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

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Overview of Our Project

- **Question**: how are sector-specific shocks propagated to macroeconomic aggregates?

- Focus on role of the *investment network*: distribution of investment of production and purchases across sectors

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- Focus on role of the *investment network*: distribution of investment of production and purchases across sectors

- **Answer**: investment network important propagation mechanism
  1. Empirically, investment network is extremely concentrated
  2. In multisector RBC model: shocks to hubs and their key suppliers have large effect on aggregate employment
  3. Shocks to hubs + suppliers account for larger share of fluctuations since 1980s $\implies$ acyclicality of labor productivity

The Investment Network

Data Sources for 37 Sector-Level Coverage

Extend various BEA data sources 1947-2018 to include finer disaggregation of manufacturing ▸ Details

Mining	Utilities
Construction	Real estate and rental services
Wood products	Non-metallic minerals
Primary metals	Fabricated metals
Machinery	Computer and electronic manufacturing
Electrical equipment manufacturing	Motor vehicles manufacturing
Other transportation equipment	Furniture and related manufacturing
Misc. Manufacturing	Food and beverage manufacturing
Textile manufacturing	Apparel manufacturing
Paper manufacturing	Printing products manufacturing
Petroleum and coal manufacturing	Chemical manufacturing
Plastics manufacturing	Wholesale trade
Retail trade	Transportation and warehousing
Information	Finance and insurance
Professional and technical services	Management of companies and enterprises
Administrative and waste management services	Educational services
Health care and social assistance	Arts, entertainment, and recreation services
Accommodation	Food services
Other services	

Empirical Investment Network

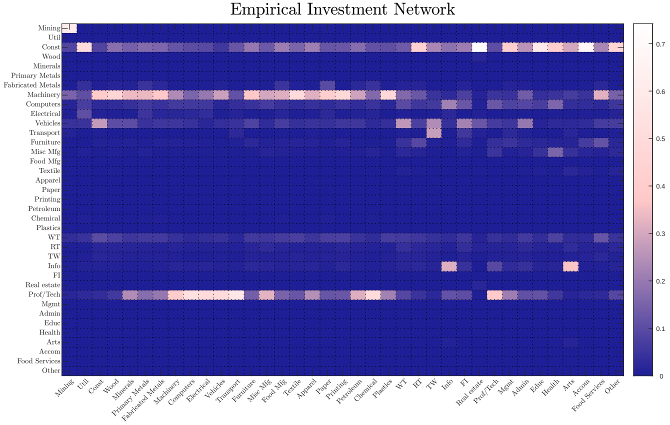
- **Investment network** = share of investment expenditure of sector *j* purchased from sectors *i* in year *t*

- BEA provides some pairwise capital flows flows data, but:
  1. Only small set of years (most recently in 1997)
  2. Does not include most of intellectual property
  3. Not consistent classification of sectors over time

- Construct estimates of pairwise flows using asset-level data
  - Compute how much of each asset purchased by sector *j*
  - Estimate how much of asset produced by sector *i* ▸ Details
  - Follows BEA practice + benchmarked to production data

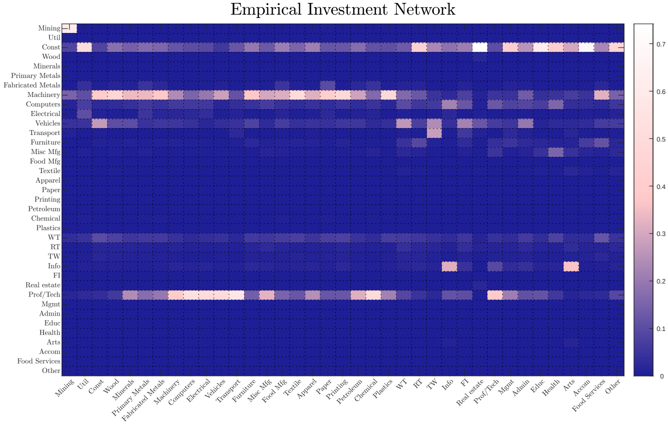
- Result: annual time series of investment network consistent w/ current national accounting regarding intellectual property

Empirical Investment Network



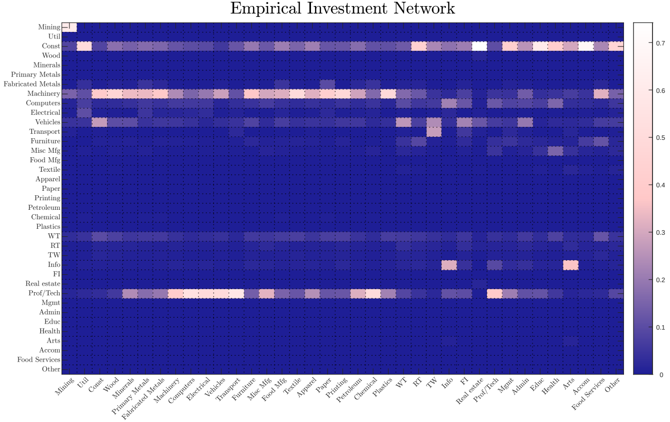
- Entry (i, j) = share of investment in sector j supplied by sector i
- Compute year-by-year, then average over sample ▸ Changes over time

Empirical Investment Network



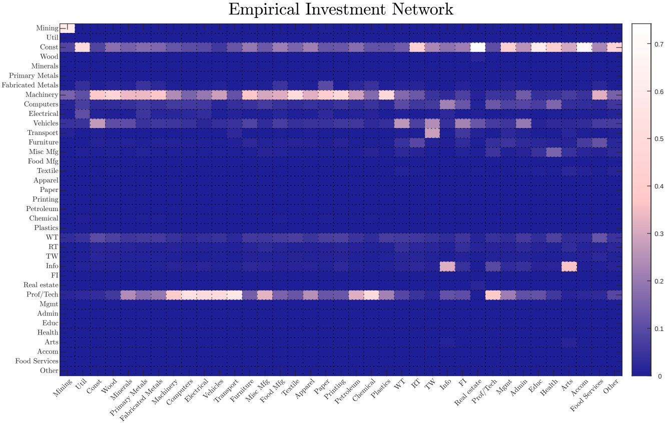
- Four **investment hubs**: construction (structures), machinery and motor vehicles (equipment), and professional/technical services (intellectual property)

Empirical Investment Network



- Hubs produce nearly 70% of aggregate investment, but only 10%-15% of aggregate value added, employment, or intermediates
- Three times as concentrated as the intermediates network ▸ Details

Empirical Investment Network



- Investment hubs more volatile at cyclical frequencies Details
- And more correlated with aggregate business cycle Details

Model and Calibration

Production

- Fixed number of sectors $j \in \{1, ..., N = 37\}$ (same as in data)
- Gross output Q_{jt} produced according to

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

- Intermediates input-output network

$$M_{jt} = \Pi_{i=1}^{N} M_{ijt}^{\gamma_{ij}}, \quad \text{where } \sum_{i=1}^{N} \gamma_{ij} = 1$$

- TFP shocks follow $\log A_{jt+1} = \rho_j \log A_{jt} + \varepsilon_{jt+1}$
  - Linear model solution $\implies$ certainty equivalence
  - Will feed in realizations of $\log \varepsilon_{jt}$ from data

Investment

- Capital accumulation technology

$$K_{jt+1} = (1 - \delta_j)K_{jt} + I_{jt}$$

- Investment network

$$I_{jt} = \Pi_{i=1}^{N} I_{ijt}^{\lambda_{ij}}, \quad \text{where } \sum_{i=1}^{N} \lambda_{ij} = 1$$

  - Investment hubs i have high λ_{ij} for many j
  - In calibration, λ_{ij} = entry in empirical investment network

Household and Equilibrium

- Representative household with preferences

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\log C_t - L_t \right), \quad \text{where } C_t = \Pi_{j=1}^{N} C_{jt}^{\xi_j} \text{ and } \sum_{j=1}^{N} \xi_j = 1$$

- Study the competitive equilibrium, which is efficient

$$Q_{jt} = C_{jt} + \sum_{k=1}^{N} M_{jkt} + \sum_{k=1}^{N} I_{jkt}$$

$$L_t = \sum_{j=1}^{N} L_{jt}$$

Calibration Overview

- Will later measure shocks from data and feed into model
- Now calibrate all parameters other than shocks so that model's steady state ≈ data's long-run averages
    - Isolates role of changes in shock process
    - But results robust to allowing for structural change
- Cobb-Douglas $\implies$ most parameters pinned down by average expenditure shares
    1. Production parameters from input-output database ▸ Details
    2. Preference parameters from final use tables ▸ Details
    3. Investment network from earlier measurement ▸ Details

Role of Investment Network in Propagating Sectoral Shocks

What Determines the Response of Employment?

Proposition

Employment is proportional to the household's value of output:

$$L_{jt} \propto \sum_{k=1}^{N} \ell_{jk} \frac{p_{kt} C_{kt}}{C_t} + \sum_{k=1}^{N} \ell_{jk} \sum_{m=1}^{N} \lambda_{km} \frac{p^I_{mt} I_{mt}}{C_t}$$

where $p^I_{mt} = \Pi_{k=1}^{N} \left(\frac{p_{kt}}{\lambda_{km}} \right)^{\lambda_{km}}$ *is the investment price index and* $[\mathcal{L}]_{jk} = \ell_{jk}$ *is the Leontief inverse.* ▸ Derivation ▸ Real GDP

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- Household's valuation of consumption constant due to Cobb-Douglas preferences $\sum_{k=1}^{N} \ell_{jk} \frac{p_{kt} C_{kt}}{C_t} = \sum_{k=1}^{N} \ell_{jk} \xi_k$
- "Consumption supply shocks" are neutral w.r.t. employment!
  - Shock increases $MRPL_{kt}$ and C_t by same proportion

    $\implies$ generate offsetting income and substitution effects

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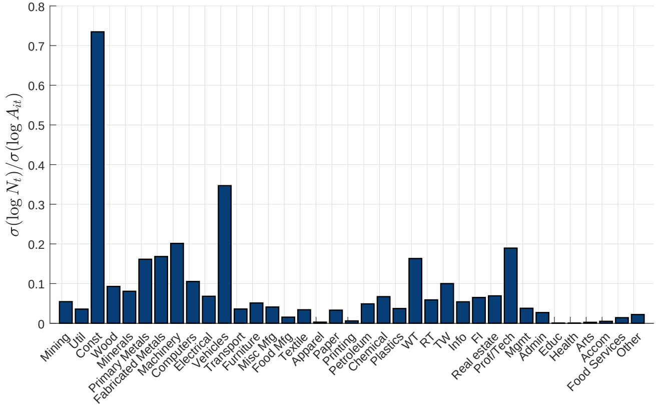
- Household's valuation of investment fluctuates because capital accumulation technology not Cobb-Douglas: $K_{jt+1} = (1 - \delta_j) K_{jt} + I_{jt}$ ▸ C-D accumulation
- "Investment supply shocks" only sources of employment fluctuations! (weaken income effect on labor supply)

▸ Leontief-adjusted investment network

Which Shocks Matter for Investment/Employment?



