Investment Networks, Sectoral Comovement, and the Changing U.S. Business Cycle

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Brigham Young University

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SED St. Louis, June 27th 2019
Changing Nature of Business Cycles Since 1980s

- **Aggregate level**: dynamics of output “decoupled” from inputs
  1. Volatility of employment + investment nearly doubled relative to output
  2. Labor productivity has become acyclical
Changing Nature of Business Cycles Since 1980s

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• **Sectoral level**: relationship between inputs and output stable
  1. Volatility of employment + investment roughly unchanged relative to output
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- **How can we reconcile these patterns?**
Our Contributions

1. **Show aggregate vs. sectoral divergence driven by changes in sectoral comovement** using BEA data on 18 sectors, 1947-2015
   - Since 1984, correlation of value added fell in half, but correlation of employment and investment stable
   - Accounts for aggregate changes in statistical sense
     - Inputs still correlated $\implies$ stabilizes volatility $\implies$ productivity less correlated with GDP
Our Contributions

1. **Show aggregate vs. sectoral divergence driven by changes in sectoral comovement** using BEA data on 18 sectors, 1947-2015

2. **Argue changes in comovement driven by Great Moderation** using multisector RBC model w/ linkages in intermediate inputs and investment goods
   - Feed in sectoral TFP process pre-1984 (high correlation) and post-1984 (low correlation)
   - \(\Rightarrow\) reproduces changes in sectoral comovement
   - Comovement of value added driven by TFP shocks, but **comovement of inputs driven by investment network**
     - Investment goods produced in two main hubs
     - Those hubs use intermediates from all sectors
Our Contributions

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3. **Show important aggregate implications** of matching changing nature of sectoral comovement
   - Model accounts for roughly 40% of aggregate decoupling
   - Sluggish investment behavior following recent recessions $\Rightarrow$ sluggish employment growth as well
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   - Model accounts for **roughly 40% of aggregate decoupling**
   - Sluggish investment behavior following recent recessions
     \[\Rightarrow\] sluggish employment growth as well

\[\Rightarrow\] **Investment network key to propagating shocks**
Empirical Results
## Data Sources

**BEA industry database, 1947 - 2015 annual**
(results on employment robust to using World KLEMS)

<table>
<thead>
<tr>
<th>Sectors</th>
<th>Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mining</td>
<td>Finance and Insurance</td>
</tr>
<tr>
<td>Utilities</td>
<td>Professional, Scientific, and Technical Services</td>
</tr>
<tr>
<td>Construction</td>
<td>Management of Companies and Enterprises</td>
</tr>
<tr>
<td><strong>Durable Manufacturing</strong></td>
<td>Administrative and Waste Management Services</td>
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<tr>
<td><strong>Non-Durable Manufacturing</strong></td>
<td>Educational Services</td>
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<td>Wholesale Trade</td>
<td>Health Care and Social Assistance</td>
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<td>Retail Trade</td>
<td>Arts, Entertainment, and Recreation Services</td>
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<tr>
<td>Transportation and Warehousing</td>
<td>Accommodation and Food Services</td>
</tr>
<tr>
<td>Information</td>
<td>Other Services</td>
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</table>
## Divergence of Aggregate and Sectoral Cycles

<table>
<thead>
<tr>
<th></th>
<th>Aggregated</th>
<th>Within-Sector (unweighted)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma(y_t) )</td>
<td>2.26%</td>
<td>1.36%</td>
</tr>
<tr>
<td>( \sigma(l_t)/\sigma(y_t) )</td>
<td>0.75</td>
<td>1.01</td>
</tr>
<tr>
<td>( \sigma(i_t)/\sigma(y_t) )</td>
<td>2.59</td>
<td>3.45</td>
</tr>
<tr>
<td>( \rho(y_t - l_t, y_t) )</td>
<td>0.64</td>
<td>0.27</td>
</tr>
</tbody>
</table>

