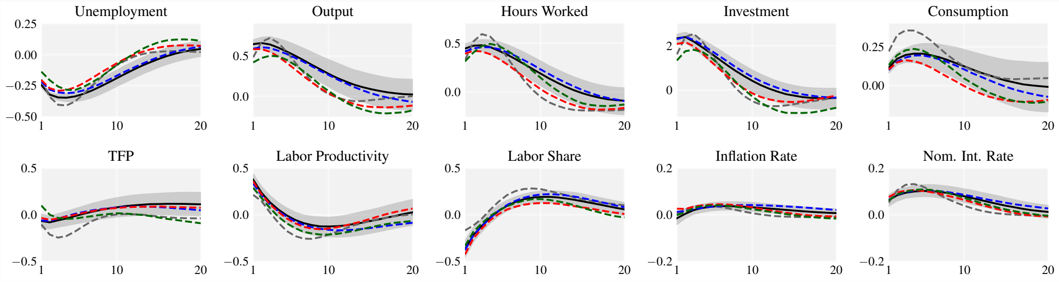
MBC Shock: Robustness

Robustness of IRFs



Baseline; VECM$_1$; 1960-2007; Extended; Financial

MBC as a Demand Shock along a Philips curve?

Challenge #1: tiny signal-to-noise ratio (negligible R^2)

Target	u	π	Wh/Y
Unemployment	73.71	6.96	27.02
Inflation	4.24	83.03	1.96
Labor Share	26.01	4.03	85.59

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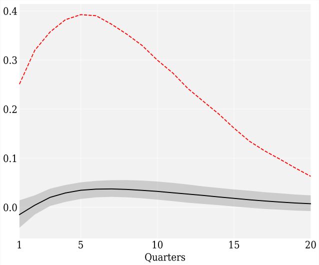
Challenge #2: magnitude



Actual inflation response; Predicted, textbook NKPC.

Bottom Line So Far

- Supports parsimonious models with dominant shock/propagation mechanism
- Rules out following candidates for that role
    - technology shocks
    - financial, uncertainty, or other shocks that map to TFP fluctuations
    - news about future TFP
    - inflationary demand shocks of textbook variety
- Remaining possibilities
    - demand shocks of DSGE variety (extremely flat Philips curve)
    - demand shocks without sticky prices/Philips curves
    - ...

Evaluating DSGE Models

Evaluating Two DSGE Models

- JPT (Justiniano, Primiceri & Tambalotti, 2010)
  - Same as CEE, SW (but estimation more suitable for our purposes)
  - Sticky prices, Sticky wages, Monetary Policy
  - Standard Bells and Whistles (Habit, Invt Adj Costs, Utilization)
  - Multiple shocks (but I shock is most important)

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- ACD (Angeletos, Collard & Dellas, 2018)
  - RBC with variation in "confidence"
  - waves of optimism and pessimism about SR economic outlook
  - example of literature on demand shocks without sticky prices/Philips curves

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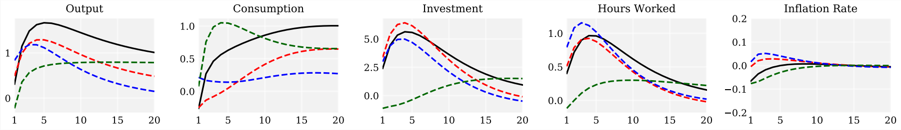
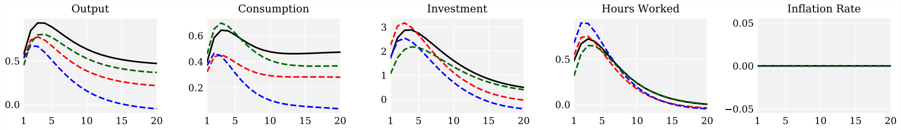
  - waves of optimism and pessimism about SR economic outlook
  - example of literature on demand shocks without sticky prices/Philips curves
- Q: Do these models match MBC template form the data?
- A: Only second meets interchangeability property

JPT vs ACD: Interchangeability of MBC Facets

JPT



ACD



—— Y factor; - - - - I factor; - - - - h factor; - - - - C factor.

Note: "factors" refer to reduced-form shocks recovered via our approach, "shocks" to theoretical shocks.