- For each sector i, simulate model in response to $\sigma(\log A_{it}) = 1\%$ (reduced-form elasticity of employment w.r.t. sectoral shock)

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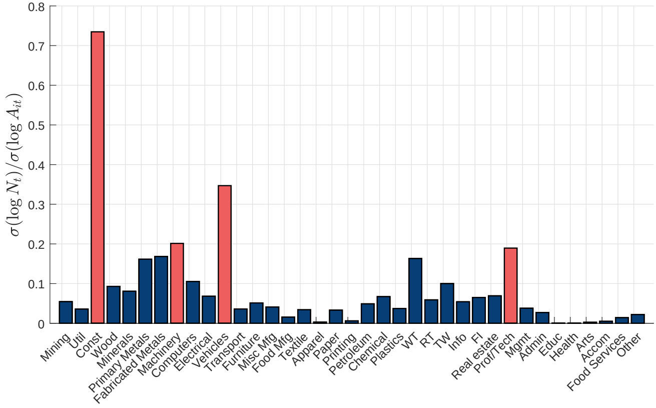
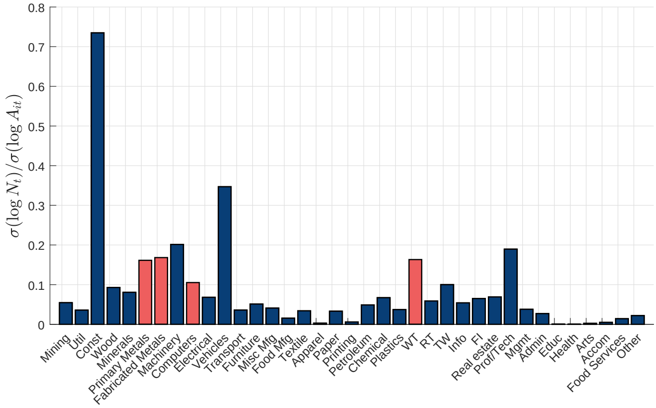


- Investment hub shocks have the largest effect on aggregate employment

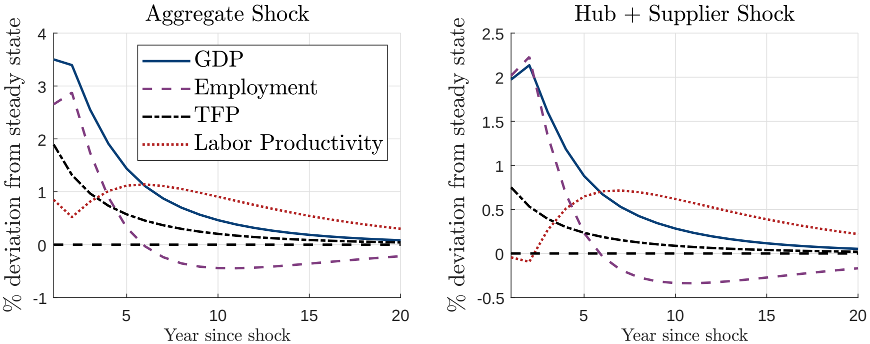
Which Shocks Matter for Investment/Employment?



- Other important sectors are important rows in Leontief-adjusted investment network (key suppliers to investment hubs)

▸ Why? ▸ Responses of Household's Valuation of Investment ▸ Supporting Evidence

Implications for Changing Business Cycles



$$d\log Y_t = \sum_{j=1}^{N} \left(\frac{p_j Q_j}{P^Y Y}\right)^* d\log A_{jt} + (1-\overline{\alpha}^*) \sum_{j=1}^{N} \left(\frac{L_j}{L}\right)^* d\log L_{jt}$$

- Pre-1980s sample dominated by aggregate shocks
- Post-1980s sample dominated by sector-specific shocks
  - Shocks to hubs/suppliers have biggest aggregate effects

$\Longrightarrow$ primary source of fluctuations post-1980s Sector-by-Sector

Changes in Business Cycles Since 1984

Quantitative Exercise

- Procedure: feed in realized shocks from data, but hold other parameters fixed over time
- Measure realizations of sector-level TFP A_{jt} as Solow residual, log-polynomially detrended ▸ Details

$$\mathbb{V}ar(\Delta \log A_t) = \underbrace{\sum_{j=1}^{N} (\omega_{jt})^2 \mathbb{V}ar(\Delta \log A_{jt})}_{\text{variances}} + \underbrace{\sum_{j=1}^{N} \sum_{o \neq j} \omega_{jt}\omega_{ot} \mathbb{C}ov(\Delta \log A_{jt}, \Delta \log A_{ot})}_{\text{covariances}}$$

	Measured TFP		**Value Added**	
	Pre-84	*Post-84*	*Pre-84*	*Post-84*
$1000\mathbb{V}ar(\Delta \log A_t)$	0.41	0.10	1.01	0.39
Variances	0.08	0.06	0.12	0.08
Covariances	0.33	0.03	0.89	0.31

Quantitative Exercise (cont'd)

- Helpful special case for interpretation: $\log A_{jt} = \log \widehat{A}_t + \log \widehat{A}_{jt}$
  - Declining covariances $\implies$ aggregate shock less volatile
  - Consistent with principal components analysis (also see Foerster et al. 2011) ▸ Details

Quantitative Exercise (cont'd)

- Helpful special case for interpretation: $\log A_{jt} = \log \widehat{A}_t + \log \widehat{A}_{jt}$
  - Declining covariances $\implies$ aggregate shock less volatile
  - Consistent with principal components analysis (also see Foerster et al. 2011) ▸ Details
- To reduce capital reallocation, allow for imperfect substitution (Huffman-Wynne 1999):

$$Q_{jt} = C_{jt} + \sum_{i=1}^{N} M_{ijt} + \left(\sum_{i=1}^{N} I_{ijt}^{-\rho} \right)^{-\frac{1}{\rho}}$$

  - $\rho \leq -1$ controls degree of imperfect substitution
  - Set $\rho = -1.04$ to match degree of reallocation in data ▸ Details

Model Matches Aggregate Business Cycle Patterns

	Data		**Model**	
	Pre-1984	*Post-1984*	*Pre-1984*	*Post-1984*
$\sigma(\Delta y_t)$	**3.18%**	**1.98%**	**3.95%**	**2.42%**

- Model generates decline in aggregate GDP volatility due to declining correlation of shocks

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	Data		Model	
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$\sigma(\Delta y_t)$	3.18%	1.98%	3.95%	2.42%
$\rho(\Delta y_t - \Delta l_t, \Delta y_t)$	**0.56**	**0.28**	**0.52**	**-0.01**
$\rho(y_t^{hp} - l_t^{hp}, y_t^{hp})$	**0.52**	**0.14**	**0.53**	**0.01**

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- Model generates decline in cyclicality of labor productivity

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$\rho(y_t^{hp} - l_t^{hp}, y_t^{hp})$	0.52	0.14	0.53	0.01
$\sigma(\Delta l_t)/\sigma(\Delta y_t)$	**0.83**	**1.01**	**0.90**	**1.03**

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- Model generates decline in cyclicality of labor productivity due to rise in relative employment volatility

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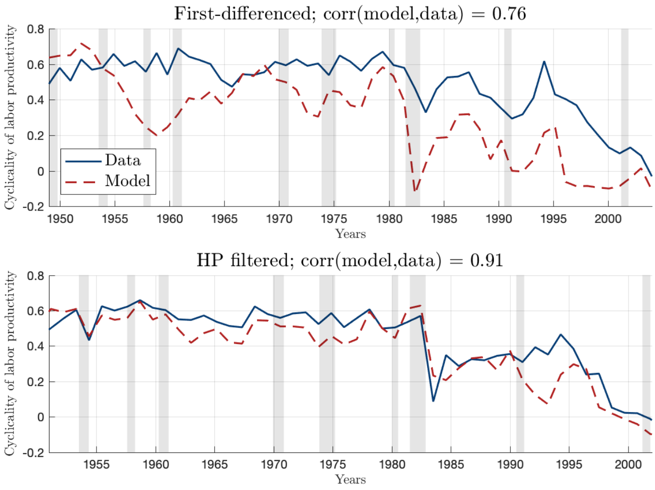
$\sigma(\Delta l_t)/\sigma(\Delta y_t)$	0.83	1.01	0.90	1.03
$\sigma(\Delta i_t)/\sigma(\Delta y_t)$	**2.25**	**3.10**	**3.78**	**4.11**

- Model generates decline in aggregate GDP volatility due to declining correlation of shocks
- Model generates decline in cyclicality of labor productivity due to rise in relative employment volatility
- Model generates rise in relative investment volatility due to rising importance of hub + supplier shocks

Model Matches Aggregate Business Cycle Patterns



- Model matches timing of change in labor productivity cyclicality (14-year forward-looking rolling windows) ▸ Postwar Time Series

Role of Investment Network

Full Model	*Pre*	*Post*	***Identity Network***	*Pre*	*Post*
$\sigma(\Delta y_t)$	3.95%	2.42%	$\sigma(\Delta y_t)$	3.16%	1.72%
$\sigma(\Delta l_t)/\sigma(\Delta y_t)$	0.90	1.03	$\sigma(\Delta l_t)/\sigma(\Delta y_t)$	0.88	0.90
$\rho(\Delta y_t - \Delta l_t, \Delta y_t)$	0.52	-0.01	$\rho(\Delta y_t - \Delta l_t, \Delta y_t)$	0.59	0.48

- **Identity Network** sets investment network to $\Lambda = I$
  $\implies$ small decline in cyclicality of labor productivity

▸ Structural Change ▸ CES production/preferences ▸ Labor Reallocation Frictions ▸ Capital Frictions
▸ Maintenance Investment ▸ Detrending ▸ Shock size ▸ Shock Decomposition

Supporting Evidence

Changing Cycles Driven by Changing Comovement

Data	*Aggregated*		*Within-Sector*	
	Pre-1984	*Post-1984*	*Pre-1984*	*Post-1984*
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	Pre-1984	*Post-1984*	*Pre-1984*	*Post-1984*
$\rho(\Delta y_t - \Delta l_t, \Delta y_t)$	0.56	0.28	0.69	0.67
$\sigma(\Delta l_t)/\sigma(\Delta y_t)$	0.83	1.01	0.76	0.81
Model				
$\rho(\Delta y_t - \Delta l_t, \Delta y_t)$	0.52	-0.01	0.79	0.85
$\sigma(\Delta l_t)/\sigma(\Delta y_t)$	0.90	1.03	0.52	0.43

- Sector-level cycles stable within sector
  $\Longrightarrow$ aggregate changes driven by comovement across sectors

▸ Existing Explanations ▸ Alternative Weights

Changing Cycles Driven by Changing Comovement

$$\frac{\mathbb{V}ar(\Delta l_t)}{\mathbb{V}ar(\Delta y_t)} \approx \underbrace{\omega_t}_{\text{variance weight}} \underbrace{\frac{\sum_{j=1}^{N}(\omega_{jt}^{l})^2 \mathbb{V}ar(\Delta l_{jt})}{\sum_{j=1}^{N}(\omega_{jt}^{y})^2 \mathbb{V}ar(\Delta y_{jt})}}_{\text{variances}} + (1-\omega_t) \underbrace{\frac{\sum_{j=1}^{N}\sum_{o\neq i}\omega_{jt}^{l}\omega_{ot}^{l}\mathbb{C}ov(\Delta l_{jt}, \Delta l_{ot})}{\sum_{j=1}^{N}\sum_{o\neq i}\omega_{jt}^{y}\omega_{ot}^{y}\mathbb{C}ov(\Delta y_{jt}, \Delta y_{ot})}}_{\text{covariances}}$$

Changing Cycles Driven by Changing Comovement

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	Data			**Model**		
	Pre-84	*Post-84*	*Cont.*	*Pre-84*	*Post-84*	*Cont.*
$\frac{\mathbb{V}ar(l_t)}{\mathbb{V}ar(y_t)}$	0.68	1.04	**100%**	0.81	1.05	**100%**
Variances	0.41	0.48	15%	0.75	0.57	10%
Covariances	0.72	1.19	85%	0.82	1.15	90%
Variance Weight	0.12	0.21		0.10	0.17	
$(\omega_t = \sum_{j=1}^{N}(\omega_{jt}^{y})^2\mathbb{V}ar(y_{jt})/\mathbb{V}ar(y_t))$						