- \( y_t \) = log of value added
- \( l_t \) = log of employment
- \( i_t \) = log of investment (in fixed assets)
- All variables have been HP filtered with smoothing = 6.25
Sectoral Comovement Has Changed Since 1980s

\[
\rho_{\tau}^X = \frac{\sum_{i=1}^{N} \sum_{j=i+1}^{N} \omega_{i\tau}^X \omega_{j\tau}^X \text{Corr}(x_{it}, x_{jt} | t \in \tau)}{\sum_{i=1}^{N} \sum_{j=i+1}^{N} \omega_{i\tau}^X \omega_{j\tau}^X}
\]

- \( x_{jt} \) is logged + HP-filtered variable of interest
- \( \tau \in \{\text{pre 1984, post 1984}\} \) is time period
- \( \omega_{i\tau}^X = \mathbb{E}[\frac{x_{jt}}{X_t}] \) are sectoral weights

<table>
<thead>
<tr>
<th></th>
<th>Employment</th>
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<th>Value added</th>
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<tbody>
<tr>
<td>1951 - 1983</td>
<td>0.58</td>
<td>0.33</td>
<td>0.41</td>
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<tr>
<td>1984 - 2012</td>
<td>0.57</td>
<td>0.34</td>
<td>0.22</td>
</tr>
<tr>
<td>Difference</td>
<td>-0.01</td>
<td>0.01</td>
<td>-0.19</td>
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Aggregate Decoupling: Rise of Employment Volatility

\[
\frac{\text{Var}(l_t)}{\text{Var}(y_t)} = \omega_t \frac{\sum_{j=1}^{N} (\omega_{jt}^l)^2 \text{Var}(l_{jt})}{\sum_{j=1}^{N} (\omega_{jt}^y)^2 \text{Var}(y_{jt})} + (1 - \omega_t) \frac{\sum_{j=1}^{N} \sum_{o \neq i} \omega_{jt}^l \omega_{ot}^l \text{Cov}(l_{jt}, l_{ot})}{\sum_{j=1}^{N} \sum_{o \neq i} \omega_{jt}^y \omega_{ot}^y \text{Cov}(y_{jt}, y_{ot})}
\]

within-sector

between-sector
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\[
\text{within-sector} + (1 - \omega_t) \text{between-sector}
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Relative Employment Variance Decomposition

0 0.5 1 1.5 2 2.5

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Aggregate Decoupling: Rise of Input Volatility

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\frac{\text{Var}(x_t)}{\text{Var}(y_t)} = \omega_t \left( \frac{\sum_{j=1}^{N} (\omega^j_{it})^2 \text{Var}(x_{jt})}{\sum_{j=1}^{N} (\omega^y_{jt})^2 \text{Var}(y_{jt})} \right) + (1 - \omega_t) \left( \frac{\sum_{j=1}^{N} \sum_{o \neq i} \omega^j_{it} \omega^y_{ot} \text{Cov}(x_{jt}, x_{ot})}{\sum_{j=1}^{N} \sum_{o \neq i} \omega^y_{jt} \omega^y_{ot} \text{Cov}(y_{jt}, y_{ot})} \right)
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Aggregate Decoupling: Acyclicality of Labor Productivity

\[ \text{Corr}(y_t, y_t - l_t) = f \left( \text{Corr}(y_t, l_t), \frac{\text{Var}(l_t)}{\text{Var}(y_t)} \right) \]
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Model
Production

• Fixed number of sectors $j \in \{1, ..., N\}$

• Gross output $Y_{jt}$ produced according to

$$Y_{jt} = A_{jt} \left( K_{jt}^{\alpha_j} L_{jt}^{1-\alpha_j} \right)^{\theta_j} X_{jt}^{1-\theta_j}$$

• Intermediates input-output network

$$X_{jt} = \prod_{i=1}^{N} M^{\gamma_{ij}}_{ijt}, \text{ where } \sum_{i=1}^{N} \gamma_{ij} = 1$$