MBC facets interchangeable in ACD model (as in data), less so in JPT
$\Longrightarrow$ JPT/CEE/SW lacks the "right" propagation mechanism

JPT and ACD: Interchangeability of MBC Facets

- Measure of Interchangeability: $D_v = \frac{1}{4} \sum_{f \in F} \sqrt{\sum_{k=0}^{20} (Z^f_{v,k} - \overline{Z}_{v,k})^2}$
- Smaller numbers mean more interchangeability

	Y	C	I	h	Average
Data	0.47	0.52	1.28	0.28	0.64
JPT	2.90	2.21	6.29	1.35	3.19
ACD	0.64	0.56	1.56	0.22	0.75

- Ranking robust to re-estimating both models on the basis of our factors

JPT and ACD: Mapping Factors to Shocks

Contribution of Theoretical Shocks to Factors

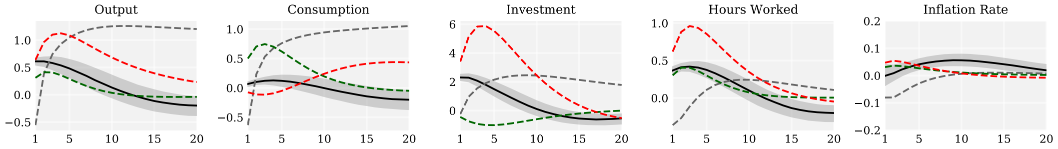
	JPT				ACD	
Factor	A shock	I shock	C shock	other	confidence	other
Y	31%	66%	1%	2%	88%	12%
I	0%	99%	0%	1%	80%	20%
C	33%	1%	65%	1%	93%	7%
h	0%	96%	2%	2%	99%	1%

In JPT, "A shock" a permanent technology shock, "I shock" a transitory investment-specific demand shock, "C shock" a transitory discount-factor; "other" include monetary policy, price, wage markup shocks. In ACD, "beliefs" a transitory shock to higher-order beliefs; "other" include both transitory and permanent technology shocks, news shocks, and I and C shocks of JPT

- JPT and many other DSGE models: specialized shocks $\Rightarrow$ poor interchangeability
- ACD: "shotgun" shock $\Rightarrow$ great interchangeability

JPT and ACD: Theoretical Shocks vs MBC in Data

JPT: A, I, and C shocks

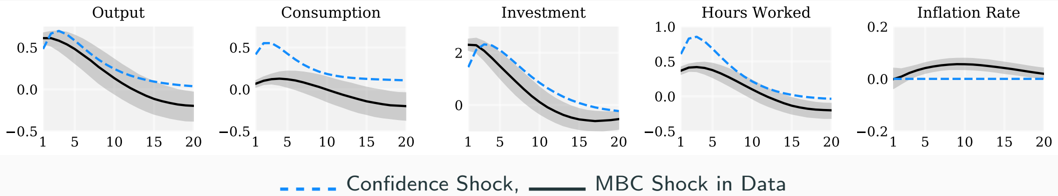


- - - - Technology Shock - - - - Investment Shock - - - - Consumption Shock —— MBC Shock in Data

$\Longrightarrow$ JPT (and many other models): **No** individual shock resembles the MBC shock in the data;

JPT and ACD: Theoretical Shocks vs MBC in Data

ACD: Confidence Shock

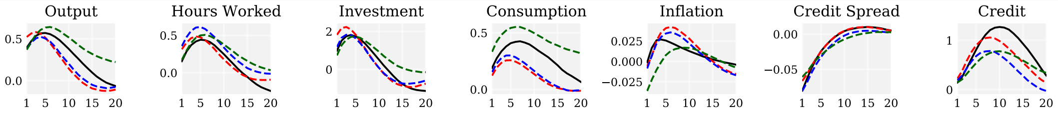


$\Longrightarrow$ ACD: the confidence shock **does**

- needless to say, this doesn't mean that ours is the "right" model
- but illustrates what the current paradigm misses and what it takes to match MBC template

Bonus: Christiano, Motto & Rostagno (2014)

(a) Data (1985-2011)



