Business Cycle Anatomy

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\textsuperscript{1}MIT and NBER  \textsuperscript{2}TSE  \textsuperscript{3}University of Bern

University of Mannheim, August 30-31, 2019
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)

- A theorist’s ambition: account for bulk of the business cycle with a single-shock model, i.e., multiple triggers but a dominant propagation mechanism
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)

- **A theorist’s ambition:** account for bulk of the business cycle with a single-shock model
  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)
What We Do

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⇒ "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 (but not news/expectations more broadly)

  • 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 used later: ACD (2018)


  older literature on coordination failures

  fixes within NK DSGE: Ascari, Phaneuf, & Sims, 2016 Furlanetto, Natvik, & Seneca, 2013; Furlanetto &
  Seneca, 2014
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)
**Baseline VAR**

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  - **Macro Quantities**: Unemployment, GDP, Hours, Invest. (inclusive of durables), Cons.
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- 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.
Main Business Cycle Shock: Targeting Unemployment

Impulse Response Functions

Variance Contributions, Business-Cycle Frequencies

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<thead>
<tr>
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Main Business Cycle Shock: Alternative Targets

Interchangeable facets of the same shock!

- Unemployment
- Output
- Hours Worked
- Investment
- Consumption
- TFP
- Labor Productivity
- Labor Share
- Inflation Rate
- Nom. Int. Rate

$u$ shock; $Y$ shock; $I$ shock; $h$ shock; $C$ shock; Shaded area: 68% HPDI.
## Main Business Cycle Shock: Alternative Targets

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<td>12.93</td>
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<td>9.93</td>
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The Main Business Cycle Shock: Alternative Targets
PCA on Business Cycle Frequencies

First Principal Component, Business Cycle Frequencies

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<td>VAR-Based</td>
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- 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

<table>
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<tr>
<th>Target</th>
<th>Y</th>
<th>I</th>
<th>C</th>
<th>TFP</th>
<th>Y / h</th>
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<td>I</td>
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<td>92.55</td>
<td>97.40</td>
<td>98.43</td>
<td>98.46</td>
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<tr>
<td>Y / h</td>
<td>98.52</td>
<td>93.36</td>
<td>98.67</td>
<td>97.70</td>
<td>99.25</td>
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Disconnect Between the Short Run and the Long Run

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<tr>
<td>MBC shock $\rightarrow$ Long Run</td>
<td>20.83</td>
<td>4.64</td>
<td>5.45</td>
<td>5.16</td>
<td>4.13</td>
<td>4.09</td>
<td>3.88</td>
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<tr>
<td>LR TFP shock $\rightarrow$ Short Run</td>
<td>9.63</td>
<td>24.78</td>
<td>11.01</td>
<td>17.56</td>
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<td>22.01</td>
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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

- $\approx 0$ comovement with TFP at BC frequencies
  - rules out technology and financial, uncertainty or other shocks that map to TFP fluctuations

- $\approx 0$ footprint on the Long Run (and conversely LR has small footprint on BC)
  - 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

Variance Contribution of News Shock to Unemployment

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

- More lags, VECM
- Varying the sample: Post vs Pre-Volcker era, w/o Great Recession/ZLB ...
- Adding variables: $SP$, $P^1/P^C$, financial variables ...
- ...
- Shifting to time domain rather than frequency domain
## MBC Shock: Robustness

### Short-Run Variance Contributions

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<td>6</td>
<td>1960-2007</td>
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<td>55.99</td>
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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 $R^2$)

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Challenge #2: magnitude

![Graph showing actual and predicted inflation responses over 20 quarters.](image)

- Actual inflation response;
- Predicted, textbook NKPC.
• 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)

- **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

Q: Do these models match MBC template form the data?
A: Only second meets interchangeability property
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  - Multiple shocks (but 1 shock is most important)

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- **Q:** Do these models match MBC template form the data?
  - **A:** Only second meets interchangeability property
JPT vs ACD: Interchangeability of MBC Facets

MBC facets interchangeable in ACD model (as in data), less so in JPT
\[ \Rightarrow \text{JPT/CEE/SW lacks the "right" propagation mechanism} \]
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

<table>
<thead>
<tr>
<th></th>
<th>Y</th>
<th>C</th>
<th>I</th>
<th>h</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>0.47</td>
<td>0.52</td>
<td>1.28</td>
<td>0.28</td>
<td>0.64</td>
</tr>
<tr>
<td>JPT</td>
<td>2.90</td>
<td>2.21</td>
<td>6.29</td>
<td>1.35</td>
<td>3.19</td>
</tr>
<tr>
<td>ACD</td>
<td>0.64</td>
<td>0.56</td>
<td>1.56</td>
<td>0.22</td>
<td>0.75</td>
</tr>
</tbody>
</table>