• TFP shocks

$$\log A_{jt+1} = \rho_j \log A_{jt} + \varepsilon_{jt+1}, \text{ where } (\varepsilon_{1t}, ..., \varepsilon_{Nt})' \sim N(0, \Sigma)$$
Investment

- Capital accumulation technology

\[ K_{jt+1} = (1 - \delta)K_{jt} + I_{jt} \]

- Investment input-output network

\[ I_{jt} = \prod_{i=1}^{N} \lambda_{ij}, \quad \text{where} \quad \sum_{i=1}^{N} \lambda_{ij} = 1 \]
Household and Equilibrium

- Representative household with preferences

\[ \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t (\log C_t - \Psi L_t), \quad \text{where } C_t = \prod_{j=1}^{N} C_{jt}^{\xi_j} \text{ and } \sum_{j=1}^{N} \xi_j = 1 \]

- Output market clearing

\[ C_{jt} + \sum_{i=1}^{N} M_{jit} + \sum_{i=1}^{N} I_{jit} = Y_{jt} \]

- Labor market clearing

\[ \sum_{j=1}^{N} L_{jt} = L_t \]
Calibration Overview

- **Main exercise**: feed in “Great Moderation,” holding structure of economy fixed
  - Great moderation = fewer aggregate shocks (good luck)
  - No consensus that other parameters have changed
  - Results robust to changing other parameters
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• **Main exercise**: feed in "Great Moderation," holding structure of economy fixed
  • Great moderation = fewer aggregate shocks (good luck)
  • No consensus that other parameters have changed
  • Results robust to changing other parameters

1. All parameters other than shocks are **constant pre vs. post 1984**
   • Production parameters from input-output database
   • Investment parameters from capital flows table
   • Preference parameters from final use tables

2. TFP process chosen to **match value added data pre vs. post 1984**
   • Persistence of value added $y_{jt}$ pins down $\rho_j$
   • Covariance of value added $(y_{jt}, y_{ot})$ pins down $\Sigma_T$
“Great Moderation” Shocks

\[ \text{Var}(y_t) = \sum_{i=1}^{N} \omega_{jt}^y \text{Var}(y_{jt}) + \sum_{i=1}^{N} \sum_{j \neq i} \omega_{jt}^y \omega_{jt}^y \sigma(y_{jt}) \sigma(y_{jt}) \rho(y_{jt}, y_{jt}) \]

<table>
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<tr>
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<th>Pre-84</th>
<th>Post-84</th>
<th>Diff.</th>
<th>Model</th>
<th>Pre-84</th>
<th>Post-84</th>
<th>Diff.</th>
</tr>
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<tbody>
<tr>
<td>Total Variance ((x10^{-3}))</td>
<td>0.42</td>
<td>0.23</td>
<td>-0.19</td>
<td>0.44</td>
<td>0.21</td>
<td>-0.23</td>
<td></td>
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<tr>
<td>Only variances</td>
<td>0.35</td>
<td>0.27</td>
<td>-0.08</td>
<td>0.35</td>
<td>0.27</td>
<td>-0.08</td>
<td></td>
</tr>
<tr>
<td>Only correlations</td>
<td>0.37</td>
<td>0.26</td>
<td>-0.11</td>
<td>0.39</td>
<td>0.23</td>
<td>-0.16</td>
<td></td>
</tr>
</tbody>
</table>
Model Results: Changes in Sectoral Comovement
Model Reproduces Changing Comovement Patterns

\[ \rho_T^X \equiv \frac{\sum_{i=1}^{N} \sum_{j=i+1}^{N} \omega_{iT}^X \omega_{jT}^X \text{Corr}(x_{jt}, x_{jt} | t \in \tau)}{\sum_{i=1}^{N} \sum_{j=i+1}^{N} \omega_{iT}^X \omega_{jT}^X} \]

