Networks and the Macroeconomy: An Empirical Exploration

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这篇文章讲啥的？不妨我们先来理一下！

Outline

1. I. Introduction
2. II. Theory
3. III. Data and Descriptive Statistics
4. IV. Results: The Input-Output Network
5. V. Conclusion

I. Introduction
Background

How small shocks are amplified and propagated through the economy to cause sizable fluctuations is at the heart of much macroeconomic research.

- to Keynesian multipliers
  - e.g., Diamond 1982; Kiyotaki 1988; Blanchard and Kiyotaki 1987; Hall 2009; Christiano, Eichenbaum, and Rebelo 2011;
- to credit market frictions facing firms, households, or banks
  - e.g., Bernanke and Gertler 1989; Kiyotaki and Moore 1997; Guerrieri and Lorenzoni 2012; Mian, Rao, and Sufi 2013.
- to the role of real and nominal rigidities and their interplay
  - Ball and Romer 1990
- to the consequences of monetary policy.
  - e.g., Friedman and Schwartz 1971; Eggertsson and Woodford 2003; Farhi and Werning 2013

Indroduction
overlooked? idea? contribute?

Overlooked: small shocks from firms or disaggregated sectors through other links to other units in the economy.

Idea:

- A shock to a single firm could have a **much larger** impact on the macroeconomy
  - it reduces the output of not only this firm, but also through a **network of input-output linkages.**
- We are not the first to empirically study these interactions.
  - Boehm, Flaaen, and Nayar (2014), Barrot and Sauvagnat (2014), and Carvalho, Nirei, and Saito (2014) and so on..

Contributes:

- four different types of shocks through the US input-output network
  - china import shocks; Federal Spending shocks;
  - TFP shocks; Foreign Patenting Shocks
- geographic network

Indroduction
implications

supply-side (productivity) shocks **propagate downstream**

- downstream customers of directly hit industries are affected more strongly than their upstream suppliers.
- supply-side shocks **change the prices** faced by customer industries, creating powerful downstream propagation

demand shocks (from imports or government spending) **propagate upstream**

- upstream suppliers of directly hit industries are affected more strongly than their downstream customers.
- propagate upstream as affected industries adjust their **production** levels and thus input **demands**.

geographic: industries with substantial exchanges frequently locate near each other to

- reduce transportation costs and facilitate information transfer.

Theory
A. Input-Output Linkages

Representative household

$$u(c_1, c_2, \ldots, c_n, l) = \gamma(l) \prod_{i=1}^{n} c_i^{\beta_i} \tag{1}$$

budget constraint

$$\sum_{i=1}^{n} p_i c_i = wl - T$$

Cobb-Douglas production function of the form:

$$y_i = e^{z_i} l_i^{\alpha_i^l} \prod_{j=1}^{n} x_{ij}^{a_{ij}} \tag{2}$$

and

$$\alpha_i^l + \sum_{j=1}^{n} a_{ij} = 1$$

the market-clearing condition

$$y_i = c_i + \sum_{j=1}^{n} x_{ji} + G_i \tag{3}$$

The government imposes a lump-sum tax, T, to finance its purchases. Denoting the price of the output of industry i by p_i, this implies $T = \sum_{i=1}^{n} p_i G_i$.

profit maximization:

$$max \quad p_i y_i - wl - p_j x_{ij} \tag{4}$$

foc:

$$a_{ij} = \frac{p_j x_{ij}}{p_i y_i}, \text{ and } \alpha_i^l = \frac{wl_i}{p_i y_i}$$

In preparation for our main results we will present, let A denote the matrix of $a_{ij}'s$

$$\mathbf{A} = \begin{pmatrix} a_{11} & a_{12} & & \cdots \\ a_{21} & a_{22} & & \\ & & \ddots & \\ & & & a_{nn} \end{pmatrix}$$

We also define

$$\mathbf{H} \equiv (\mathbf{I} - \mathbf{A})^{-1} \tag{5}$$

as the Leontief inverse of the input-output matrix $\mathbf{A}$, and denote its typical entry by h_{ij}.