- Comovement of value added falls $\implies$ aggregate volatility falls
- Comovement of employment stable $\implies$ agg. volatility stable

▸ Derivation ▸ Decomposition accuracy ▸ Comovement ▸ NBER-CES ▸ Model Fit

Conclusion

Our contributions

Investment network important propagation mechanism
for business cycle analysis

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1. Empirical investment network dominated by investment hubs which are highly cyclical, especially post-1984

2. Standard multisector business cycle model implies that hub + supplier shocks generate large changes in employment

3. Quantitatively, these shocks account for rising share of fluctuations and explain declining cyclicality of labor productivity

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▸ Investment Stimulus Policy

Appendix

Construction of the Data Set ▸ Back

1. **Value added, gross output, and intermediates** from BEA industry database, 1947 - 2018 (37 NAICS sector level)

2. **Investment** and capital stocks from BEA fixed asset tables aggregated to sector level using shares of capital types, 1947 - 2018 (37 NAICS sector level)

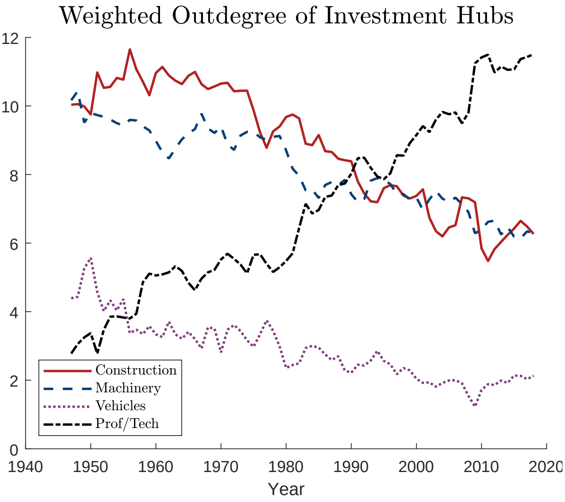
3. **Employment** from two sources, harmonized using Fort-Klimek (2016) crosswalk
    - 1997-2018: all sectors in BEA industry database
    - 1948-1997, non-manufacturing: BEA industry database
    - 1948-1997, manufacturing: historical supplements + Fort-Klimek crosswalk

Measurement of Investment Network ▸ Back

- All **non-residential structures** produced by construction, except for mining (following BEA practice)
- **Intellectual property** also follows BEA practice (McGrattan 2020)
    - Pre-packed software and part of artistic originals from info
    - Other software and R&D investment from prof/technical
    - Adjust for margin payments (wholesale trade, retail trade, transportation and warehousing)
- All **residential investment** purchased by real estate
    - 1997 - 2018: observe production
    - Before 1997: impute production as share of aggregate
- **Equipment production** combines three BEA cases
    - 1997 - 2017: BEA provides bridge file
    - 1987 + 1992: BEA provides SIC bridge, use Fort-Klimek
    - Remaining years: extrapolate based on observed bridge files and total production

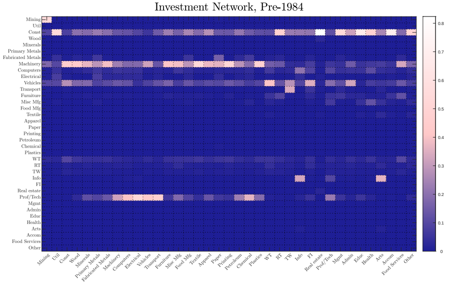
Changes in Investment Network Over Time

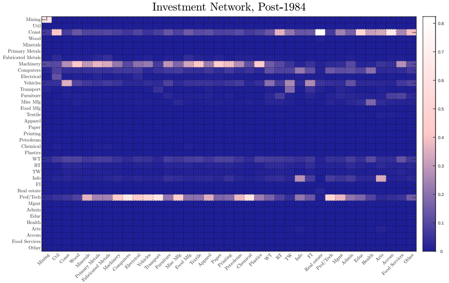
▸ Back



Changes in Investment Network Over Time

▸ Back





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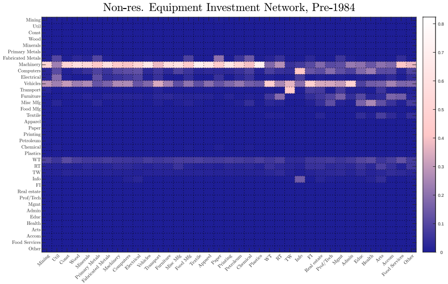

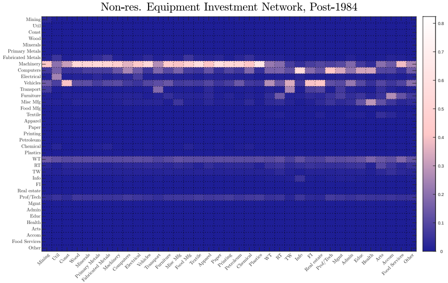

Changes in Investment Network Over Time

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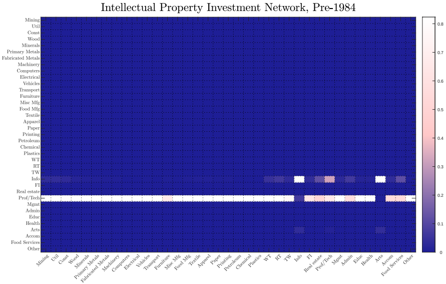
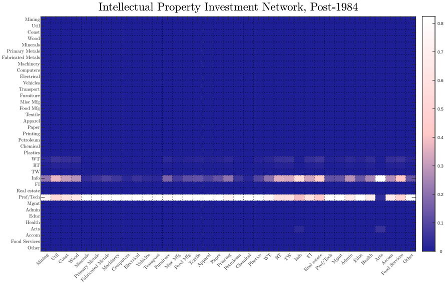
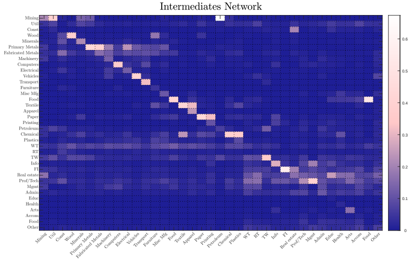
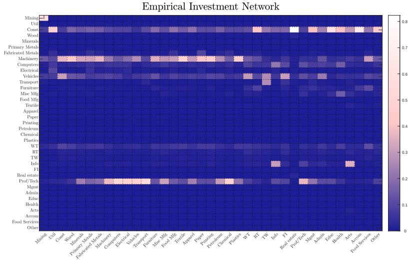




Concentration of Investment Network ▸ Back





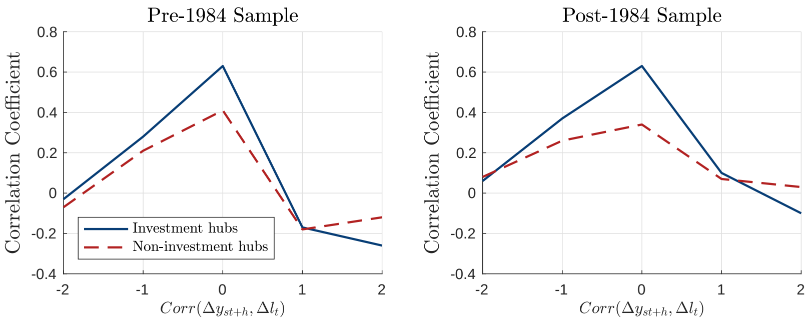
	Eigenvalue Centrality	**Weighted Outdegree**
Investment net.	3.22	2.57
Intermediates net.	1.42	0.68

Investment Hubs are Highly Cyclical ▸ Back

	Investment Hubs		Non-Hubs	
	Pre-1984	*Post-1984*	*Pre-1984*	*Post-1984*
$\sigma(\Delta y_{st})$	9.13%	9.18%	6.63%	5.51%
$\sigma(\Delta l_{st})$	6.14%	4.83%	3.81%	3.14%
$\sigma(y_{st}^{hp})$	5.64%	6.29%	3.91%	3.40%
$\sigma(l_{st}^{hp})$	4.08%	3.21%	2.29%	1.91%

- y_{st} = log of real value added
- l_{st} = log of employment
- Δ = first differences
- ^{hp} = HP-filtered w/ smoothing $\lambda = 6.25$
- Statistics are averaged across sectors unweighted

Investment Hubs are Highly Cyclical ▸ Back



- y_{st} = log of real value added
- l_t = log of aggregate employment
- Δ = first differences

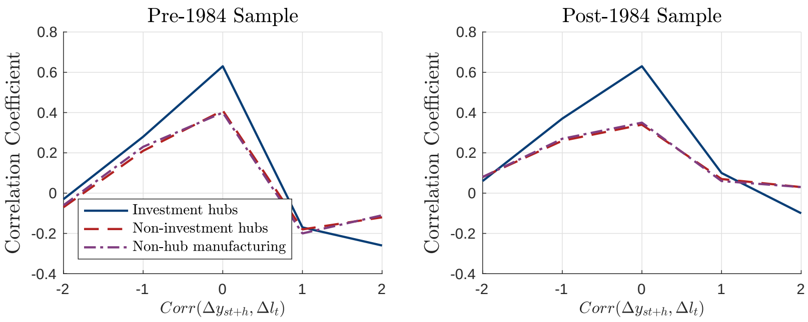
▸ Not driven by manufacturing ▸ Correlogram with GDP

Investment Hubs are More Cycical than Other Manufacturing Sectors ▸ Back

	Investment Hubs		Non-Hubs		Non-Hub Manuf.	
	Pre-84	*Post-84*	*Pre-84*	*Post-84*	*Pre-84*	*Post-84*
$\sigma(\Delta y_{st})$	9.13%	9.18%	6.63%	5.51%	9.14%	6.97%
$\sigma(\Delta l_{st})$	6.14%	4.83%	3.81%	3.14%	5.12%	3.77%

- y_{st} = log of real value added
- l_{st} = log of employment
- Δ = first differences
- Statistics are averaged across sectors unweighted

Investment Hubs are More Cyclical than Other Manufacturing Sectors ▸ Back



- y_{st} = log of real value added
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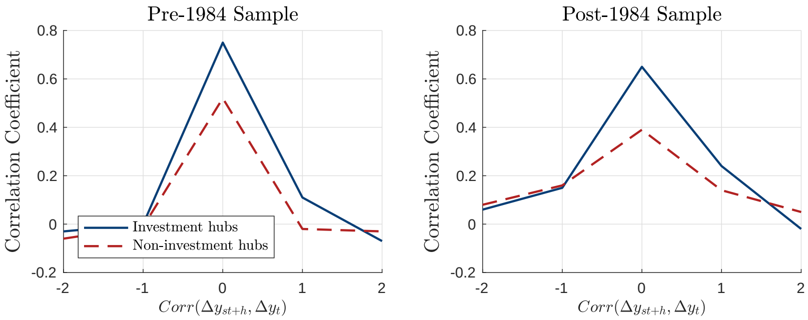
Correlogram with GDP ▸ Back



- y_{st} = log of real value added
- y_t = log of real GDP
- Δ = first differences

Calibration of Production Parameters ▸ Back

$$Q_{jt} = A_{jt}(K_{jt}^{\alpha_j} L_{jt}^{1-\alpha_j})^{\theta_j} M_{jt}^{1-\theta_j} \quad \text{where } X_{jt} = \Pi_{i=1}^{N} M_{ijt}^{\gamma_{ij}}$$