- \( x_{jt} \) is HP-filtered + logged variable of interest
- \( \omega_{iT}^X = \mathbb{E}[\frac{x_{jt}}{\chi_s}] \) are sectoral weights
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<td>1951-1983</td>
<td>0.58</td>
</tr>
<tr>
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<td>Difference</td>
<td><strong>-0.01</strong></td>
</tr>
</tbody>
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### Investment Network Key to Comovement Changes

<table>
<thead>
<tr>
<th>Year</th>
<th>Baseline Model</th>
<th>No Investment Network</th>
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<tbody>
<tr>
<td></td>
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<td>0.14</td>
</tr>
<tr>
<td>Difference</td>
<td>-0.03</td>
<td>-0.13</td>
</tr>
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</table>

- Without investment network $\Lambda$, input correlations counterfactually fall post-1984
  
  $\rightarrow$ **investment network necessary** to match data
Role of Investment Network

- **Key mechanism**: value added comovement driven by shocks, input comovement driven by sectoral shocks + networks

- Why? Sectoral shock increases investment demand
  1. *Investment network*: goods produced in two “hubs”
  2. *Intermediates network*: hubs use all sectors’ intermediates
     \[ \implies \text{correlated increase in input demand} \]
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Investment Network Generates Spillovers from Sectoral Shocks...

(a) Aggregate investment

(b) Aggregate employment

- Shock to durable manufacturing (an investment hub)
- Spillovers to employment and investment are stronger with investment linkages
...Which Makes Inputs More Correlated Post-1983

(a) Correlation of TFP shocks

(b) Correlation of value added

(c) Correlation of employment
Model Results: Aggregate Implications of Matching the Investment Network
Aggregate Implication 1: Rise of Input Volatility

\[
\frac{\text{Var}(x_t)}{\text{Var}(y_t)} = \omega_t \left( \sum_{j=1}^{N} (\omega_{jt}^l)^2 \text{Var}(x_{jt}) \right) \left( \sum_{j=1}^{N} (\omega_{jt}^y)^2 \text{Var}(y_{jt}) \right) + (1 - \omega_t) \left( \sum_{j=1}^{N} \sum_{o \neq i} \omega_{jt}^l \omega_{ot}^l \text{Cov}(x_{jt}, x_{ot}) \right) \left( \sum_{j=1}^{N} \sum_{o \neq i} \omega_{jt}^y \omega_{ot}^y \text{Cov}(y_{jt}, y_{ot}) \right)
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<td>Var(l_t)</td>
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<tr>
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<td>6.04</td>
<td>6.90</td>
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Aggregate Implication 2: Sluggish Recoveries Following Shocks to Investment Hubs

- In our model, agg. employment linked to investment demand
  \[ \Rightarrow \] investment-driven recessions spill over to employment

- **Big picture**: sluggish investment growth can drive sluggish employment growth
  - Last two recessions arguably caused by shocks which generate sluggish investment growth during recovery
  - Can this channel account for sluggish employment growth in last two recoveries?
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• In our model, agg. employment linked to investment demand \( \Rightarrow \) investment-driven recessions spill over to employment

• **Big picture**: sluggish investment growth can drive sluggish employment growth
  - Last two recessions arguably caused by shocks which generate sluggish investment growth during recovery
  - Can this channel account for sluggish employment growth in last two recoveries?

• **Exercise today**: case study of shock to construction sector
  - Investment network \( \Rightarrow \) deep recession and slow recovery
Aggregate Implication 2: Sluggish Recovery Following Shock to Construction Sector

(a) Aggregate investment

(b) Aggregate employment

- Feed in $-2$ s.d. shock in periods $t = 0, 1$
- Investment and employment have deep and persistent recession due to investment linkages
Conclusion
Our contributions

1. “Aggregate decoupling” driven by changes in sectoral comovement
   - Inputs still comove over the cycle, output does not

2. In our model, changing comovement driven by Great Moderation + structure of investment network
   - Sectoral shocks generate correlated increases in inputs

