Uncertainty through the Production Network: Sectoral Origins and Macroeconomic Implications

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Context and Questions

- Recent events highlight the importance of sectoral shocks for inflation dynamics
    - E.g., supply shortages and rising relative prices in key upstream industries
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- NK production network model with time-varying uncertainty to interpret the results

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3. Aggregate effects: contractionary; inflationary if uncertainty originates upstream
4. Theory: production linkages central to understanding sectoral effects
   - Lower input demand for suppliers and higher marginal cost for customers (input complementarity)
   - Results hold for both supply- or demand-side driven uncertainty

Literature

1. Effects of time-varying uncertainty
   Bloom(2009), Berger Dew-Becker Giglio (2020), Cesa-Bianchi Pesaran Rebucci (2020), Christiano Motto Rostagno (2014), Basu Bundick (2017) Bloom Floetotto Jaimovich Saporta-Eksten Terry (2018), Dew-Becker and Giglio (2022), Basu Candian Chahrour Valchev (2023), Alfaro Bloom Lin (2023) ..
   - We examine sector-specific uncertainty and study network propagation
2. Macro implications of production networks Acemoglu Carvalho Ozdaglar Tahbaz-Salehi (2012), Acemoglu Ackigit Kerr (2016), Baqaee Farhi (2019a, b), Carvalho Nirei Saito Tahbaz-Salehi (2020) Barattieri Cacciatore (2023) Barattieri Cacciatore Traum (2023) Kopytov Mishra Nimark Taschereau-Dumouchel (2024) ..
   - We focus on the effects of second-moment shocks
3. Sectoral or production network dimensions of uncertainty
   Segal (2019), Ma Samaniego (2019), Castelnuovo et al. (2022) Grigoris Segal (2021) Saijo (2025)
   - We identify high-frequency sectoral uncertainty shocks that are uncorrelated to first-moment shocks and to uncertainty originating in connected industries

Outline

1. Data and Measurement
2. Identification
3. Local Projections and Results
4. Model

Implied Volatility (IV) from OptionMetrics

- Daily firm-level uncertainty: implied volatility of US stock options 1996-2019
- *IV* is the conditional variance of the stock return over the life of the option
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- Different from realized volatility (RV): backward-looking, reflecting past price movements (realized first-moment shocks)
- **Focus:** equity-based, at-the-money options with 30-days maturity
  - Firms listed in at least one major U.S. stock exchange
  - Most liquid options; same time horizon as the VIX
  - Options traded for at least 10 years
  - Industries for which option issuers jointly represent > 0.20 of mkt cap
  - 14m observations for 6,345 firms

Measures of Sectoral Uncertainty

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$$IV_{i,d} = \sum_{f \in i} s_{f,i,d-1} IV_{f,i,d}$$

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- Monthly measure: last-5-trading days average of $IV_{i,d}$

- Realized vol defined analogously using realized squared returns over month

More

Uncertainty Measures: Properties

Panel I: Sectoral Component in Firm Implied Volatility

	No aggregate IV_t control		Aggregate IV_t control	
	Unweighted	Weighted	Unweighted	Weighted
R^2	0.66	0.75	0.25	0.30

Panel II: Contemporaneous Correlations

	Sectoral Unc. (pw)	IP	Aggregate Unc.	Inflation
Sectoral Unc.	0.87	-0.14	0.71	0.02
	(0.74, 0.91)	(-0.30, 0.02)	(0.68, 0.90)	(-0.09, 0.10)

Notes: Panel I: average R^2 from monthly regressions: $IV_{f,i,t} = \alpha_f + \beta_{f,i} IV_{i,t} + \gamma_{f,i} IV_t + \epsilon_{f,i,t}$, where $IV_{f,i,t}$ is the daily firm f's implied volatility averaged over the last 5 trading days of each month, and $IV_{i,t}$ is the corresponding industry-level measure. Panel II: 10th & 90th in brackets.

Identification Challenges

- Consider the following local projection at horizon h:

$$\ln X_{it+h} - \ln X_{it-1} = \alpha_{ih} + \beta_h \sigma_{i,t} + \epsilon_{it}$$

$X_{i,t}$: industry's outcome , e.g., employment, prices

$\sigma_{i,t} = \ln IV_{i,t}$

- Sectoral uncertainty $\sigma_{i,t}$ is endogenous:
    - Sector-specific or aggregate 1st-moment shocks
      e.g., ↑ commodity prices may ↑ uncertainty in energy-intensive industries
    - Uncertainty elsewhere
        - Changes in uncertainty originating in supplier and customer industries
    - Aggregate uncertainty

Supplier and Customer Industry Uncertainty

- Combine uncertainty measures with 2007 total requirement I-O tables (e.g., Acemoglu et al, 2016)

- Supplier uncertainty for industry i :

$$\sigma^S_{i,t} = \sum_k \omega_{ki}\sigma_{k,t},$$

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- Customer uncertainty for industry i :

$$\sigma_{i,t}^{C} = \sum_{k} \tilde{\omega}_{ik} \sigma_{k,t},$$

  $\tilde{\omega}_{ik}$: fraction of i's output demanded by k-th sector in Leontief Inverse form.