1. **Primary inputs shares** θ: average value added as share of gross output (BEA I-O database 1947 - 2018) ▸ Details

Calibration of Production Parameters ▸ Back

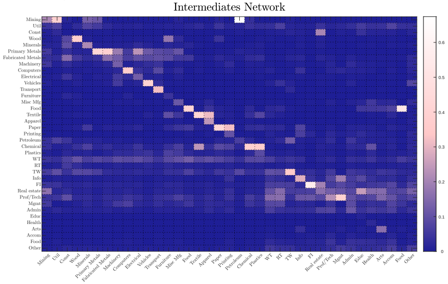
$$Q_{jt} = A_{jt}(K_{jt}^{\alpha_j} L_{jt}^{1-\alpha_j})^{\theta_j} M_{jt}^{1-\theta_j} \quad \text{where } X_{jt} = \Pi_{i=1}^{N} M_{ijt}^{\gamma_{ij}}$$

1. **Primary inputs shares** θ
2. **Labor shares** α: average labor compensation as share of total costs adjusted for self-employment
(BEA I-O database extended back to 1947 - 2018) ▸ Details

Calibration of Production Parameters ▸ Back

$$Q_{jt} = A_{jt}(K_{jt}^{\alpha_j} L_{jt}^{1-\alpha_j})^{\theta_j} X_{jt}^{1-\theta_j} \quad \text{where } X_{jt} = \Pi_{i=1}^{N} M_{ijt}^{\gamma_{ij}}$$

1. **Primary inputs shares** θ
2. **Labor shares** α
3. **Intermediates input-output network** Γ: average intermediates cost from *i* as share of total intermediates costs for *j* (BEA I-O database 1947-2018)



Calibration of Investment Parameters ▸ Back

$$K_{jt+1} = (1 - \delta_j)K_{jt} + I_{jt} \quad \text{where } I_{jt} = \Pi_{i=1}^{N} I_{ijt}^{\lambda_{ij}}$$

1. **Depreciation rate** δ_j: average annual depreciation (BEA fixed assets 1947 - 2017) ▸ Details

Calibration of Investment Parameters ▸ Back

$$K_{jt+1} = (1 - \delta_j)K_{jt} + I_{jt} \quad \text{where } I_{jt} = \Pi_{i=1}^{N} I_{ijt}^{\lambda_{ij}}$$

1. **Depreciation rate** δ_j
2. **Investment input-output network** Λ: already constructed

Calibration of Preference Parameters ▸ Back

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\log C_t - \chi L_t\right), \quad \text{where } C_t = \Pi_{j=1}^{N} C_{jt}^{\xi_j} \text{ and } \sum_{j=1}^{N} \xi_j = 1$$

1. **Discount factor** $\beta = 0.96$ (annual)

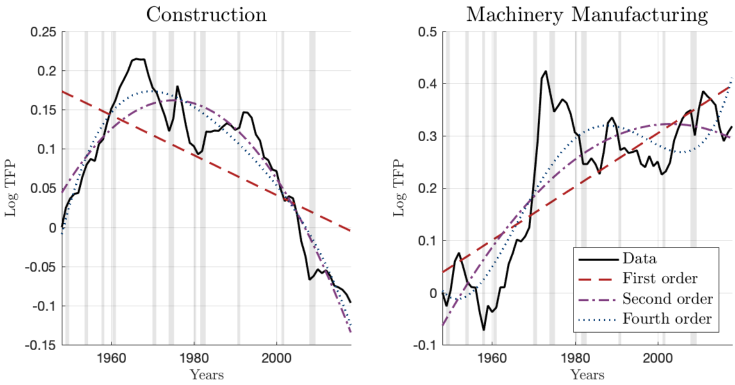
Calibration of Preference Parameters ▸ Back

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\log C_t - \chi L_t\right), \quad \text{where } C_t = \Pi_{j=1}^{N} C_{jt}^{\xi_j} \text{ and } \sum_{j=1}^{N} \xi_j = 1$$

1. **Discount factor** $\beta = 0.96$ (annual)

2. **Consumption shares** ξ_j: average consumption expenditure on j as share of total consumption expenditure (BEA I-O database 1947 - 2018) ▸ Details

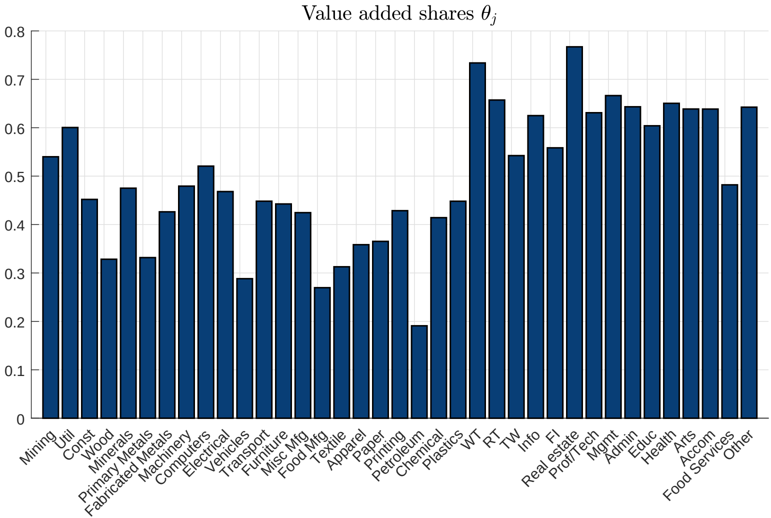
Detrending Sector-Level Data [Back]



- Sector-level data is not well-described by linear trend
- Choose log-polynomial trend with order = 4 in order to balance:
  1. Flexibility of the trend ($\Longrightarrow$ higher order)
  2. Overfitting of the data ($\Longrightarrow$ lower order)

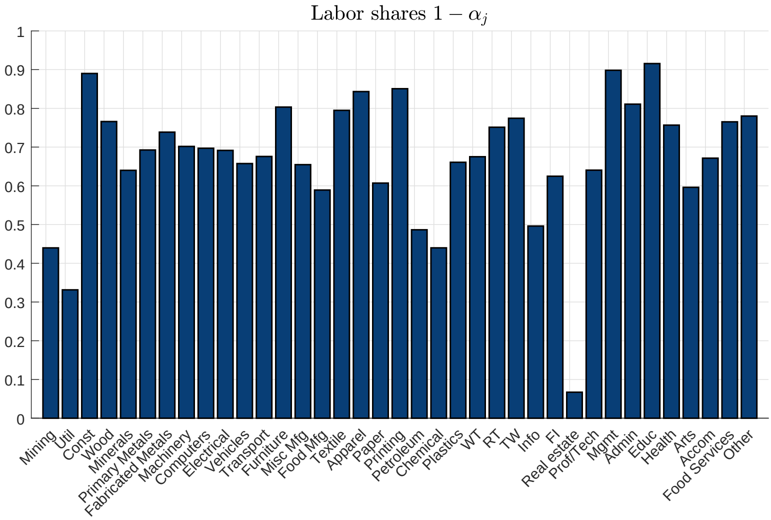
Measured Intermediates Shares

Back

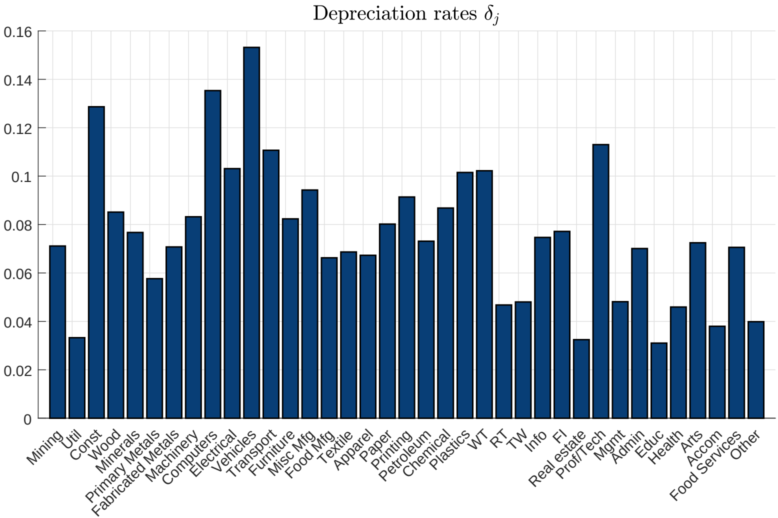


Measured Labor Shares

Back

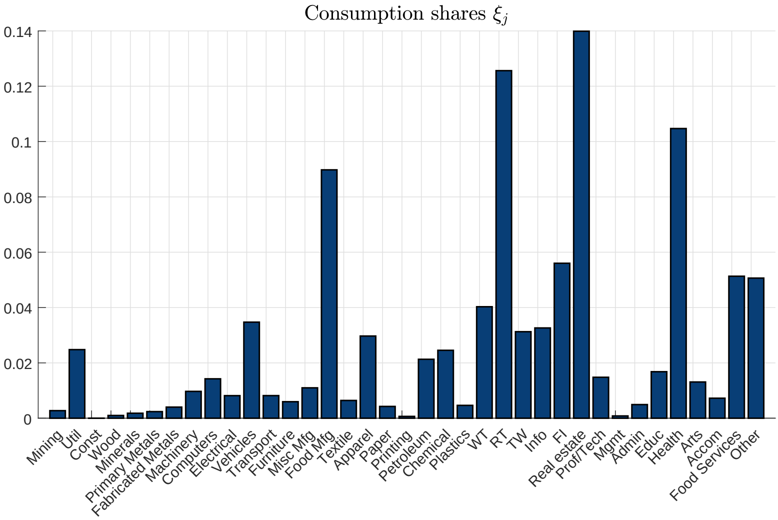


Measured Depreciation Rates ▸ Back



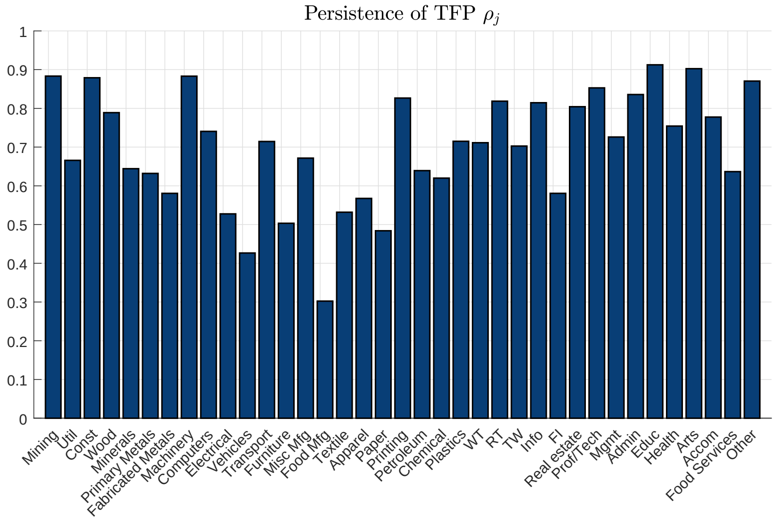
Measured Consumption Shares

Back



Measured TFP Persistence

Back



Interpretation of Change in Shock Process ▸ Back

- Helpful special case to interpret change in shock process:

$$\log A_{jt} = \underbrace{\log \widehat{A}_t}_{\text{aggregate shock}} + \underbrace{\log \widehat{A}_{jt}}_{\text{sector-specific shock}}$$

- Characterize using principal components analysis:

Sample period	$1000\mathbb{V}ar(\Delta \log A_t)$	Due to 1st component	Residual
1949-1983	0.41	0.31 (75%)	0.10 (25%)
1984-2018	0.09	0.03 (35%)	0.06 (65%)

- Volatility of aggregate factor falls in half, but volatility of idiosyncratic factor stable

Aggregating Sector-Level Production ▸ Back

Proposition

Up to first order, the impact effect of a sector-specific shock A_{it} on real GDP Y_t is given by

$$d\log Y_t = \underbrace{\sum_{j=1}^{N}\left(\frac{p_j Q_j}{P^Y Y}\right)^{*} d\log A_{jt}}_{\equiv d\log TFP_t} + (1-\overline{\alpha}^{*})\underbrace{\sum_{j=1}^{N}\left(\frac{L_j}{L}\right)^{*} d\log L_{jt}}_{\equiv d\log L_t}$$

where $1-\overline{\alpha}^{*} = \left(\frac{WL}{P^Y Y}\right)^{*}$ is the steady state labor share. ▸ Derivation

Aggregating Sector-Level Production ▸ Back

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where $1-\overline{\alpha}^* = \left(\frac{WL}{P^Y Y}\right)^*$ *is the steady state labor share.* ▸ Derivation

- Effect on $d\log TFP_t$ given by steady state *Domar weight* $\left(\frac{p_j Q_j}{P^Y Y}\right)^*$
  - **Hulten's theorem**: due to Cobb-Douglas technology and competitive + frictionless markets ▸ Distribution of Domar Weights
- Effect on $d\log L_t$ is endogenous and depends on $\{d\log L_{jt}\}_{j=1}^{N}$

Aggregating Sector-Level Value Added ▸ Back

- Straightforward to compute aggregate employment $L_t = \sum_{j=1}^{N} L_{jt}$, but real GDP difficult due to changes in relative prices
- Compute real GDP using a **Divisia index**
  1. Begin with definition of nominal GDP is $P_t^Y Y_t = \sum_{j=1}^{N} p_{jt}^Y Y_{jt}$
  2. Then compute growth rate, holding prices fixed

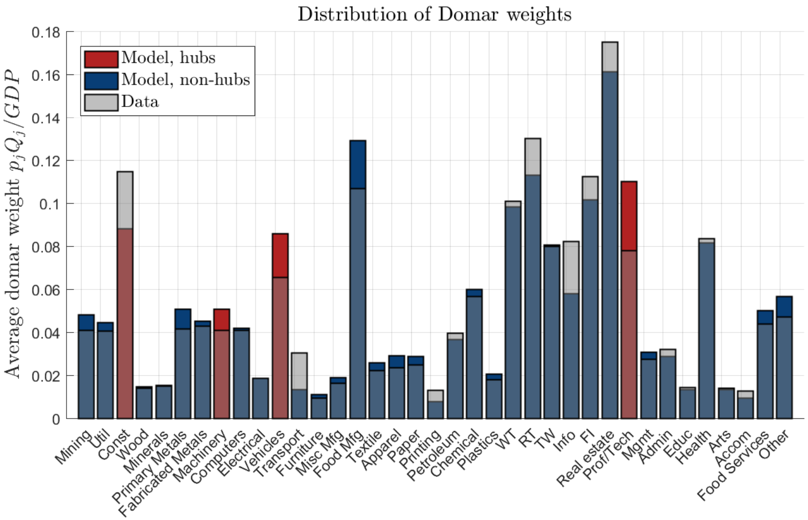
$$d \log Y_t = \sum_{j=1}^{N} \left(\frac{p_{jt}^Y Y_{jt}}{P_t^Y Y_t} \right) d \log Y_{jt}$$

- Sector-level value added depends only on TFP and primary inputs:

$$d \log Y_{jt} = \frac{1}{\theta_j} d \log A_{jt} + \alpha_j d \log K_{jt} + (1 - \alpha_j) d \log L_{jt}$$

Stationary Distribution of Domar Weights

▸ Back



Derivation of Employment Allocation ▸ Back

- Equilibrium is efficient, so allocation of employment satisfies

$$\alpha_j \theta_j \frac{p_{jt} Q_{jt}}{L_{jt}} = C_t \implies L_{jt} = \alpha_j \theta_j \frac{p_{jt} Q_{jt}}{C_t}$$

- Focus on characterizing the household's value of output $\frac{p_{jt} Q_{jt}}{C_t}$

Derivation of Employment Allocation ▸ Back

- Equilibrium is efficient, so allocation of employment satisfies

$$\alpha_j \theta_j \frac{p_{jt} Q_{jt}}{L_{jt}} = C_t \quad \Longrightarrow \quad L_{jt} = \alpha_j \theta_j \frac{p_{jt} Q_{jt}}{C_t}$$

- Focus on characterizing the household's value of output $\frac{p_{jt} Q_{jt}}{C_t}$
- Define the **input-output matrix**

$$\Gamma = \begin{bmatrix} \gamma_{11}(1-\theta_1) & \dots & \gamma_{1N}(1-\theta_N) \\ \vdots & & \vdots \\ \gamma_{N1}(1-\theta_1) & \dots & \gamma_{NN}(1-\theta_N) \end{bmatrix}$$

  - Entry $(i,j) = j$'s expenditure share on intermediates from i
  - Cobb-Douglas technology $\Longrightarrow$ expenditure shares constant

- **Leontief inverse** $\mathcal{L} = (I - \Gamma)^{-1} = I + \Gamma + (\Gamma)^2 + \dots, [\mathcal{L}]_{ij} = \ell_{ij}$
  - Captures importance of i as supplier to j directly + indirectly

Derivation of Employment Allocation ▸ Back

- Market clearing condition for gross output multiplied by price:

$$P_{jt}Q_{jt} = P_{jt}C_{jt} + \sum_{i=1}^{N} P_{jt}M_{jit} + \sum_{i=1}^{N} P_{jt}I_{jit}$$

- Use Cobb-Douglas demand functions for consumption + inputs:

$$P_{jt}Q_{jt} = \xi_j C_t + \sum_{i=1}^{N}(1-\theta_i)\gamma_{ji}P_{it}Q_{it} + \sum_{i=1}^{N}\lambda_{ji}P^I_{it}I_{it}$$

- Divide by total consumption expenditure and solve system of equations:

$$\frac{P_{jt}Q_{jt}}{C_t} = \sum_{k=1}^{N}\ell_{jk}\xi_k + \sum_{k=1}^{N}\ell_{jk}\left(\sum_{m=1}^{N}\frac{P^I_{mt}I_{mt}}{C_t}\right)$$

Cobb-Douglas Capital Accumulation ▸ Back

Proposition

(Rossi-Hansberg and Wright 2007) Consider the version of our model in which $K_{jt+1} = K_{jt}^{1-\delta_j} I_{jt}^{\delta_j}$. *Then the household's valuation of investment* $\frac{p^I_{mt} I_{mt}}{C_t}$ *is constant, so employment* L_{jt} *is constant over time.*

- C-D technology: investment expenditure $\propto$ total income
  C-D preferences: consumption expenditure $\propto$ total income
  $\implies$ investment expenditure proportional to total conusmption
- Standard technology increases elasticity of capital w.r.t investment, breaking proportionality
- NB: full depreciation $\delta_j = 1$ special case of C-D technology

The Leontief-Adjusted Investment Network ▸ Back

Proposition

Fluctuations in sector-level employment L_{jt} are given by, up to first order,

$$d\log L_{jt} = \sum_{m=1}^{N} \omega_{jm} \left(\frac{P^I_m I_m}{P_j Q_j}\right)^* d\log\left(\frac{p^I_{mt} I_{mt}}{C_t}\right), \text{ where } \omega_{jm} = \sum_{k=1}^{N} \ell_{jk}\lambda_{km}.$$

The Leontief-Adjusted Investment Network

Back

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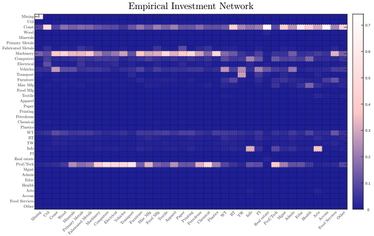
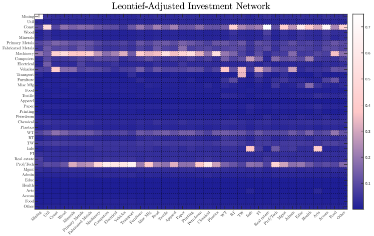
- Role of sector j in supplying investment goods determined by **Leontief-adjusted investment network** $\Omega = \mathcal{L}\Lambda$ Networks Literature





The Leontief-Adjusted Investment Network ▸ Back

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- Role of sector j in supplying investment goods determined by **Leontief-adjusted investment network** $\Omega = \mathcal{L}\Lambda$ ▸ Networks Literature
- Given fluctuations in $d \log \left(\frac{p^I_{mt} I_{mt}}{C_t} \right)$, Leontief-adjusted network Ω determines response of L_{jt}

The Leontief-Adjusted Investment Network ▸ Back

Proposition

Fluctuations in sector-level employment L_{jt} are given by, up to first order,

$$d\log L_{jt} = \sum_{m=1}^{N} \omega_{jm} \left(\frac{P^I_m I_m}{P_j Q_j}\right)^* d\log\left(\frac{p^I_{mt} I_{mt}}{C_t}\right), \text{ where } \omega_{jm} = \sum_{k=1}^{N} \ell_{jk}\lambda_{km}.$$

- Role of sector j in supplying investment goods determined by **Leontief-adjusted investment network** $\Omega = \mathcal{L}\Lambda$ ▸ Networks Literature
- Given fluctuations in $d\log\left(\frac{p^I_{mt} I_{mt}}{C_t}\right)$, Leontief-adjusted network Ω determines response of L_{jt}
- Will now show that Leontief-adjusted network Ω also determines which shocks generate fluctuations in $d\log\left(\frac{p^I_{mt} I_{mt}}{C_t}\right)$

Relationship to Networks Literature ▸ Back

- Primarily studies static models without investment
- Our model without investment $\implies$ employment is constant, so:
  1. Hulten's holds for real GDP: $d\log Y_t = \sum_{j=1}^{N} \left(\frac{p_j Q_j}{P^Y Y}\right)^* d\log A_{jt}$
  2. Hulten's globally true (Domar weights constant)
- Networks literature breaks Hulten's theorem with deviations from
  - Cobb-Douglas production (e.g. Baqaee-Farhi 2019)
  - Competitive + frictionless markets (e.g. Baqaee-Farhi 2020)
- Our paper: investment breaks strong Hulten's theorem as well
  1. Employment and GDP also depend on Leontief-adjusted investment network Ω
  2. Domar weights fluctuate reflecting changes in household's valuation of investment (relevant for higher-order)

Which Shocks Matter for Investment/Employment?

Back

$$\underbrace{\frac{p^I_{mt}}{C_t}}_{\text{MC}} = \underbrace{\beta \mathbb{E}_t \left[\alpha_j \theta_j \frac{p_{m,t+1}}{C_{t+1}} \frac{Q_{m,t+1}}{K_{m,t+1}} + (1-\delta) \frac{p^I_{m,t+1}}{C_{t+1}} \right]}_{\text{MB = MRPK + value of undepreciated capital}}$$

Which Shocks Matter for Investment/Employment?

▸ Back

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- Shock to hub/supplier ≈ aggregate investment supply shock

  ▸ Investment-Specific Shock Literature

  - Direct effect on price, holding primary input prices fixed:

    $$d \log p^I_{mt} = -\sum_{j=1}^{N} \omega_{jm} d \log A_{jt}$$

  - Hubs/suppliers have high ω_{jm} for many m

Which Shocks Matter for Investment/Employment?