3. Aggregate implications of matching investment network:
   - Rising volatility of inputs relative to output
   - Sluggish recoveries in investment and employment are linked
Appendix
Changes in Sectoral Comovement After 1984: Comovement with Aggregate

\[ \hat{\rho}_T^x \equiv \frac{\sum_{i=1}^{N} \omega_{i_T} \rho_{i_T}^x}{\sum_{i=1}^{N} \omega_{iT}} \]

- \( x_{jt} \) is HP-filtered + logged variable of interest
- \( \omega_{i_T}^x = \mathbb{E}[\frac{x_{jt}}{x_s}] \) are sectoral weights
- \( \tau \in \{ \text{pre 1984, post 1984} \} \) is time period
- \( \rho_{jT}^x \) is sector’s correlation w/ agg.

<table>
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Changes in Sectoral Comovement After 1984: Investment Comovement

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Changes in Sectoral Comovement After 1984: Results by Industry
## Changes in Sectoral Comovement After 1984: Bandpass Filter

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Changes in Sectoral Comovement After 1984: Unweighted

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Changes in Sectoral Comovement After 1984: World KLEMS Data
Changes in Sectoral Comovement After 1984: Rolling Windows

Rolling windows of sectoral correlations

Pre-1983: 0.58
Post-1983: 0.57

Pre-1983: 0.41
Post-1983: 0.22

Value added correlations
Employment correlations
### Allowing the Networks to Change

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- Value added shares $\theta$, intermediates network $\Gamma$, and consumption shares $\xi$ straightforward to compute in two subperiods.
- **Investment network** $\Lambda_\tau$ imputed from final use table and capital flows table.
- Labor shares $\alpha_\tau$ from World KLEMS and sectoral crosswalk to BEA.
Model Replicates Changing Comovement Patterns

$\Delta$employment correlation$\tau$ – $\Delta$value added correlation$\tau$

$R^2 = 0.52$

$\Rightarrow$ Model explains 50% of sector level changes
Production Parameters

\[ Y_{jt} = A_{jt}(K_{jt}^\alpha L_{jt}^{1-\alpha_j})^{\theta_j}X_{jt}^{1-\theta_j} \]
where \( X_{jt} = \Pi_{i=1}^N M_{ijt}^{\gamma_{ij}} \)

1. **Value added shares \( \theta \):** average value added as share of gross output, BEA I-O database 1947 - 2015
Production Parameters

\[ Y_{jt} = A_{jt} (K_{jt}^{\alpha_j} L_{jt}^{1-\alpha_j})^{\theta_j} X_{jt}^{1-\theta_j} \]
where \( X_{jt} = \prod_{i=1}^{N} M_{ijt}^{\gamma_{ij}} \)

1. Value added shares \( \theta \)

2. Labor shares \( \alpha \): average labor compensation as share of total costs, BEA I-O database 1987-2015
Production Parameters

\[ Y_{jt} = A_{jt}(K_{jt}^{\alpha_j} L_{jt}^{1-\alpha_j})^{\theta_j} X_{jt}^{1-\theta_j} \quad \text{where} \quad X_{jt} = \prod_{i=1}^{N} M_{ijt}^{\gamma_{ij}} \]

1. Value added shares $\theta$
2. Labor shares $\alpha$
3. Intermediates input-output network $\Gamma$: average intermediates cost as share of total costs, BEA I-O database 1947-2015
Investment Parameters

\[ K_{jt+1} = (1 - \delta)K_{jt} + l_{jt} \quad \text{where} \quad l_{jt} = \prod_{i=1}^{N} I_{ijt}^{\lambda_{ij}} \]

1. Depreciation rate \( \delta = 0.1 \) (annual)
\[ K_{jt+1} = (1 - \delta)K_{jt} + l_{jt} \quad \text{where} \quad l_{jt} = \prod_{i=1}^{N} l_{ijt}^{\lambda_{ij}} \]