Identification Approach – First-Stage Regression

- Purge $\sigma_{i,t}$ of endogenous variation via industry-level time-series regressions:

$$\sigma_{i,t} = \alpha_i + \sum_{\ell=1}^{p} \varphi_i^{\ell} \sigma_{i,t-\ell} + \sum_{\ell=0}^{p} \psi_{rv_i}^{\ell} rv_{t-\ell} + \sum_{\ell=0}^{p} \psi_{\sigma_i}^{\ell} \sigma_{t-\ell} + \sum_{\ell=0}^{p} \mathbf{\Psi}_i^{\ell} \mathbf{Z}_{i,t-\ell} + \nu_{i,t}$$

$$\mathbf{Z}_{i,t} = [rv_{i,t}, rv_{i,t}^{S}, rv_{i,t}^{C}, \sigma_{i,t}^{S}, \sigma_{i,t}^{C}]'$$

1. Control for realized volatility (rv): parse out effects of 1st-moment shocks
   - rv (1st-moment shocks) can affect uncertainty immediately
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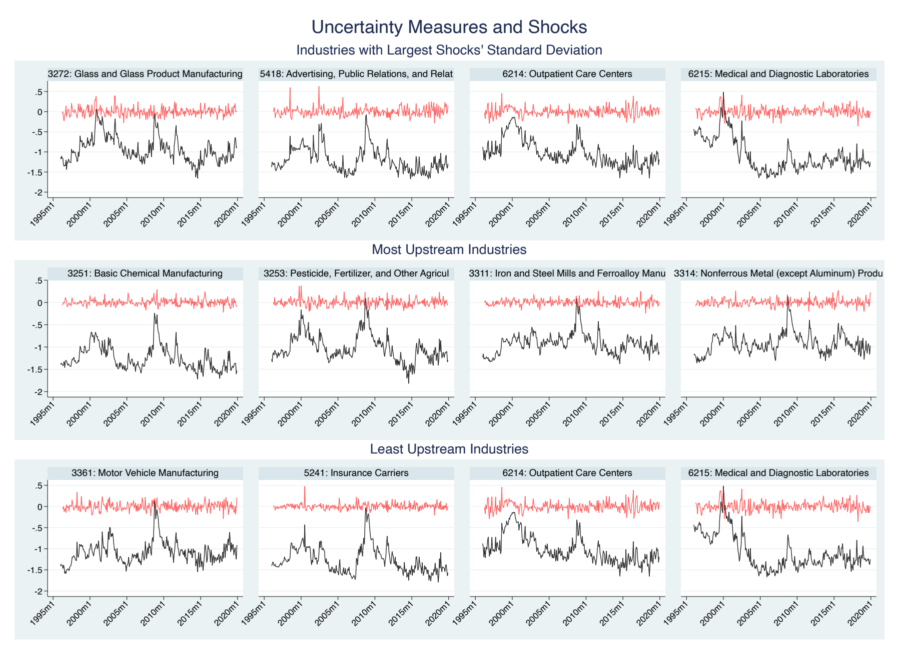
3. Control for aggregate uncertainty


Uncertainty Measures and Shocks
Industries with Largest Shocks' Standard Deviation
3272: Glass and Glass Product Manufacturing
5418: Advertising, Public Relations, and Relat
6214: Outpatient Care Centers
6215: Medical and Diagnostic Laboratories
Most Upstream Industries
3251: Basic Chemical Manufacturing
3253: Pesticide, Fertilizer, and Other Agricul
3311: Iron and Steel Mills and Ferroalloy Manu
3314: Nonferrous Metal (except Aluminum) Produ
Least Upstream Industries
3361: Motor Vehicle Manufacturing
5241: Insurance Carriers
6214: Outpatient Care Centers
6215: Medical and Diagnostic Laboratories
.5
0
-.5
-1
-1.5
-2
1995m1
2000m1
2005m1
2010m1
2015m1
2020m1

First-Stage Results: Shocks Properties

- Estimated shocks have desirable statistical properties
  1. Not autocorrelated
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- Distribution of shock sizes relatively similar upstream and downstream
- What do these shocks capture?
  - Changes in uncertainty common across firms within a NAICS 4-digit industry
  - Idiosyncratic uncertainty affecting large firms within the industry
- Large shocks associated with:
  - Regulatory changes
  - Financial restructuring
  - Technological transformations
  - Trade tensions