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$$\underbrace{\frac{p^I_{mt}}{C_t}}_{\text{MC}} = \underbrace{\beta \mathbb{E}_t \left[\alpha_j \theta_j \frac{p_{m,t+1}}{C_{t+1}} \frac{Q_{m,t+1}}{K_{m,t+1}} + (1-\delta) \frac{p^I_{m,t+1}}{C_{t+1}} \right]}_{\text{MB = MRPK + value of undepreciated capital}}$$

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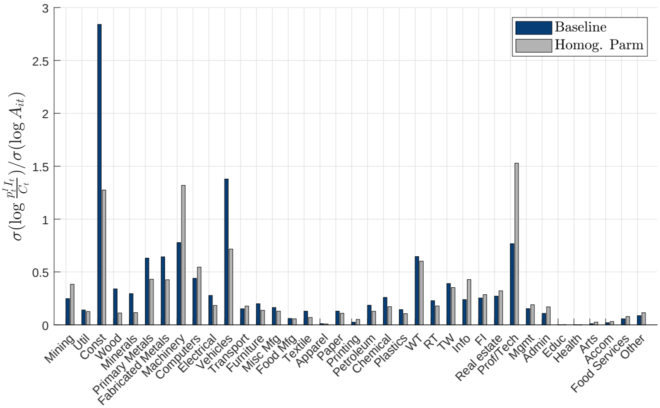
    $$d \log p^I_{mt} = -\sum_{j=1}^{N} \omega_{jm} d \log A_{jt}$$

  - Hubs/suppliers have high ω_{jm} for many m
- Shock to other sectors ≈ idiosyncratic investment demand shock
  - Primarily increases MRPK in own sector, but small effect on other sectors

Which Shocks Matter for Investment? Back



- Responses of $\frac{P_t^I I_t}{C_t}$ similar to responses of employment N_t
- Heterogeneity driven by Leontief-adjusted investment network
    - Heterogeneity in depreciation δ_j and capital shares α_j also matter for construction

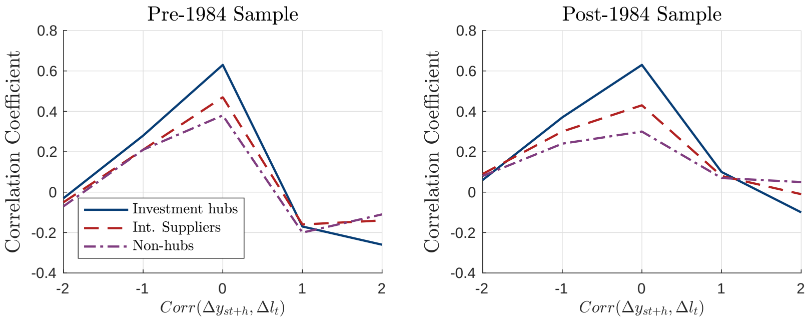
Supporting Evidence for Role of Key Suppliers ▸ Back

	Investment Hubs		**Suppliers**		**Others**	
Data	*Pre-84*	*Post-84*	*Pre-84*	*Post-84*	*Pre-84*	*Post-84*
$\sigma(\Delta y_{st})$	9.13%	9.18%	8.03%	6.72%	5.94%	4.90%
$\sigma(\Delta l_{st})$	6.14%	4.83%	6.04%	4.04%	2.70%	2.69%
Model	*Pre-84*	*Post-84*	*Pre-84*	*Post-84*	*Pre-84*	*Post-84*
$\sigma(\Delta y_{st})$	12.92%	9.63%	9.02%	7.03%	5.57%	4.93%
$\sigma(\Delta l_{st})$	9.37%	6.65%	5.93%	4.28%	1.68%	1.18%

- y_{st} = log of real value added
- l_{st} = log of employment
- Δ = first differences
- Statistics are averaged across sectors unweighted

Supporting Evidence for Role of Key Suppliers

Back



- y_{st} = log of real value added
- l_t = log of aggregate employment
- Δ = first differences

Relationship to Investment-Specific Shocks ▸ Back

- Existing literature on effects of **investment-specific technology shocks** (e.g. Greenwood et al. 2000, Justiniano et al. 2010)
  - Like our model without intermediates network $\implies \Omega \approx \Lambda$

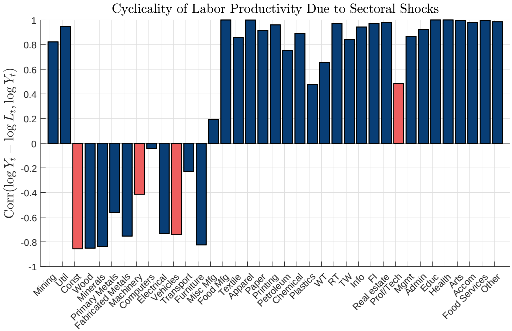
$$d\log L_{jt} = \sum_{m=1}^{N} \lambda_{jm} \left(\frac{P^I_m I_m}{P_j Q_j} \right)^* \left(d\log p^I_{mt} I_{mt} - d\log C_t \right)$$

- Comovement problem between consumption and investment
  - Inconsistent with empirical degree of comovement
    $\implies$ smaller agg effects of investment-specific shocks
  - Typical solution: strong nominal or real rigidities
  - Our model generates comovement through intermediates network (Hornstein and Praschnik 1997)
- Debate about measurement of investment-specific shocks
  - Our model: TFP shocks to hubs + key suppliers

Labor Productivity in Response to Sectoral Shocks

Back

- The impact effect of shock on aggregate labor productivity is
$$d\log LP_t = d\log TFP_t - \alpha^* d\log L_t$$
  - Effect on $d\log TFP_t$ determined by Domar weight $\frac{p_j Q_j}{P^Y Y}$
  - Effect on $d\log L_t$ depends on role in Leontief-adjusted investment network Ω



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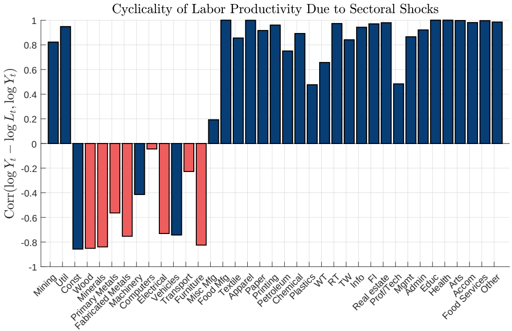


Capital Reallocation Frictions

Back

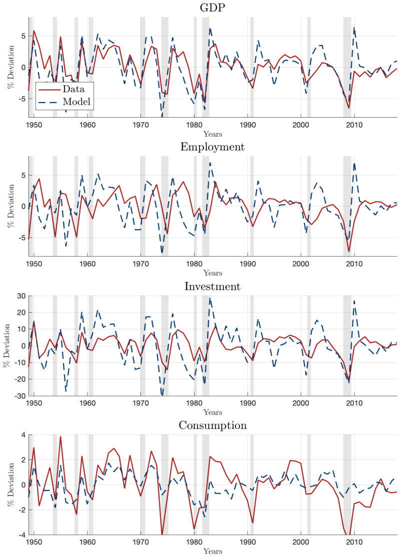
	Data	Baseline Model	Extended Model
$1000 \times \mathbb{E}[\Delta \lvert \frac{p^I_{jt} I_{jt}}{\sum_{k=1}^N p^I_{kt} I_{kt}} \rvert]$	2.0%	9.7%	2.0%
$1000 \times \sigma \left(\frac{p^I_{jt} I_{jt}}{\sum_{k=1}^N p^I_{kt} I_{kt}} \right)$	2.7%	14.1%	2.7%

- Baseline model generates excessive volatility in the composition of investment purchases across sectors
- Extend model to allow for imperfect substitution (Huffman-Wynne 1999):

$$Q_{jt} = C_{jt} + \sum_{i=1}^{N} M_{ijt} + \left(\sum_{i=1}^{N} I_{ijt}^{-\rho} \right)^{-\frac{1}{\rho}}$$

  - $\rho \leq -1$ controls degree of imperfect substitution
  - Set $\rho = -1.04$ to match degree of reallocation in data

Postwar Time Series: First Differences ▸ Back



Postwar Time Series: HP Filtered ▸ Back

Structural Change: Transition Path Approach ▸ Back

	Baseline		Changing Parameters	
	Pre-1984	*Post-1984*	*Pre-1984*	*Post-1984*
$\sigma(\Delta y_t)$	3.95%	2.42%	4.57%	2.10%
$\rho(\Delta y_t - \Delta l_t, \Delta y_t)$	0.52	-0.01	0.50	0.05
$\sigma(\Delta l_t)/\sigma(\Delta y_t)$	0.90	1.03	0.89	1.02

- **Changing parameters** also allows for changes in: production function α_{jt}, θ_{jt}, intermediates network γ_{ijt}, investment network λ_{ijt}, depreciation rates δ_{jt}, and preferences ξ_{jt}
    - Compute fourth-order trend of these parameters
    - Assume perfect foresight over path using Maliar et al. (2015)

- Parameter changes also generate fluctuations, so increase investment production frictions to $\rho = -1.3$

Structural Change: Simulation Approach ▸ Back

	Simulated Moments		Changing Parameters	
	Pre-1984	*Post-1984*	*Pre-1984*	*Post-1984*
$\sigma(\Delta y_t)$	3.63%	2.13%	4.07%	2.04%
$\rho(\Delta y_t - \Delta l_t, \Delta y_t)$	0.76	0.42	0.80	0.43
$\sigma(\Delta l_t)/\sigma(\Delta y_t)$	0.83	0.92	0.83	0.92

- **Simulated moments** from model with estimated covariance matrix of shocks pre-1984 vs. post-1984
  - Must collapse non-durable manufacturing to one sector (30 total)
- **Changing parameters** allows for different parameter values in pre-1984 vs. post-1984 subsample: production function α_j, θ_j, intermediates network γ_{ij}, investment network λ_{ij}, depreciation rates δ_j, preferences ξ_j, and persistence ρ_j

CES Production and Preferences ▸ Back

- Extend model to incorporate **CES production function**

$$Y_{jt} = \left(\theta_j^{\frac{1}{\sigma_V}} V_{jt}^{\frac{\sigma_V - 1}{\sigma_V}} + (1-\theta_j)^{\frac{1}{\sigma_V}} M_{jt}^{\frac{\sigma_V - 1}{\sigma_V}} \right)^{\frac{\sigma_V}{\sigma_V - 1}}, \sigma_V = 0.8 \text{ (Oberfield-Raval 2020)}$$

$$V_{jt} = A_{jt} \left(\alpha_j^{\frac{1}{\sigma_k}} K_{jt}^{\frac{\sigma_k - 1}{\sigma_k}} + (1-\alpha_j)^{\frac{1}{\sigma_k}} L_{jt}^{\frac{\sigma_k - 1}{\sigma_k}} \right)^{\frac{\sigma_k}{\sigma_k - 1}}, \sigma_k = 0.6 \text{ (Oberfield-Raval 2020)}$$

$$M_{jt} = \left(\sum_{i=1}^{N} \gamma_{ij}^{\frac{1}{\sigma_m}} M_{jt}^{\frac{\sigma_m - 1}{\sigma_m}} \right)^{\frac{\sigma_m}{\sigma_m - 1}}, \sigma_m = 0.1 \text{ (Atalay 2017)}$$

- Also allow for **CES preferences** over the bundle

$$C_t = \left(\sum_{j=1}^{N} \xi_j^{\frac{1}{\sigma_C}} C_{jt}^{\frac{\sigma_C - 1}{\sigma_C}} \right)^{\frac{\sigma_C}{\sigma_C - 1}}, \sigma_C = 0.75 \text{ (Oberfield-Raval 2020)}$$