Theory

A. Input-Output Linkages

Proposition 1. The impact of sectoral productivity (supply-side) shocks on the output of sector i is

$$d\ln y_i = \underbrace{dz_i}_{\text{own effect}} + \underbrace{\sum_{j=1}^{n} (h_{ij} - \mathbf{1}_{j=i}) \times dz_j}_{\text{network effect}} \tag{6}$$

- This equation implies that in response to productivity shocks, there are no upstream effects
  - i.e., no effects on suppliers of affected industries
- only downstream effects
  - only effects on customers of affected industries

Theory–A. supply-side Derive

Proof of Proposition 1:

①准备工作

Profit $\max P_i y_i - wl - P_j x_{ij}$

$\Rightarrow$ FOC $\alpha_{ij} = \dfrac{P_j x_{ij}}{P_i y_i}$ $\Rightarrow d\ln y_i + d\ln P_i = d\ln x_{ij} + d\ln P_j$

$\alpha_i^l = \dfrac{w l_i}{P_i y_i}$ $\Rightarrow d\ln y_i + d\ln P_i = d\ln l_i \quad (d\ln w = 0)$

Utility max $\Rightarrow \dfrac{P_i C_i}{\beta_i} = \dfrac{P_j C_j}{\beta_j}$ $\Rightarrow d\ln P_i + d\ln C_i = d\ln P_j + d\ln C_j$

Assume no G, $\sum_{j=1}^{n} P_i C_i = wl$

$\Rightarrow P_i C_i = \beta_i wl \Rightarrow d\ln P_i + d\ln C_i = 0$

② $z_j \to y_i$? $z_i \to y_i$

$$\text{CD} \Rightarrow d\ln y_i = dz_i + \alpha_i^l d\ln l_i + \sum_{j=1}^{n} \alpha_{ij} d\ln x_{ij}$$

$$\Rightarrow d\ln y_i = dz_i + \alpha_i^l (d\ln y_i + d\ln P_i) + \sum_{j=1}^{n} \alpha_{ij} (d\ln y_i + d\ln P_i - d\ln P_j)$$

$$\Rightarrow d\ln y_i = dz_i + \alpha_i^l (d\ln y_i - d\ln C_i) + \sum_{j=1}^{n} \alpha_{ij} (d\ln y_i - d\ln C_i + d\ln C_j)$$

$$\Rightarrow d\ln y_i = dz_i + \left(\alpha_i^l + \sum_{j=1}^{n} \alpha_{ij}\right)(d\ln y_i - d\ln C_i) + \sum_{j=1}^{n} \alpha_{ij} d\ln C_j$$

$$\Rightarrow d\ln C_i = dz_i + \sum_{j=1}^{n} \alpha_{ij} d\ln C_j$$

$$\Rightarrow d\ln C = dz + A\, d\ln C$$

$$\Rightarrow d\ln C = (I - A)^{-1} dz$$

$$\Rightarrow d\ln y = (I - A)^{-1} dz$$

补充： market-clearing : $y_i = C_i + \sum_{j=1}^{n} x_{ij} = C_i + \sum_{j=1}^{n} \alpha_{ij} \cdot \dfrac{P_i y_i}{P_j}$ $\quad \left(\dfrac{P_i}{P_j} = \dfrac{\beta_i}{\beta_j} \dfrac{C_j}{C_i}\right)$

$$\Rightarrow \frac{y_j}{C_j} = 1 + \sum_{i=1}^{n} \alpha_{ij} \frac{\beta_i y_i}{\beta_j C_i}$$

$$\Rightarrow d\ln y = d\ln C$$

Theory

A. Input-Output Linkages

Suppose $\gamma(l) = (1-l)^{\lambda}$. Then the impact of government-spending (demand side) shocks on the output of sector i is

$$
\begin{aligned}
d \ln y_i = \underbrace{\frac{d\tilde{G}_i}{p_i y_i}}_{\text{own effect}} &+ \underbrace{\sum_{j=1}^{n} \left(\hat{h}_{ji} - \mathbf{1}_{j=i} \right) \times \frac{1}{p_j y_j} \times d\tilde{G}_j}_{\text{network effect}} \\
&- \underbrace{\sum_{j=1}^{n} \hat{h}_{ji} \times \frac{1}{p_j y_j} \times \frac{\beta_j}{1+\lambda} \times \sum_{k=1}^{n} d\tilde{G}_k}_{\text{resource constraint effect}}
\end{aligned}
\tag{7}
$$

- This implies that demand-side shocks do not propagate downstream (i.e., to customers of affected industries),
- only upstream (i.e., only to suppliers of affected industries).

Theory–A. Demand-side Derive

Part 2.