Example

Local Projections

- Construct supplier and customer industries shocks as before

$$\hat{v}_{it}^{S} = \sum_{k} \omega_{ki} \hat{v}_{kt} \qquad \hat{v}_{it}^{C} = \sum_{k} \tilde{\omega}_{ik} \hat{v}_{kt}$$

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- Estimate panel local projections: (Jorda, 2005)

$$\ln X_{it+h} - \ln X_{it-1} = \alpha_{ih} + \beta^O_h \hat{v}_{it} + \beta^D_h \hat{v}^S_{it} + \beta^U_h \hat{v}^C_{it} + \varpi_{t+h} + \sum_{\kappa=1}^{p_x} \mathbf{\Phi}^{\kappa}_{x} \mathbf{x}_{t-\kappa} + \epsilon_{it+h}$$

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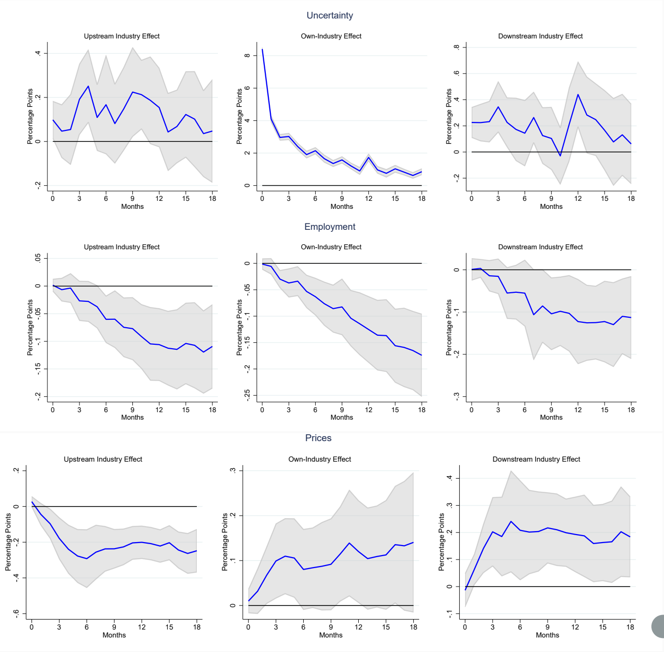
- $\beta_h^O \equiv$ average own-industry effect at horizon h
- $\beta_h^D \equiv$ average downstream effect at horizon h
- $\beta_h^U \equiv$ average upstream effect at horizon h
- $x_{t-\kappa} \equiv$ lags of $\ln X_{it} - \ln X_{it-1}$, lags of shocks

Local Projections: Industry-Level Effects



Robustness

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- X: VIX, aggregate employment, Core CPI
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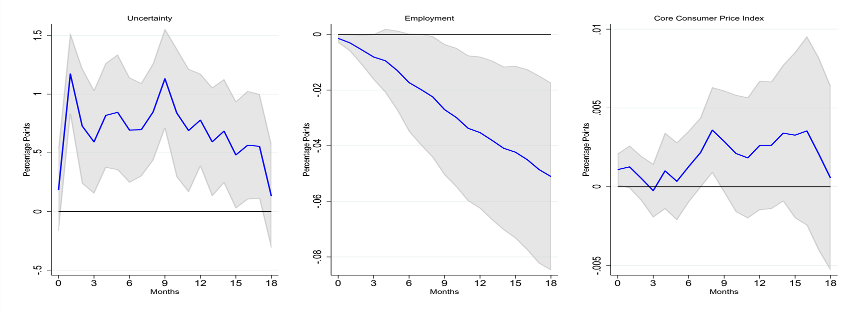

Aggregate Inflation Effects for Upstream and Downstream Uncertainty

- Does inflation response depend on whether uncertainty originates upstream/downstream?