1. Depreciation rate \( \delta = 0.1 \)

2. Investment input-output network \( \Lambda \): cost of investment as share of total investment, BEA capital flows database 1997 (+ maintenance investment out of own-sector output)
\[ E_0 \sum_{t=0}^{\infty} \beta^t (\log C_t - \psi L_t), \quad \text{where } C_t = \prod_{j=1}^{N} C_{jt}^{\xi_j} \text{ and } \sum_{j=1}^{N} \xi_j = 1 \]

1. Discount factor $\beta = 0.96$
\[ E_0 \sum_{t=0}^{\infty} \beta^t (\log C_t - \psi L_t), \quad \text{where } C_t = \Pi_{j=1}^N C_{jt} \xi_j \text{ and } \sum_{j=1}^N \xi_j = 1 \]

1. Discount factor $\beta = 0.96$

2. Labor disutility $\psi = 0.55$ (normalization)
\[ E_0 \sum_{t=0}^{\infty} \beta^t (\log C_t - \Psi L_t), \text{ where } C_t = \prod_{j=1}^{N} C_{jt}^{\xi_j} \text{ and } \sum_{j=1}^{N} \xi_j = 1 \]

1. Discount factor $\beta = 0.96$
2. Labor disutility $\Psi = 0.55$ (normalization)
3. Consumption shares $\xi_j$ from share of consumption in final use table
\[ \log A_{jt+1} = \rho_j \log A_{jt} + \varepsilon_{jt+1}, \text{ where } (\varepsilon_{1t}, \ldots, \varepsilon_{Nt})' \sim N(0, \Sigma_T) \]
and \( \tau \in \{\text{pre-1984, post-1984}\} \)

1. Persistence parameters \( \rho_j \) to match persistence of value added \( V_{jt} \)
\[
\log A_{jt+1} = \rho_j \log A_{jt} + \varepsilon_{jt+1}, \quad \text{where } (\varepsilon_{1t}, \ldots, \varepsilon_{Nt})' \sim N(0, \Sigma_{\tau}) \\
\text{and } \tau \in \{\text{pre-1984,post-1984}\}
\]

1. Persistence parameters \( \rho_j \)
2. Covariance matrix \( \Sigma_{\tau} \) parameterized to match covariance matrix of value-added \( V_{jt} \) in each subsample

### Variances, pre-1984

![Graph showing variances pre-1984]
\[ \log A_{jt+1} = \rho_j \log A_{jt} + \varepsilon_{jt+1}, \text{ where } (\varepsilon_{1t}, \ldots, \varepsilon_{Nt})' \sim N(0, \Sigma_\tau) \]
and \( \tau \in \{\text{pre-1984}, \text{post-1984}\} \)

1. Persistence parameters \( \rho_j \)
2. Covariance matrix \( \Sigma_\tau \) parameterized to match covariance matrix of value-added \( V_{jt} \) in each subsample

**Variances, post-1984**
\[ \log A_{jt+1} = \rho_j \log A_{jt} + \varepsilon_{jt+1}, \text{ where } (\varepsilon_{1t}, \ldots, \varepsilon_{Nt})' \sim N(0, \Sigma_\tau) \]

and \( \tau \in \{\text{pre-1984, post-1984}\} \)

1. Persistence parameters \( \rho_j \)
2. Covariance matrix \( \Sigma_\tau \) parameterized to match covariance matrix of value-added \( V_{jt} \) in each subsample

Pairwise correlations, pre-1984
\[ \log A_{jt+1} = \rho_j \log A_{jt} + \varepsilon_{jt+1}, \text{ where } (\varepsilon_{1t}, \ldots, \varepsilon_{Nt})' \sim N(0, \Sigma_T) \]

and \( \tau \in \{\text{pre-1984, post-1984}\} \)

1. Persistence parameters \( \rho_j \)

2. Covariance matrix \( \Sigma_T \) parameterized to match covariance matrix of value-added \( V_{jt} \) in each subsample

**Pairwise correlations, post-1984**

![Data vs Model Plot]