① 准备工作

$$\max \ \ln u(c_1, c_2, \cdots, c_n, l) = \ln y(l) + \ln \sum_{i=1}^{n} \beta_i c_i$$

$$\text{s.t.} \quad \sum_{i=1}^{n} p_i c_i = wl - T$$

$$\overset{\text{FOC}}{\Rightarrow} \{l\}: -\lambda w = \frac{y'(l)}{y(l)}, \quad \{c_i\}: \frac{\beta_i}{c_i} = \lambda p_i \Rightarrow \lambda = \frac{\beta_i}{p_i c_i} = \frac{1}{wl - T}$$

$$\Rightarrow \frac{wl}{wl - T} = -\frac{l\, y'(l)}{y(l)}, \quad T = \sum_{i=1}^{n} p_i G_i$$

$$\text{when} \quad y(l) = (1-l)^{\lambda} \Rightarrow y'(l) = \lambda(1-l)$$

$$\because w = 1 \Rightarrow l = \frac{1 + \lambda T}{1 + \lambda}$$

$$\because p_i c_i = \beta_i [lw - T] = \frac{\beta_i}{1+\lambda} \left[1 - \sum_{j=1}^{n} p_j G_j\right]$$

$$\Rightarrow d(p_i c_i) = -\frac{\beta_i}{1+\lambda} \sum_{j=1}^{n} d(p_j G_j)$$

(Resource constraint effect)

② begin.

$$dy_i = dc_i + \sum_{j=1}^{n} x_{ji} + dG_i$$

$$\Rightarrow \frac{d(p_i y_i)}{p_i y_i} = \sum_{j=1}^{n} a_{ji} \frac{d(p_j y_j)}{p_i y_i} + \frac{dG_i}{y_i} - \frac{\beta_i}{1+\lambda} \sum_{j=1}^{n} \frac{d p_j G_j}{p_i y_i}$$

$$= \sum_{j=1}^{n} \hat{a}_{ji} \frac{d(p_j y_j)}{p_j y_j} + \frac{d\tilde{G}_i}{p_i y_i} - \frac{\beta_i}{1+\lambda} \sum_{j=1}^{n} \frac{d\tilde{G}_j}{p_i y_i}, \quad \begin{cases} \tilde{G}_j = p_j G_j \\ \hat{a}_{ij} = \frac{x_{ij}}{y_i} \end{cases}$$

$$\because \frac{d(p_i y_i)}{p_i y_i} = d\ln y_i$$

$$\Rightarrow d\ln y = \hat{A}^T d\ln y + \Lambda d\tilde{G}$$

$$= (I - \hat{A}^T)\Lambda d\tilde{G}$$

$$= \hat{H}^T \Lambda d\tilde{G}$$

$$\Rightarrow d\ln y_i = \sum_{j=1}^{n} \hat{h}_{ji} \frac{1}{p_j y_j} \left(d\tilde{G}_j - \frac{\beta_j}{1+\lambda} \sum_{k=1}^{n} d\tilde{G}_k\right)$$

Theory A. Input-Output Linkages

Example 1 (Downstream propagation of supply-side shocks).

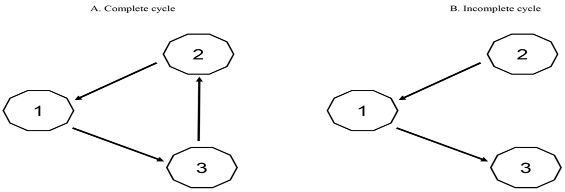


Fig. 2. Theoretical examples

The sectoral production functions

$$y_1 = e^{z_1} l_1^{\alpha_1^l} x_{12}^{a_{12}}, \quad y_2 = e^{z_2} l_2^{\alpha_2^l} x_{23}^{a_{23}}, \quad y_3 = e^{z_3} l_3^{\alpha_3^l} x_{31}^{a_{31}}$$

It follows from Proposition 1 that sector 1's output is:

$$d \ln y_1 = \frac{dz_1 + a_{12} dz_2 + a_{12} a_{23} dz_3}{1 - a_{12} a_{23} a_{31}}$$

Theory A. Input-Output Linkages

Example 1 (Downstream propagation of supply-side shocks).

this is purely because of the propagation of productivity (supply-side) shocks downstream.

To see further that there is no upstream propagation, consider a modification of this input-output network as shown in panel (B) of figure 2, where the link between sector 2 and sector 3 is severed (i.e., $a_{23} = 0$). The output of sector 1 then becomes

$$d \ln y_1 = dz_1 + a_{12} dz_2$$

Intuition: Downstream propagation

- an adverse productivity shock to a sector leads to an **increase** in the **price** of that sector's output
- encouraging its customer industries to use this input less intensively and thus **reduce** their own **production**.