CES Production and Preferences ▸ Back

	Cobb-Douglas		CES	
	Pre-1984	*Post-1984*	*Pre-1984*	*Post-1984*
$\sigma(\Delta y_t)$	3.89%	2.79%	4.31%	2.94%
$\rho(\Delta y_t - \Delta l_t, \Delta y_t)$	0.52	-0.15	0.30	-0.38
$\sigma(\Delta l_t)/\sigma(\Delta y_t)$	0.90	1.05	0.96	1.08
$\sigma(\Delta i_t)/\sigma(\Delta y_t)$	3.78	4.09	3.73	4.17

- CES structure raises overall level of employment volatility, but generates similar changes over time

CES Production and Preferences ▸ Back

	σ_c **only**		σ_k **only**	
	Pre-1984	*Post-1984*	*Pre-1984*	*Post-1984*
$\sigma(\Delta y_t)$	3.87%	2.79%	4.43%	2.98%
$\rho(\Delta y_t - \Delta l_t, \Delta y_t)$	0.54	-0.14	0.24	-0.35
$\sigma(\Delta l_t)/\sigma(\Delta y_t)$	0.89	1.04	0.97	1.08
$\sigma(\Delta i_t)/\sigma(\Delta y_t)$	3.79	4.11	3.71	4.01
	σ_v **only**		σ_m **only**	
$\sigma(\Delta y_t)$	3.85%	2.76%	3.86%	2.79%
$\rho(\Delta y_t - \Delta l_t, \Delta y_t)$	0.50	-0.20	0.55	-0.12
$\sigma(\Delta l_t)/\sigma(\Delta y_t)$	0.90	1.06	0.89	1.04
$\sigma(\Delta i_t)/\sigma(\Delta y_t)$	3.81	4.13	3.77	4.14

- Higher volatility under CES primarily due to capital-labor complementarity

CES Production and Preferences ▸ Back

	First Order CD		Second Order CD	
	Pre-1984	*Post-1984*	*Pre-1984*	*Post-1984*
$\sigma(\Delta y_t)$	3.89%	2.79%	3.87%	2.74%
$\rho(\Delta y_t - \Delta l_t, \Delta y_t)$	0.52	-0.15	0.52	-0.11
$\sigma(\Delta l_t)/\sigma(\Delta y_t)$	0.90	1.05	0.89	1.04
$\sigma(\Delta i_t)/\sigma(\Delta y_t)$	3.78	4.09	3.98	4.45
	First Order CES		**Second Order CES**	
$\sigma(\Delta y_t)$	4.31%	2.94%	4.38%	3.07%
$\rho(\Delta y_t - \Delta l_t, \Delta y_t)$	0.30	-0.38	0.29	-0.43
$\sigma(\Delta l_t)/\sigma(\Delta y_t)$	0.96	1.08	0.96	1.10
$\sigma(\Delta i_t)/\sigma(\Delta y_t)$	3.73	4.17	3.98	4.52

- Nonlinearities fairly unimportant for these unconditional statistics (but may generate different conditional behavior)

Allowing for Labor Reallocation Frictions ▸ Back

	Baseline		Labor Reallocation Frictions	
	Pre-1984	*Post-1984*	*Pre-1984*	*Post-1984*
$\sigma(\Delta y_t)$	3.95%	2.42%	3.63%	2.21%
$\rho(\Delta y_t - \Delta l_t, \Delta y_t)$	0.52	-0.01	0.71	0.33
$\sigma(\Delta l_t)/\sigma(\Delta y_t)$	0.90	1.03	0.83	0.95
$\sigma(\Delta i_t)/\sigma(\Delta y_t)$	3.78	4.11	3.49	3.81

- Modify preferences to become

$$\mathbb{E}_0 \left[\sum_{t=0}^{\infty} \beta^t \left(\log C_t - \left(\sum_{j=1}^{N} L_{jt}^{\frac{\tau+1}{\tau}} \right)^{\frac{\tau}{\tau+1}} \right) \right]$$

  - τ controls substitutability of labor across sectors

- Set τ to match $\sigma(\Delta l_t)/\sigma(\Delta y_t)$ in pre-84 period

Role of Investment Production Frictions ▸ Back

	Baseline		No Frictions	
	Pre-1984	*Post-1984*	*Pre-1984*	*Post-1984*
$\sigma(\Delta y_t)$	3.95%	2.42%	3.97%	2.64%
$\rho(\Delta y_t - \Delta l_t, \Delta y_t)$	0.52	-0.01	0.38	-0.31
$\sigma(\Delta l_t)/\sigma(\Delta y_t)$	0.90	1.03	0.93	1.13
$\sigma(\Delta i_t)/\sigma(\Delta y_t)$	3.78	4.11	5.63	9.22
	Large Frictions			
$\sigma(\Delta y_t)$	3.86%	2.38%		
$\rho(\Delta y_t - \Delta l_t, \Delta y_t)$	0.57	0.10		
$\sigma(\Delta l_t)/\sigma(\Delta y_t)$	0.88	1.00		
$\sigma(\Delta i_t)/\sigma(\Delta y_t)$	3.74	4.16		

- **No frictions** assumes $\rho = -1$ as in theory section
- **Large frictions** assumes $\rho = -1.5$ (baseline $\rho = -1.04$)

Allowing for Maintenance Investment ▸ Back

	Baseline		Maintenance Investment	
	Pre-1984	*Post-1984*	*Pre-1984*	*Post-1984*
$\sigma(\Delta y_t)$	3.95%	2.42%	3.49%	2.10%
$\rho(\Delta y_t - \Delta l_t, \Delta y_t)$	0.52	-0.01	0.70	0.33
$\sigma(\Delta l_t)/\sigma(\Delta y_t)$	0.90	1.03	0.82	0.95
$\sigma(\Delta i_t)/\sigma(\Delta y_t)$	3.78	4.11	4.02	4.38

- McGrattan and Schmitz (1999) estimate maintenance $\approx$ 30% as big as new investment, but no systematic estimates available
- Open question: from which sectors is maintenance purchased?
  - One extreme is same mix as new investment
  - Another is all from own-sector output
- **Maintenance investment** assumes half of maintenance is done out of own-sector investment

Alternative Trends for Sector-Level TFP ▸ Back

	Baseline (4th order)		2nd order	
	Pre-1984	*Post-1984*	*Pre-1984*	*Post-1984*
$\sigma(\Delta y_t)$	3.95%	2.42%	3.75%	2.30%
$\rho(\Delta y_t - \Delta l_t, \Delta y_t)$	0.52	-0.01	0.66	0.23
$\sigma(\Delta l_t)/\sigma(\Delta y_t)$	0.90	1.03	0.85	0.98
$\sigma(\Delta i_t)/\sigma(\Delta y_t)$	3.78	4.11	3.65	3.95
	5th order			
$\sigma(\Delta y_t)$	3.88%	2.66%		
$\rho(\Delta y_t - \Delta l_t, \Delta y_t)$	0.47	0.07		
$\sigma(\Delta l_t)/\sigma(\Delta y_t)$	0.92	1.01		
$\sigma(\Delta i_t)/\sigma(\Delta y_t)$	3.87	4.07		

- Results robust to allowing for different detrending (third order similar)

Role of Changing Shock Size ▸ Back

Full Model	*Pre*	*Post*	***Uniform Var.***	*Pre*	*Post*
$\sigma(\Delta y_t)$	3.95%	2.42%	$\sigma(\Delta y_t)$	1.76%	1.29%
$\sigma(\Delta l_t)/\sigma(\Delta y_t)$	0.90	1.03	$\sigma(\Delta l_t)/\sigma(\Delta y_t)$	0.88	1.03
$\rho(\Delta y_t - \Delta l_t, \Delta y_t)$	0.52	-0.01	$\rho(\Delta y_t - \Delta l_t, \Delta y_t)$	0.55	0.03

- **Uniform variances** standardizes shocks to have SD = 1% pre-1984 and post-1984 (only shock comovement changes, not size of shocks)

Rising Importance of Sector-Specific Shocks ▸ Back

	Agg. Shocks Only		Sectoral Shocks Only	
	Pre-1984	*Post-1984*	*Pre-1984*	*Post-1984*
$\sigma(\Delta y_t)$	3.46%	1.67%	1.65%	1.36%
$\sigma(\Delta l_t)$	2.74%	1.42%	1.78%	1.54%
$\rho(\Delta y_t - \Delta l_t, \Delta y_t)$	0.85	0.79	-0.15	-0.24
$\sigma(\Delta i_t)/\sigma(\Delta y_t)$	3.31	3.48	4.41	4.60

	All Shocks	
	Pre-1984	*Post-1984*
$\sigma(\Delta y_t)$	3.95%	2.42%
$\sigma(\Delta l_t)$	3.55%	2.48%
$\rho(\Delta y_t - \Delta l_t, \Delta y_t)$	0.52	-0.01
$\sigma(\Delta i_t)/\sigma(\Delta y_t)$	3.78	4.11

- Aggregate shock = first principal component (as in empirics)

Existing Explanations for Changing Business Cycles

▸ Back

1. **Changing shock process**:
   - Aggregate demand shocks: Gali and Gambetti (2009); Barnichon (2010); Sarte, Schwartzman, and Lubik (2015)
   - Reallocation shocks become more important: Garin, Pries, and Sims (2018)
2. **More flexible labor markets**: Barnichon (2010), Gali-van Rens (2013)
3. **Selective hiring/firing**:
   - Streamline in recessions: Koenders-Rogerson (2005); Berger (2018)
   - Labor hoarding: Gali-Gambetti (2009); Bachmann (2012)
4. **Mismeasurement of inputs or outputs**:
   - Utilization less procyclical: Fernald- Wang (2016)
   - Non-measured intangible investment is procyclical: McGrattan-Prescott (2007, 2012); McGrattan (2020)

Existing Explanations for Changing Business Cycles

Back

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Existing mechanisms abstract from sectoral heterogeneity, so cannot speak to empirical results

Existing Explanations for Changing Business Cycles

Back

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Existing mechanisms abstract from sectoral heterogeneity,

$\Longrightarrow$ need new explanation for falling cyclicality of labor productivity

Within vs. Between Sector Cycles ▸ Back

	Fixed Weights		Unweighted	
	Pre-1984	*Post-1984*	*Pre-1984*	*Post-1984*
$\rho(y_t - l_t, y_t)$	0.68	0.69	0.76	0.76
$\sigma(l_t)/\sigma(y_t)$	0.78	0.78	0.66	0.63

Decomposition on Role of Comovement ▸ Back

$$\mathbb{V}ar(x_t) = \underbrace{\sum_{j=1}^{N} (\omega_{jt}^{x})^2 \mathbb{V}ar(x_{jt})}_{\text{within-sector}} + \underbrace{\sum_{j=1}^{N} \sum_{o \neq j} \omega_{jt}^{x} \omega_{ot}^{x} \mathbb{C}ov(x_{jt}, x_{ot})}_{\text{between-sector}}$$

Decomposition on Role of Comovement

Back

$$\mathbb{V}ar(x_t) = \sum_{j=1}^{N} (\omega_{jt}^{x})^2 \mathbb{V}ar(x_{jt}) + \sum_{j=1}^{N} \sum_{o \neq j} \omega_{jt}^{x} \omega_{ot}^{x} \mathbb{C}ov(x_{jt}, x_{ot})$$

$$\mathbb{V}ar(y_t) = \sum_{j=1}^{N} (\omega_{jt}^{y})^2 \mathbb{V}ar(y_{jt}) + \sum_{j=1}^{N} \sum_{o \neq j} \omega_{jt}^{y} \omega_{ot}^{y} \mathbb{C}ov(y_{jt}, y_{ot})$$