$\hat{\nu}_t^A = \sum_i s_{it} \hat{\nu}_{it} \mathbb{1}[i \in \text{top upstream decile}]$ *or* $\hat{\nu}_t^A = \sum_i s_{it} \hat{\nu}_{it} \mathbb{1}[i \in \text{bottom upstream decile}]$

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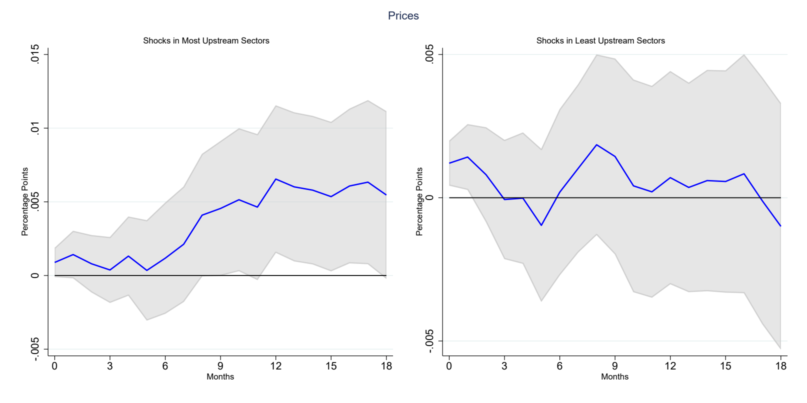

NK-IO network model with time-varying volatility

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- Households maximize

$$\mathbb{V}_t = \max \left[(1-\beta)(C_t^{\eta_l}(1-N_t)^{1-\eta_l})^{1-1/\psi} + \beta(\mathbb{E}_t \mathbb{V}_{t+1}^{1-\gamma})^{\frac{1-1/\psi}{1-\gamma}} \right]^{\frac{1}{1-1/\psi}},$$

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- Monetary policy: $\log(R_t/R) = \rho_i \log(R_{t-1}/R) + (1-\rho_i)\psi_\pi \log(\Pi_t/\Pi)$
- Exogenous processes:

$$\log A_{s,t} = (1-\rho_a)\log A_s + \rho_a \log A_{s,t-1} + \sigma_{s,t-1}^a \varepsilon_{s,t}^a$$

$$\sigma_{s,t}^a = (1-\rho_{\sigma_a})\log \sigma^a + \rho_{\sigma_a} \log \sigma_{s,t-1}^s + \sigma_{\sigma_a} \varepsilon_{s,t}^\sigma$$

Impulse Responses to Sectoral Uncertainty Shock

- Study propagation of sectoral uncertainty shocks in a 3-sector case
  - Linear network for intuition ($S1 \rightarrow S2 \rightarrow S3$);
  - Uncertainty shock in $S2$

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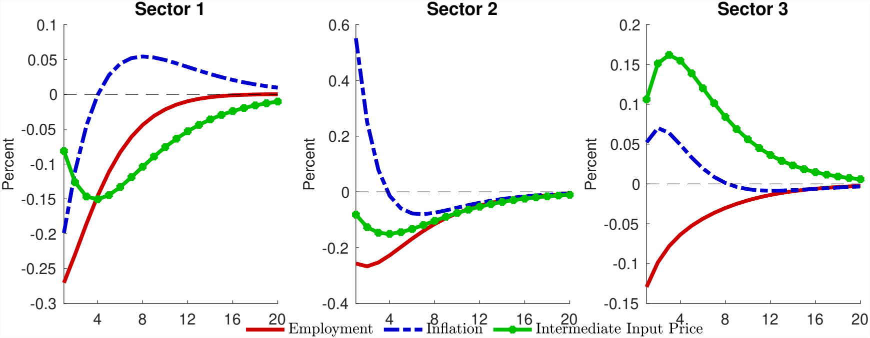
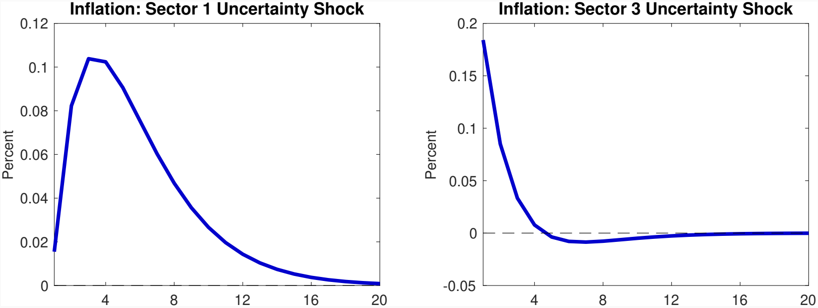
(a) Baseline Network



Supply vs Demand Uncertainty Complementarity Aggregate Shock

Aggregate Inflation Response

- Aggregate inflation response depends on sectoral origin of uncertainty



Propagation of Uncertainty Shocks

- Regardless of the source of uncertainty (supply- vs demand-side):
    - Higher prices and lower input demand where uncertainty increases
    - Lower input demand in the upstream sector (deflationary)
    - Price pass-through downstream (inflationary)
- These effects dominate other GE forces
  (e.g., wealth effects on labor supply, precautionary savings)
- Aggregate inflation response depends on sectoral origin of uncertainty