Theory A. Input-Output Linkages

Example 2 (Upstream propagation of demand-side shocks).

with **government-spending shocks,** expressed in nominal terms as $d\tilde{G}_1, d\tilde{G}_2$, and $d\tilde{G}_3$, rather than productivity shocks (Setting $dz_1 = dz_2 = dz_3 = 0$), Setting $\beta_1 = \beta_2 = \beta_3 = 1/3$. In this case, the change in the nominal output of sector 1

$$d\tilde{y}_1 = \frac{1}{1 - a_{12}a_{23}a_{31}} \left\{ \begin{array}{c} d\tilde{G}_1 + a_{23}a_{31}d\tilde{G}_2 + a_{31}d\tilde{G}_3 \\ -\frac{(1+a_{31}+a_{23}a_{31})}{3(1+\lambda)} \left[d\tilde{G}_1 + d\tilde{G}_2 + d\tilde{G}_3 \right. \end{array} \right\}$$

When the link between sectors 2 and 3 is severed (or equivalently when $a_{23} = 0$), the change in the nominal output of sector 1 becomes

$$d\tilde{y}_1 = d\tilde{G}_1 + a_{31}d\tilde{G}_3 - \frac{(1 + a_{31})}{3(1 + \lambda)} \left[d\tilde{G}_1 + d\tilde{G}_2 + d\tilde{G}_3 \right]$$

Theory A. Input-Output Linkages
implication

- A third implication of equations (6) and (7) concerns the magnitudes of the coefficients of the own and network effects.

$$d \ln y_i = h_{ii} \times dz_i + \sum_{j \neq i} h_{ij} \times dz_{j'}$$

$$d \ln y_i = \hat{h}_{ii} \frac{d\tilde{G}_i}{p_i y_i} + \sum_{j \neq i} \hat{h}_{ji} \frac{d\tilde{G}_j}{p_j y_j} - \sum_{j=1}^{n} \hat{h}_{ji} \frac{\beta_j}{1+\lambda} \sum_{k=1}^{n} d\tilde{G}_{k'}$$

  - the coefficients of the own and the network effects, when properly scaled by the entries of the Leontief inverse, should be equal.
- Fourth, what matters in our theoretical framework are the contemporaneous shocks, not some future anticipated shocks.
- Finally, we further note that the implications of **import shocks** are also very similar to government-spending shocks.

Theory B. The Effects of the Geographic Network

Reduced-form model capturing local demand effects：

$$d\ln y_{r,i} = \eta \sum_{j\neq i} \frac{y_{r,j}}{y_r} d\ln y_{r,j} + dz_i \tag{8}$$

$$d\ln y_{r,i} \approx dz_i + \eta \sum_{j\neq i} \frac{y_{r,j}}{y_r} dz_j$$

Now using the fact that $d\ln y_{r,i} = dy_{r,i}/y_{r,i}$ and summing across regions, we obtain

$$dy_i = \sum_r dy_{r,i} \approx y_i dz_i + \eta \sum_r \sum_{j\neq i} \frac{y_{r,i} y_{r,j}}{y_r} dz_{j'} \tag{10}$$

$$d\ln y_i \approx dz_i + \eta \sum_r \frac{y_{r,i} y_{r,j}}{y_i y_r} dz_j$$

where geographic overlay $_{i,j} \equiv \sum_r \frac{y_{r,i} y_{r,j}}{y_i y_r}$ is the noncentered **cross-region correlation coefficient of industries** i **and** j, normalized by their national levels of production, and **represents their tendency to collocate.**

III. Data and Descriptive Statistics

Outline

- This section describes our various data sources
- the construction of the key measures of downstream and upstream effects and the geographic network.

A. Data Sources

- NBER- CES Manufacturing Industry Database
- We utilize data for the years 1991—2009
- our estimations cover 17 changes from 1992—1993 to 2008—2009.
  - In the first four changes, we have 392 four-digit industries; thereafter, we have 384 industries for 6,560 total observations.
- To construct our linkages between industries, we use the Bureau of Economic Analysis 1992 Input-Output Matrix and the 1991 County Business Patterns database as described further below.

III. Data and Descriptive Statistics

B. Upstream and Downstream Networks

We construct the matrix **A** from the 1992 "Make" and "Use" Tables of the Bureau of Economic Analysis.

- This matrix has input share entries corresponding to

$$a_{ij} \equiv \frac{\text{Sales}_{\ j \to i}}{\text{Sales}_{\ i}}$$

  - We use **input%** $_{j \to i}$ to represent these Leontief inverse terms.

- The empirical counterparts of the $\hat{a}_{ij}$ terms are

$$\frac{\text{Sales}_{\ i \to j}}{\text{Sales}_{\ i}} \equiv a_{ji} \frac{\text{Sales}_{\ j}}{\text{Sales}_{\ i}}$$

  - We use **Output%** $_{i \to j}$ to represent these Leontief inverse terms.