Decomposition on Role of Comovement ▸ Back

$$\frac{\mathbb{V}ar(x_t)}{\mathbb{V}ar(y_t)} = \frac{\sum_{j=1}^{N}(\omega_{jt}^{x})^2\mathbb{V}ar(x_{jt})}{\sum_{j=1}^{N}(\omega_{jt}^{y})^2\mathbb{V}ar(y_{jt}) + \sum_{j=1}^{N}\sum_{o\neq j}\omega_{jt}^{y}\omega_{ot}^{y}\mathbb{C}ov(y_{jt}, y_{ot})} + \frac{\sum_{j=1}^{N}\sum_{o\neq j}\omega_{jt}^{x}\omega_{ot}^{x}\mathbb{C}ov(x_{jt}, x_{ot})}{\sum_{j=1}^{N}(\omega_{jt}^{y})^2\mathbb{V}ar(y_{jt}) + \sum_{j=1}^{N}\sum_{o\neq j}\omega_{jt}^{y}\omega_{ot}^{y}\mathbb{C}ov(y_{jt}, y_{ot})}$$

Decomposition on Role of Comovement ▸ Back

$$\frac{\mathbb{V}ar(x_t)}{\mathbb{V}ar(y_t)} = \frac{\sum_{j=1}^{N}(\omega_{jt}^{y})^2\mathbb{V}ar(y_{jt})}{\mathbb{V}ar(y_t)} \frac{\sum_{j=1}^{N}(\omega_{jt}^{x})^2\mathbb{V}ar(x_{jt})}{\sum_{j=1}^{N}(\omega_{jt}^{y})^2\mathbb{V}ar(y_{jt})}$$

$$+ \frac{\sum_{j=1}^{N}\sum_{o\neq j}\omega_{jt}^{x}\omega_{ot}^{x}\mathbb{C}ov(x_{jt}, x_{ot})}{\sum_{j=1}^{N}(\omega_{jt}^{y})^2\mathbb{V}ar(y_{jt}) + \sum_{j=1}^{N}\sum_{o\neq j}\omega_{jt}^{y}\omega_{ot}^{y}\mathbb{C}ov(y_{jt}, y_{ot})}$$

Decomposition on Role of Comovement ▸ Back

$$\frac{\mathbb{V}ar(x_t)}{\mathbb{V}ar(y_t)} = \frac{\sum_{j=1}^{N}(\omega_{jt}^{y})^2\mathbb{V}ar(y_{jt})}{\mathbb{V}ar(y_t)} \frac{\sum_{j=1}^{N}(\omega_{jt}^{x})^2\mathbb{V}ar(x_{jt})}{\sum_{j=1}^{N}(\omega_{jt}^{y})^2\mathbb{V}ar(y_{jt})}$$

$$+ \frac{\sum_{j=1}^{N}\sum_{o\neq j}\omega_{jt}^{y}\omega_{ot}^{y}\mathbb{C}ov(y_{jt}, y_{ot})}{\mathbb{V}ar(y_t)} \frac{\sum_{j=1}^{N}\sum_{o\neq j}\omega_{jt}^{x}\omega_{ot}^{x}\mathbb{C}ov(x_{jt}, x_{ot})}{\sum_{j=1}^{N}\sum_{o\neq j}\omega_{jt}^{y}\omega_{ot}^{y}\mathbb{C}ov(y_{jt}, y_{ot})}$$

Accuracy of Decomposition ▸ Back

$$\frac{\mathbb{V}ar(l_t)}{\mathbb{V}ar(y_t)} \approx \underbrace{\omega_t}_{\text{within weight}} \underbrace{\frac{\sum_{j=1}^{N}(\omega_j^l)^2 \mathbb{V}ar(l_{jt})}{\sum_{j=1}^{N}(\omega_j^y)^2 \mathbb{V}ar(y_{jt})}}_{\text{within-sector}} + (1-\omega_t) \underbrace{\frac{\sum_{j=1}^{N}\sum_{o \neq j} \omega_j^l \omega_o^l \mathbb{C}ov(l_{jt}, l_{ot})}{\sum_{j=1}^{N}\sum_{o \neq j} \omega_j^y \omega_o^y \mathbb{C}ov(y_{jt}, y_{ot})}}_{\text{between-sector}}$$

	Pre-84	*Post-84*
Actual, variance	0.68	1.02
Approximation, variance	0.68	1.04
Actual, standard deviation	0.83	1.01
Approximation, standard deviation	0.83	1.02

Sectoral Comovement ▸ Back

$$\rho^x_\tau \equiv \frac{\sum_{i=1}^N \sum_{j=i+1}^N \omega^x_i \omega^x_j \mathbb{C}orr(x_{it}, x_{jt} | t \in \tau)}{\sum_{i=1}^N \sum_{j=i+1}^N \omega^x_i \omega^x_j}$$

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

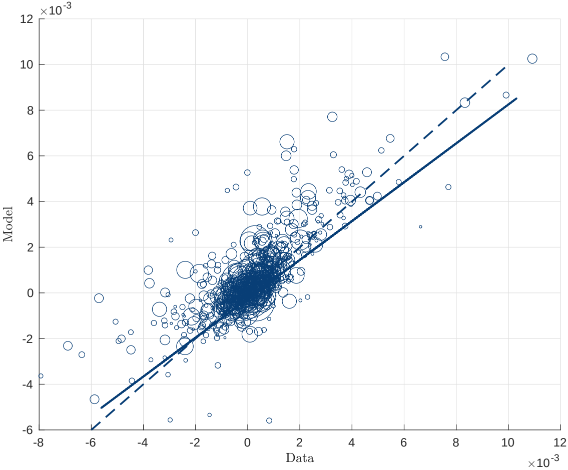
	Data		Model	
	Employment	*Value added*	*Employment*	*Value added*
1951-1983	0.50	0.29	0.98	0.32
1984-2012	0.49	0.17	0.95	0.14
Difference	-0.01	-0.12	-0.03	-0.18

Decomposition at 450 Sector Level (NBER-CES Manufacturing Data) ▸ Back

$$\frac{\mathbb{V}ar(l_t)}{\mathbb{V}ar(y_t)} \approx \underbrace{\omega_t}_{\text{within weight}} \underbrace{\frac{\sum_{j=1}^{N}(\omega_{jt}^{l})^2\mathbb{V}ar(l_{jt})}{\sum_{j=1}^{N}(\omega_{jt}^{y})^2\mathbb{V}ar(y_{jt})}}_{\text{within-sector}} + (1-\omega_t)\underbrace{\frac{\sum_{j=1}^{N}\sum_{o\neq j}\omega_{jt}^{l}\omega_{ot}^{l}\mathbb{C}ov(l_{jt},l_{ot})}{\sum_{j=1}^{N}\sum_{o\neq j}\omega_{jt}^{y}\omega_{ot}^{y}\mathbb{C}ov(y_{jt},y_{ot})}}_{\text{between-sector}}$$

	Pre-84	*Post-84*	*Contribution of entire term*
$\frac{\mathbb{V}ar(l_t)}{\mathbb{V}ar(y_t)}$	0.40	0.57	**100%**
Within Sector	0.34	0.20	1.4%
Between Sector	0.37	0.60	98.6%
Within Weight	0.03	0.06	
$(\omega_t = \sum_{j=1}^{N}(\omega_{jt}^{y})^2\mathbb{V}ar(y_{jt})/\mathbb{V}ar(y_t))$			

Model Fit to Sector-Pair Level Changes ▸ Back



- Plot *sector-pair level* "diff-in-diff" $\Delta\mathbb{C}ov(n_{jt}, n_{ot}) - \Delta\mathbb{C}ov(y_{jt}, y_{ot})$
- Model's $R^2 = 53\%$!

Implications for Investment Stimulus Policy ▸ Back

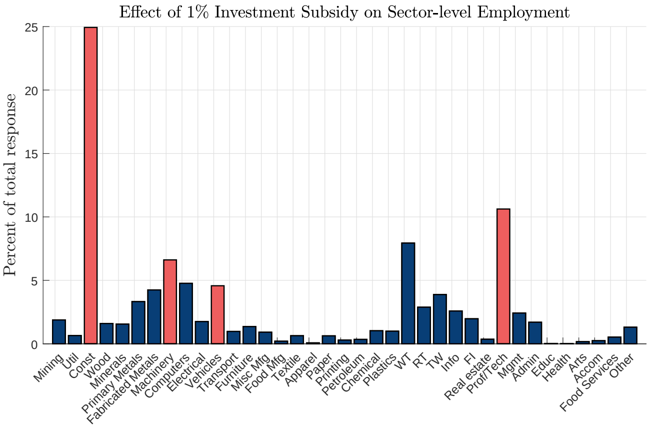
- Stimulus policy = shock sub_t to cost of capital

$$\underbrace{(1 - sub_t)}_{\text{reduced-form subsidy}} \times \underbrace{\nu_{jt}}_{\text{marginal cost of investment goods}}$$

- Reduced-form subsidy captures class of fiscal stimulus, e.g. investment tax credits or accelerated depreciation
- Assume financed from outside the economy
- Study effect of one-time $sub_t = 1\%$ subsidy

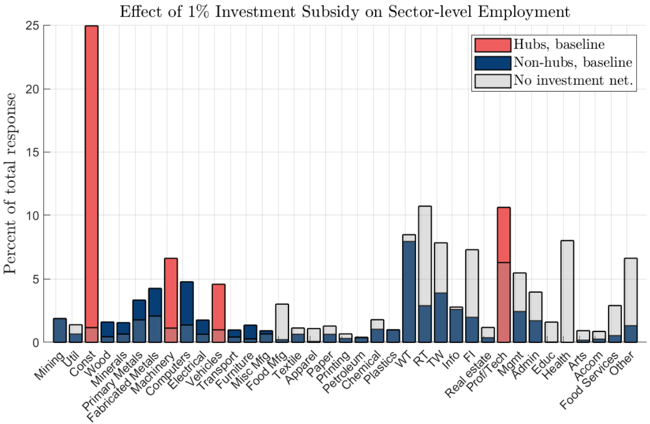
Implications for Investment Stimulus Policy

▸ Back



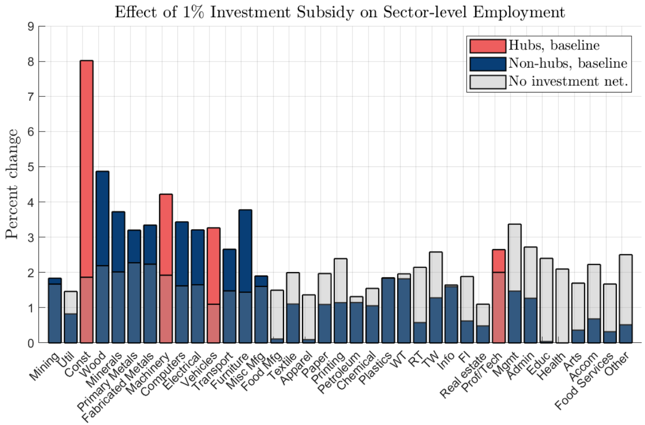
- Increases aggregate investment by 6.5% and employment by 2%
- Employment increase concentrated in hubs + key suppliers

Implications for Investment Stimulus Policy ▸ Back



- More uniform effect in model without investment network
  $\Longrightarrow$ network creates uneven effect on production/employment
  - Despite investment *purchases* being equally subsidized

Implications for Investment Stimulus Policy ▸ Back



- Easier to see uniformity looking at percentage changes