Conclusions

- Uncertainty shocks are significantly transmitted along the supply chain
  - Transmit upstream like a negative demand shock
  - Propagate downstream like an adverse supply shock
- Aggregate effects are contractionary; inflationary if uncertainty originates upstream
- NK production network model rationalizes the empirical estimates

Conclusions

- Uncertainty shocks are significantly transmitted along the supply chain
  - Transmit upstream like a negative demand shock
  - Propagate downstream like an adverse supply shock
- Aggregate effects are contractionary; inflationary if uncertainty originates upstream
- NK production network model rationalizes the empirical estimates
- Implications for macro policy design
  - Uncertainty arising upstream intensifies the inflation-output tradeoff
  - Uncertainty may exacerbate or dampen the inflationary impact of first-moment shocks (e.g., supply disruptions, demand shortfalls)

Thank you!

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Measuring Sectoral Uncertainty

- Start from sector-i version of CAPM:

$$r_{f,t+1} = \beta_{f,i} r_{i,t+1} + \epsilon_{f,t+1} \quad \textit{where} \quad r_{i,t+1} \equiv s_{f,i,t} r_{f,t+1}$$

- Take conditional variance:

$$\sigma^2_{f,t} = \beta^2_{f,i} \sigma^2_{i,t} + \sigma^2_{\epsilon,i,t+1}$$

- Following Campbell et al. (2001), using $\sum_f s_{f,i,t}\beta_{f,i} = 1$, one can show:

$$\sum_f s_{f,i,t}\sigma^2_{f,t} = \underbrace{\sigma^2_{i,t}}_{\text{common uncertainty}} + \underbrace{\sum_f s_{f,i,t}\sigma^2_{\epsilon,i,t+1}}_{\text{average id uncertainty}}$$

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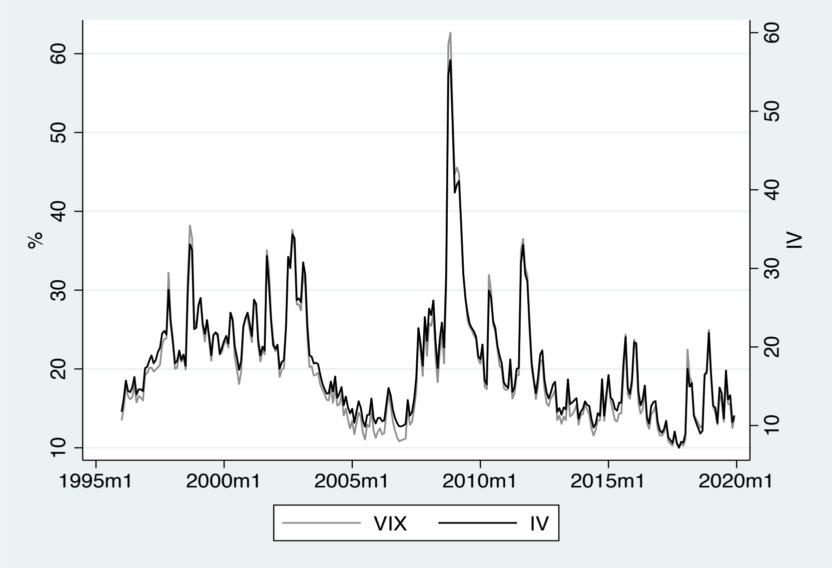
Aggregate Implied Volatility vs VIX



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Examples

- **Insurance industry** (5241), October 2004. Antifraud investigation by the NY attorney general led many insurance companies to announce they would stop paying contingent commissions to their agents.
- **Outpatient care industry** (6214), series of large shocks in 2015. At this time, the Centers for Medicare & Medicaid Services began implementing value-based care initiatives. Outpatient care centers faced uncertainties in adapting to these new business models.
- **Motor vehicle manufacturing industry** (3361), important spike in 1998 when Daimler-Benz AG acquired Chrysler Corporation. This merger represented a major consolidation in the automotive industry.
- **Ferrous and non-ferrous metal industries** (3311 and 3314) rising uncertainty during the late 2010 ' following US-China escalating trade tensions.
- **Advertising industry** (5418). Shock series captures key events that transformed the sector: digital shift of the late 1990s, launch of Google AdWords in Oct 2000, and launch of YouTube in Feb 2005.