C. Geographic Overlay

$$\text{geographic overlay}_{\ i,j} \equiv \sum_r \frac{y_{r,i} y_{r,j}}{y_i y_r}$$

IV. Results: The Input-Output Network

demand-side shocks

- import penetration
- federal spending changes

two are supply side, approximating productivity shocks.

- TFP growth
- foreign-patenting growth

IV. Results: The Input-Output Network
A. Empirical Approach

Take the following form:

$$\Delta \ln Y_{i,t} = \delta_t + \psi \Delta \ln Y_{i,t-1} + \beta^{\text{own}} \text{ Shock}_{i,t-1} + \beta^{\text{upstream}} \text{ Upstream }_{i,t-1} + \beta^{\text{downstream}} \text{ Downstream }_{i,t-1} + \varepsilon_{i,t}$$

- Y real value added , employment, and real labor productivity (real value added divided by employment).

Measure downstream effects (due to supplier shocks) and upstream effects (due to customer shocks)

$$\text{Downstream }_{i,t} = \Sigma_j \left(\text{ Input } \%^{1991}_{j \to i} - \mathbf{1}_{j=i} \right) \cdot \text{ Shock }_{j,t} \tag{9}$$

and

$$\text{Upstream }_{i,t} = \Sigma_j \left(\text{ Output } \%^{1991}_{i \to j} - \mathbf{1}_{j=i} \right) \cdot \text{ Shock }_{j,t} \tag{10}$$

IV. Results: The Input-Output Network

B. China Import Shocks

ChinaTrade to capture this industry exposure to rising Chinese trade：

$$\text{ChinaTrade}_{j,t} = -\frac{\text{US Imports from China}_{j,t}}{\text{US market size}_{j,1991}}$$

Shocks:

$$\text{Downstream}_{i,t}^{\text{Trade}} = \sum_{j} \left(\text{Input } \%_{j \to i}^{1991} - \mathbf{1}_{j=i} \right) \cdot \Delta \text{ ChinaTrade}_{j,t}$$

IV. Results: The Input-Output Network
B. China Import Shocks

Table 2A
China Trade Shock Analysis

	Δ Log Real Value Added		Δ Log Employment		Δ Log Real Labor Productivity	
	(1)	(2)	(3)	(4)	(5)	(6)
Δ Dependent variable $t-1$	0.019	0.020	0.149***	0.132***	−0.117***	−0.120***
	(0.025)	(0.025)	(0.020)	(0.019)	(0.028)	(0.033)
Δ Dependent variable $t-2$		0.047**		0.109***		−0.057
		(0.024)		(0.020)		(0.037)
Δ Dependent variable $t-3$		0.033		0.089***		−0.002
		(0.021)		(0.016)		(0.033)
Downstream effects $t-1$	−0.140	−0.124	−0.056	−0.044	−0.100	−0.108
	(0.086)	(0.081)	(0.040)	(0.037)	(0.099)	(0.099)
Upstream effects $t-1$	0.076***	0.076***	0.049***	0.039***	0.021	0.021
	(0.024)	(0.023)	(0.016)	(0.015)	(0.013)	(0.014)
Own effects $t-1$	0.034***	0.031***	0.023***	0.018***	0.007	0.007
	(0.009)	(0.009)	(0.005)	(0.004)	(0.007)	(0.007)
Observations	6,560	5,776	6,560	5,776	6,560	5,776
P-value: Upstream = own	0.071	0.054	0.086	0.139	0.333	0.350

The coefficient estimates in these regression equations do not directly translate into quantitative effects for “**multipliers**,” however.

IV. Results: The Input-Output Network
B. China Import Shocks

This is because the upstream effect (the relevant dimension of the network effects in this case) corresponds to the impact of the shock of all other industries, weighted by their upstream linkages, ***on the focal industry****. Instead, to obtain an economically meaningful multiplier, measuring how large the total impact of a shock is relative to its direct effect, we need to measure its impact on* ***all other industries.*** *To achieve this, we convert upstream and downstream effects into a weighted average of shocks in other industries using the Leontief inverse elements of weights.*