- 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

<table>
<thead>
<tr>
<th>Factor</th>
<th>JPT</th>
<th>ACD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A shock</td>
<td>I shock</td>
</tr>
<tr>
<td>Y</td>
<td>31%</td>
<td>66%</td>
</tr>
<tr>
<td>I</td>
<td>0%</td>
<td>99%</td>
</tr>
<tr>
<td>C</td>
<td>33%</td>
<td>1%</td>
</tr>
<tr>
<td>h</td>
<td>0%</td>
<td>96%</td>
</tr>
</tbody>
</table>

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 ⇒ poor interchangeability
- ACD: “shotgun” shock ⇒ great interchangeability
JPT and ACD: Theoretical Shocks vs MBC in Data

JPT: $A$, $I$, and $C$ shocks

\[ \text{MBC Shock in Data} \]

\[ \text{Technology Shock} \quad \text{Investment Shock} \quad \text{Consumption Shock} \]

\[ \Rightarrow \text{JPT (and many other models): No individual shock resembles the MBC shock in the data;} \]
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
Christiano, Motto & Rostagno (2014)

(a) Data (1985-2011)
(a) Data (1985-2011)

(b) Christiano, Motto & Rostagno (2014)

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

$Y$ factor; $h$ factor; $I$ factor; $C$ factor.
Additional Results: Second Business Cycle Shock

$u$ shock; $Y$ shock; $I$ shock; $h$ shock; $C$ shock; Shaded area: 68% HPDI.
Additional Results: Cycles

Unemployment

Hours Worked

Unemployment

Hours Worked

Quarters

Hours Worked

Quarters

0.0
0.5
1.0
1.5
2.0
2.5
3.0

0.0
0.4
0.2
0.0
-0.2
-0.4

0.0
0.2
0.4

0.0
0.2

0.0
0.5
1.0
1.5
2.0
2.5
3.0

4 6 120 200

0 2 4 6 8

4 6 24 32 40 64 80 120 200

4 6 24 32 40 64 80 120 200

4 6 120 200

4 6 24 32 40 64 80 120 200
Summary

• Simple and flexible method for dissecting the macroeconomic dynamics
• Supports hypothesis of dominant propagation mechanism
• Provides an empirical template for it ⇒ 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

<table>
<thead>
<tr>
<th></th>
<th>Data</th>
<th>Experiment 1</th>
<th>Experiment 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>st.dev($y_t$)</td>
<td>1.41</td>
<td>1.39</td>
<td>1.01</td>
</tr>
<tr>
<td>st.dev($\pi_t$)</td>
<td>0.21</td>
<td>0.30</td>
<td>0.25</td>
</tr>
<tr>
<td>corr($y_t$, $y_{t-1}$)</td>
<td>0.92</td>
<td>0.91</td>
<td>0.89</td>
</tr>
<tr>
<td>corr($y_t$, $y_{t-2}$)</td>
<td>0.70</td>
<td>0.67</td>
<td>0.61</td>
</tr>
<tr>
<td>corr($\pi_t$, $\pi_{t-1}$)</td>
<td>0.91</td>
<td>0.89</td>
<td>0.86</td>
</tr>
<tr>
<td>corr($\pi_t$, $\pi_{t-2}$)</td>
<td>0.67</td>
<td>0.61</td>
<td>0.49</td>
</tr>
<tr>
<td>corr($y_t$, $\pi_{t-2}$)</td>
<td>-0.11</td>
<td>0.11</td>
<td>-0.08</td>
</tr>
<tr>
<td>corr($y_t$, $\pi_{t-1}$)</td>
<td>0.06</td>
<td>0.18</td>
<td>-0.15</td>
</tr>
<tr>
<td>corr($y_t$, $\pi_t$)</td>
<td>0.22</td>
<td>0.22</td>
<td>-0.17</td>
</tr>
<tr>
<td>corr($y_t$, $\pi_{t+1}$)</td>
<td>0.34</td>
<td>0.20</td>
<td>-0.13</td>
</tr>
<tr>
<td>corr($y_t$, $\pi_{t+2}$)</td>
<td>0.43</td>
<td>0.13</td>
<td>-0.07</td>
</tr>
</tbody>
</table>

Moments obtained from bandpass-filtered series (6-32 Quarters). The two model-based experiments are those described in the text.
• 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 \( S = \tilde{S}Q \), where \( \tilde{S} \) is the Cholesky decomposition of \( \Sigma \), and \( Q \) is an orthonormal matrix \( (QQ' = I) \)

\[ \varepsilon_t = S^{-1}u_t = Q'\tilde{S}^{-1}u_t \]

\( \Rightarrow \) Each \( \varepsilon_t \) is associated to a column of \( Q \).
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 $u_t = \tilde{S} Q \varepsilon_t$,

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

where $C(L) = B(L)\tilde{S}$ 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 $[\omega, \bar{\omega}]$ is given by

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

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