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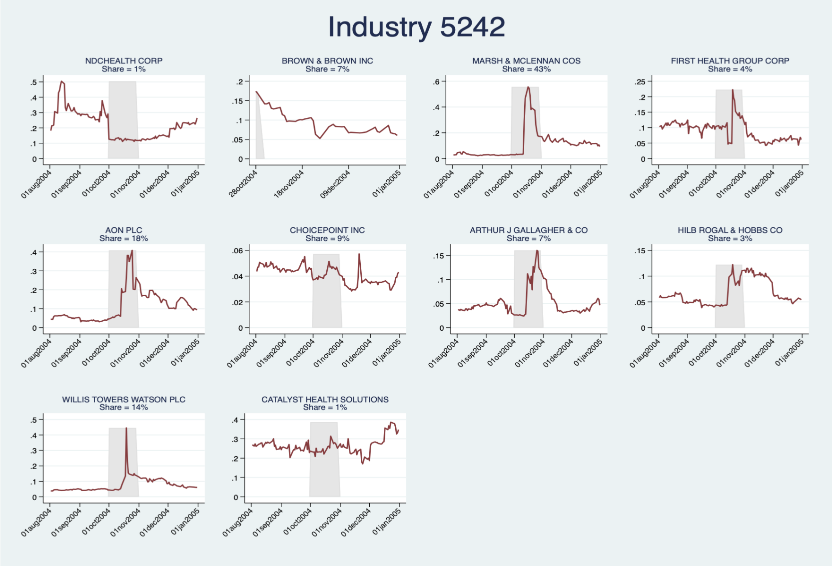
Shocks: Agencies, Brokerages, and Other Insurance Related Activities



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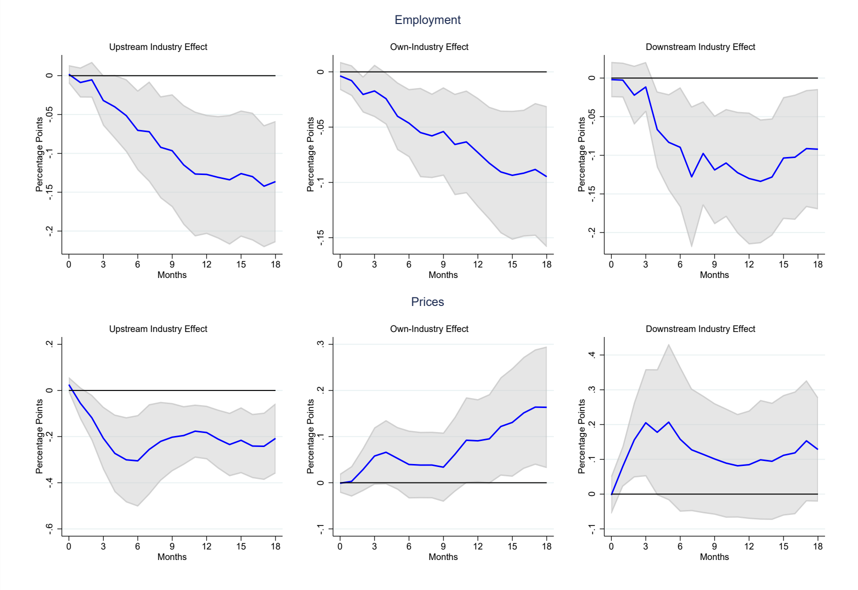
Robustness - Responses to an Uncertainty Shock - Sales Weights



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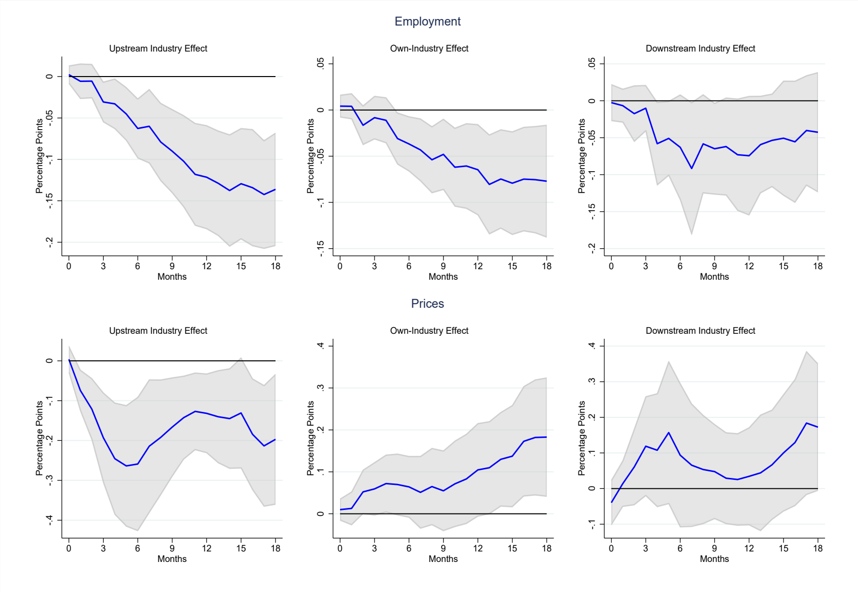
Robustness - Responses to an Uncertainty Shock - Fixed Effect