APPENDIX: More specifically, focusing on upstream effects, recall that Upstream $_{i,t} = \Sigma_j ($ Output $\%_{i \to j}^{1991} - \mathbf{1}_{j=i}\Big) \cdot$ Shock $_{j,t}$, whereas for this term to capture the quantitative impact of shocks on supplier industries, we would need it to take the form

$$\sum_j \frac{\left(\text{ Output } \%_{i \to j}^{1991} - \mathbf{1}_{j=i} \right)}{\Sigma_k \left(\text{ Output } \%_{i \to k}^{1991} - \mathbf{1}_{k=i} \right)} \cdot \text{ Shock }_{j,t}$$

so that it corresponds to a weighted average of shocks hitting industries. The simplest and most transparent approach to make this adjustment is to divide our coefficient estimates by the average of the $\Sigma_k \left(\text{ Output } \%_{i \to k}^{1991} - \mathbf{1}_{k=i} \right)' \mathrm{s}$, i.e., by $(1/n) \Sigma_i \Sigma_k ($ Output $\%_{i \to k}^{1991} - \mathbf{1}_{k=i})$ (where n is the number of industries). The adjustment for the downstream effect is very similar. From the US input-output matrix, this adjustment factor is 2.156.

IV. Results: The Input-Output Network

B. China Import Shocks–real value

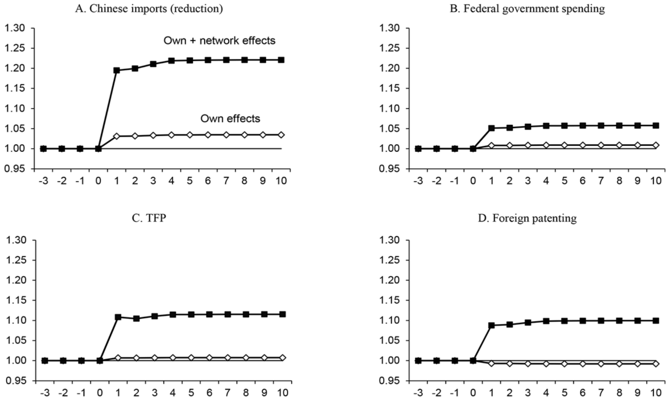


Fig. 1. Responses to a one standard deviation shock taken in isolation, value added

The implied multiplier in this case (for real value changes) is **6.4**

IV. Results: The Input-Output Network
B. China Import Shocks–employment

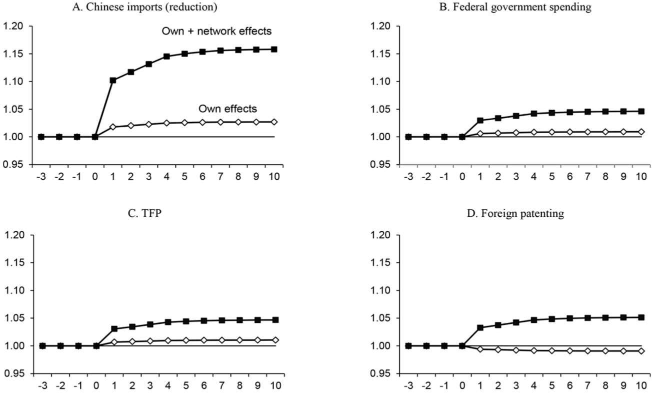


Fig. 3. Responses to a one standard deviation shock taken in isolation, employment

The implied multiplier in this case (for employment changes) is **5.86.**

IV. Results: The Input-Output Network

B. China Import Shocks

- ? we weight observations by log 1991 value added or by 1991 employment levels.
- we include a full set of two-, three-, and four-digit Standard Industrial Code (SIC) dummies.