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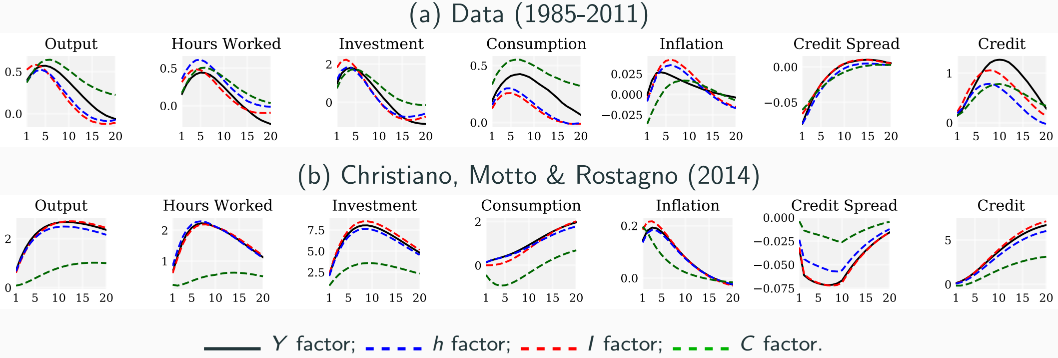

- Interchangeability: great in terms of Y, h, I, worse in terms of C
- Real-financial nexus: misses dynamics of credit spread and credit level

Summary

- Simple and flexible method for dissecting the macroeconomic dynamics
- Supports hypothesis of dominant propagation mechanism
- Provides an empirical template for it $\Rightarrow$ looks like a non-inflationary AD shock
- Detects defects in propagation dynamics of DSGE models fitted to the data
- Perhaps resolution rests on accommodating demand-driven cycles even without sticky prices

Business-Cycle Moments

	Data	Experiment 1	Experiment 2
st.dev(y_t)	1.41	1.39	1.01
st.dev(π_t)	0.21	0.30	0.25
corr(y_t, y_{t-1})	0.92	0.91	0.89
corr(y_t, y_{t-2})	0.70	0.67	0.61
corr(π_t, π_{t-1})	0.91	0.89	0.86
corr(π_t, π_{t-2})	0.67	0.61	0.49
corr(y_t, π_{t-2})	-0.11	0.11	-0.08
corr(y_t, π_{t-1})	0.06	0.18	-0.15
corr(y_t, π_t)	0.22	0.22	-0.17
corr(y_t, π_{t+1})	0.34	0.20	-0.13
corr(y_t, π_{t+2})	0.43	0.13	-0.07

Moments obtained from bandpass-filtered series (6-32 Quarters). The two model-based experiments are those described in the text.

Back

Technicalities

- Consider the VAR

$$A(L)X_t = u_t,$$

with $A(L) \equiv \sum_{\tau=0}^{p} A_\tau L^\tau$, $A(0) = I$ and $\mathbb{E}(u_t u_t') = \Sigma$;

- Orthogonalize the residuals as $u_t = S\varepsilon_t$ where $\mathbb{E}(\varepsilon_t \varepsilon_t') = I$;
- Rewrite S as $S = \widetilde{S}Q$, where $\widetilde{S}$ is the Cholesky decomposition of Σ, and Q is an orthonormal matrix $(QQ' = I)$

$$\implies \varepsilon_t = S^{-1}u_t = Q'\widetilde{S}^{-1}u_t$$

$\implies$ Each ε_t is associated to a column of Q.

▸ Back

Technicalities

- Let us write the $VMA(\infty)$ representation of the VAR

$$X_t = B(L)u_t$$

where $B(L) = A(L)^{-1}$ is an infinite matrix polynomial of the form $B(L) = \sum_{\tau=0}^{\infty} B_\tau L^\tau$.
- Replace $u_t = \widetilde{S}Q\varepsilon_t$,

$$X_t = C(L)Q\varepsilon_t = \Gamma(L)\varepsilon_t,$$

where $C(L) = B(L)\widetilde{S}$ and $\Gamma(L) = C(L)Q$ are infinite matrix polynomials.
- The contribution of shock j to the spectral density of variable k over the frequency band $[\underline{\omega}, \overline{\omega}]$ is given by

$$\Upsilon(q; k, \underline{\omega}, \overline{\omega}) \equiv \int_{\omega \in [\underline{\omega}, \overline{\omega}]} \left(\overline{C^{[k]}(e^{-i\omega})q}\, C^{[k]}(e^{-i\omega})q \right) \mathrm{d}\omega = q' \left(\int_{\omega \in [\underline{\omega}, \overline{\omega}]} \overline{C^{[k]}(e^{-i\omega})}\, C^{[k]}(e^{-i\omega}) \mathrm{d}\omega \right)$$

- q is then determined by maximizing the latter quantity $\Longrightarrow$ Standard eigenvalue problem.

Back