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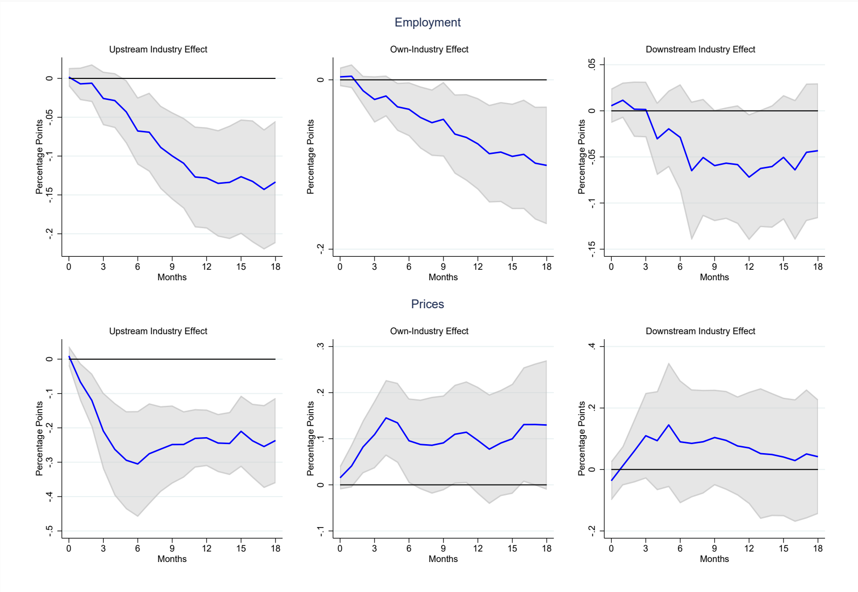
Robustness - Responses to an Uncertainty Shock - Options Traded > 5 Years



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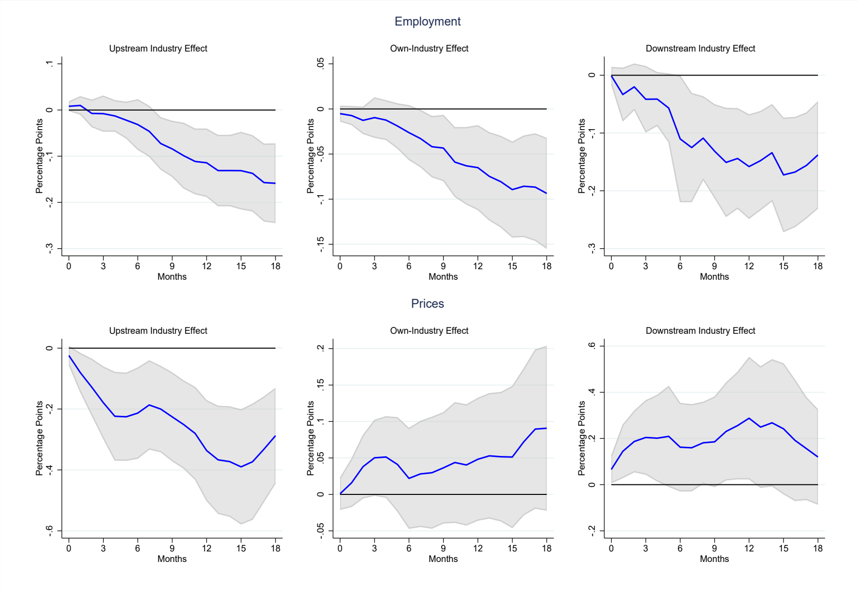
Robustness - Responses to an Uncertainty Shock - Simple First Stage



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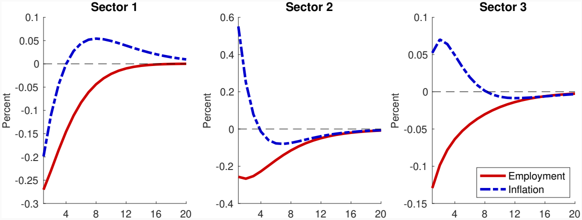
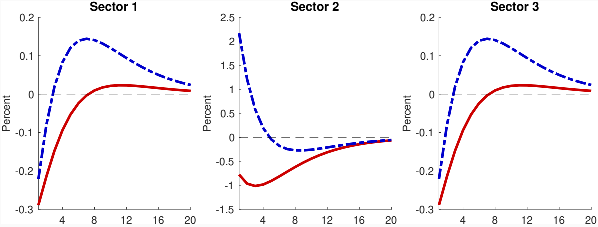
Baseline vs No Network Economy