Table 2B

Robustness Checks on China Trade Shock Analysis

	Baseline Estimation (1)	Excluding Own Lagged Shock (2)	Weighting by 1991 Log Value Added (3)	Weighting by 1991 Employees (4)	Adding SIC2 Fixed Effects (5)	Adding SIC3 Fixed Effects (6)	Adding SIC4 Fixed Effects (7)	Adding Resource Constraints (8)
			A. Δ Log Real Value Added					
Δ Dependent variable $t-1$	0.019	0.021	0.023	0.114	−0.008	−0.038*	−0.071***	0.018
	(0.025)	(0.025)	(0.026)	(0.071)	(0.025)	(0.023)	(0.020)	(0.025)
Downstream effects $t-1$	−0.140	−0.022	−0.152*	−0.209*	0.000	0.138	0.192	−0.163*
	(0.086)	(0.083)	(0.086)	(0.123)	(0.109)	(0.106)	(0.129)	(0.092)
Upstream effects $t-1$	0.076***	0.068***	0.078***	0.075**	0.051**	0.053*	0.051	0.107**
	(0.024)	(0.023)	(0.023)	(0.034)	(0.023)	(0.032)	(0.042)	(0.042)
Own effects $t-1$	0.034***		0.033***	0.022	0.018**	0.015	0.016	0.032***
	(0.009)		(0.009)	(0.014)	(0.009)	(0.010)	(0.014)	(0.009)
Observations	6,560	6,560	6,560	6,560	6,560	6,560	6,560	6,560
P-value: Upstream = own	0.071		0.053	0.076	0.159	0.266	0.489	0.080
			B. Δ Log Employment					
Δ Dependent variable $t-1$	0.149***	0.156***	0.153***	0.257***	0.097***	0.044**	0.010	0.146***
	(0.020)	(0.021)	(0.020)	(0.034)	(0.020)	(0.019)	(0.020)	(0.020)
Downstream effects $t-1$	−0.056	0.024	−0.055	−0.034	0.009	0.036	0.080	−0.082*
	(0.040)	(0.037)	(0.040)	(0.059)	(0.049)	(0.054)	(0.067)	(0.047)
Upstream effects $t-1$	0.049***	0.044***	0.051***	0.048**	0.029*	0.014	0.012	0.084***
	(0.016)	(0.016)	(0.016)	(0.022)	(0.016)	(0.018)	(0.025)	(0.028)
Own effects $t-1$	0.023***		0.023***	0.020***	0.009**	0.005	0.001	0.021***
	(0.005)		(0.005)	(0.007)	(0.004)	(0.004)	(0.005)	(0.005)
Observations	6,560	6,560	6,560	6,560	6,560	6,560	6,560	6,560
P-value: Upstream = own	0.086		0.069	0.185	0.209	0.616	0.667	0.027

IV. Results: The Input-Output Network
C. Federal Spending Shocks

We first calculate from the 1992 BEA Input-Output Matrix the share of sales for each industry that went to the federal government

$$\text{FedSales\%}_{\,i} = \frac{\text{Sales}_{\,i\rightarrow\text{ Fed}}}{\text{Sales}_{\,i}}$$

$$\text{FederalShock}_{\,i,t} = \text{ Fed Sales }\%_i^{1991} \cdot \Delta \ln \text{ FederalSpending}_{\,t-1}$$

$$\text{Downstream } m_{i,t}^{\text{Federal}} = \sum_j \left(\text{ Input } \%_{j\rightarrow i}^{1991} - \mathbf{1}_{j=i} \right) \cdot \text{ FederalShock}_{\,j,t}$$

- This share ranges from zero dependency for about 10% of industries to over 50% for the top percentile of industries in terms of dependency.
  - 3731 Ship Building and Repairing (76%)
  - 3482 Small Arms Ammunition (65%)
  - 3812 Search, Detection, Navigation, Guidance, Aeronautical and Nautical Systems and Instruments (51%)

IV. Results: The Input-Output Network
C. Federal Spending Shocks

Table 3A
Federal Spending Shock Analysis

	Δ Log Real Value Added		Δ Log Employment		Δ Log Real Labor Productivity	
	(1)	(2)	(3)	(4)	(5)	(6)
Δ Dependent variable $t-1$	0.019	0.018	0.158***	0.135***	–0.117***	–0.119***
	(0.025)	(0.024)	(0.021)	(0.019)	(0.030)	(0.036)
Δ Dependent variable $t-2$		0.051**		0.116***		–0.057
		(0.023)		(0.019)		(0.038)
Δ Dependent variable $t-3$		0.038*		0.102***		–0.002
		(0.021)		(0.016)		(0.035)
Downstream effects $t-1$	0.017	0.023	0.007	0.013	0.007	0.004
	(0.021)	(0.021)	(0.015)	(0.012)	(0.016)	(0.017)
Upstream effects $t-1$	0.022**	0.020**	0.010*	0.011**	0.012	0.010
	(0.009)	(0.008)	(0.006)	(0.005)	(0.008)	(0.008)
Own effects $t-1$	0.004	0.008**	0.003	0.006***	0.001	0.002
	(0.003)	(0.004)	(0.003)	(0.002)	(0.001)	(0.002)
Observations	6,560	5,776	6,560	5,776	6,560	5,776
P-value: Upstream = own	0.076	0.191	0.321	0.383	0.147	0.330