(a) Baseline Network



(b) No Network



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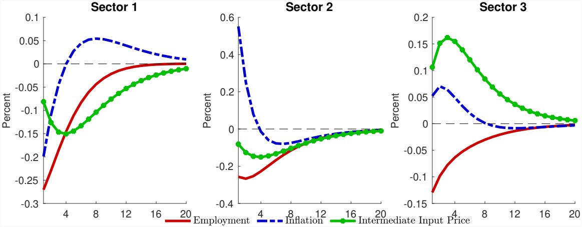
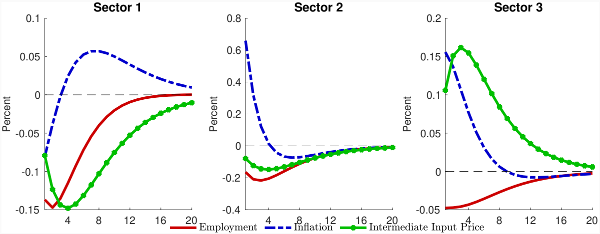
Baseline vs No Precautionary Savings

(a) Baseline Network



(b) No Precautionary Savings



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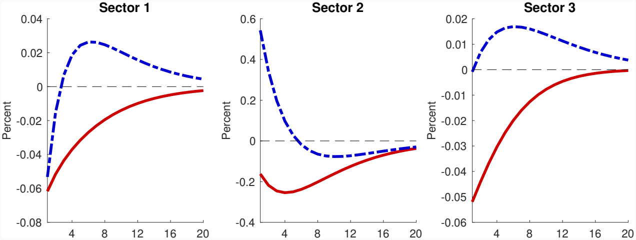
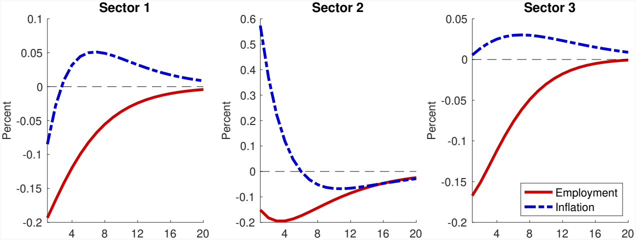
Robustness: Supply vs Demand Uncertainty Shocks

(a) Empirical Network - Supply Uncertainty Shock



(b) Empirical Network - Demand Uncertainty Shock



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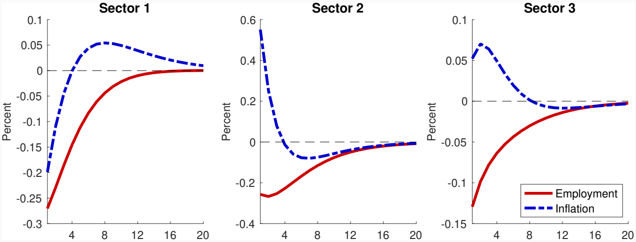
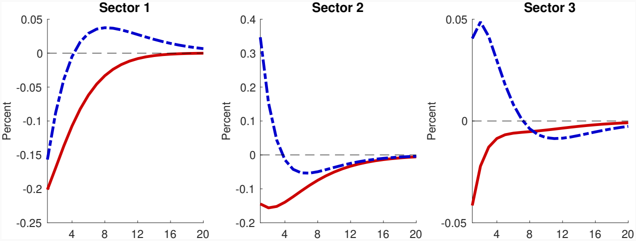
Robustness: Complementarity in Production Function

(a) Baseline ($\vartheta = 0.5$)



(b) Cobb Douglas Production ($\vartheta = 1$)



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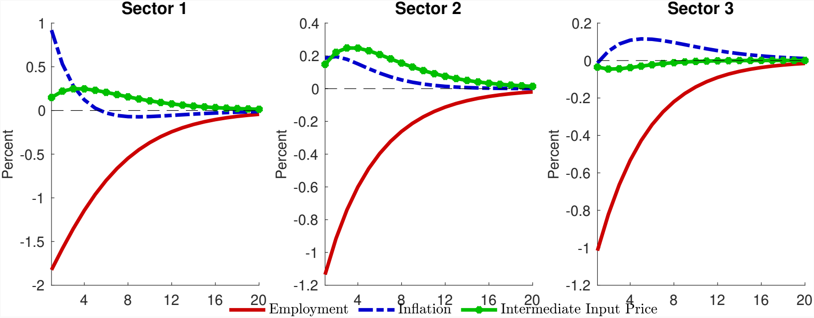
Aggregate Uncertainty Shock



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