IV. Results: The Input-Output Network
C. Federal Spending Shocks

Table 3B
Robustness Checks on Federal Spending Shock Analysis

	Baseline Estimation (1)	Excluding Own Lagged Shock (2)	Weighting by 1991 Log Value Added (3)	Weighting by 1991 Employees (4)	Adding SIC2 Fixed Effects (5)	Adding SIC3 Fixed Effects (6)	Adding SIC4 Fixed Effects (7)	Adding Resource Constraint (8)
			A. Δ Log Real Value Added					
Δ Dependent variable $t-1$	0.019	0.019	0.023	0.115*	–0.011	–0.042*	–0.076***	0.019
	(0.025)	(0.025)	(0.026)	(0.068)	(0.025)	(0.024)	(0.021)	(0.025)
Downstream effects $t-1$	0.017	0.034*	0.015	0.008	–0.006	0.029	–0.040	0.017
	(0.021)	(0.019)	(0.020)	(0.014)	(0.021)	(0.024)	(0.062)	(0.021)
Upstream effects $t-1$	0.022**	0.022**	0.022**	0.030**	0.012	0.025*	0.069***	0.022*
	(0.009)	(0.009)	(0.010)	(0.014)	(0.008)	(0.015)	(0.023)	(0.012)
Own effects $t-1$	0.004		0.004	0.001	0.002	0.005	0.011	0.004
	(0.003)		(0.003)	(0.002)	(0.003)	(0.005)	(0.011)	(0.003)
Observations	6,560	6,560	6,560	6,560	6,560	6,560	6,560	6,560
P-value: Upstream = own	0.076		0.077	0.027	0.254	0.183	0.031	0.130
			B. Δ Log Employment					
Δ Dependent variable $t-1$	0.158***	0.159***	0.163***	0.269***	0.099***	0.041**	0.006	0.158***
	(0.021)	(0.021)	(0.021)	(0.033)	(0.020)	(0.019)	(0.019)	(0.021)
Downstream effects $t-1$	0.007	0.021**	0.006	0.007	–0.011	0.018	–0.046	0.009
	(0.015)	(0.010)	(0.013)	(0.007)	(0.015)	(0.013)	(0.046)	(0.014)
Upstream effects $t-1$	0.010*	0.010*	0.009	0.009	0.004	0.016***	0.020*	0.006
	(0.006)	(0.006)	(0.006)	(0.005)	(0.005)	(0.006)	(0.011)	(0.007)
Own effects $t-1$	0.003		0.003	0.001	0.002	0.009**	0.022**	0.003
	(0.003)		(0.003)	(0.001)	(0.003)	(0.004)	(0.009)	(0.003)
Observations	6,560	6,560	6,560	6,560	6,560	6,560	6,560	6,560
P-value: Upstream = own	0.321		0.346	0.156	0.747	0.160	0.829	0.717

IV. Results: The Input-Output Network
D. TFP Shocks—supply-side shocks

- Baseline TFP shocks for manufacturing industries are the lagged change in four- factor TFP taken from the NBER Productivity Database.
- Downstream $^{TFP}_{i,t} = \sum_j \left(\text{Input } \%^{1991}_{j\to i} - \mathbf{1}_{j=i} \right) \cdot \Delta \ln TFP_{j,t}$

Table 4A
TFP Shock Analysis

	Δ Log Real Value Added		Δ Log Employment		Δ Log Real Labor Productivity	
	(1)	(2)	(3)	(4)	(5)	(6)
Δ Dependent variable $t-1$	–0.024	–0.031	0.141***	0.118***	–0.194***	–0.211***
	(0.040)	(0.041)	(0.021)	(0.020)	(0.029)	(0.034)
Δ Dependent variable $t-2$		0.049**		0.118***		–0.071**
		(0.023)		(0.019)		(0.034)
Δ Dependent variable $t-3$		0.037*		0.102***		–0.008
		(0.020)		(0.016)		(0.032)
Downstream effects $t-1$	0.060***	0.047**	0.016*	0.011	0.047***	0.043**
	(0.020)	(0.020)	(0.009)	(0.009)	(0.018)	(0.018)
Upstream effects $t-1$	0.024**	0.020*	0.009	0.008	0.015*	0.014
	(0.011)	(0.012)	(0.006)	(0.006)	(0.009)	(0.009)
Own effects $t-1$	0.004	0.007	0.006***	0.007***	0.011**	0.013***
	(0.007)	(0.006)	(0.002)	(0.002)	(0.005)	(0.004)
Observations	6,560	5,776	6,560	5,776	6,560	5,776
P-value: Downstream = own	0.005	0.034	0.041	0.161	0.101	0.276

IV. Results: The Input-Output Network
D. TFP Shocks—supply-side shocks–Robust

Table 4B
Robustness Checks on TFP Shock Analysis

	Baseline Estimation (1)	Excluding Own Lagged Shock (2)	Weighting by 1991 Log Value Added (3)	Weighting by 1991 Employees (4)	Adding SIC2 Fixed Effects (5)	Adding SIC3 Fixed Effects (6)	Adding SIC4 Fixed Effects (7)
		A. Δ Log Real Value Added					
Δ Dependent variable $t-1$	−0.024	−0.002	−0.024	−0.075	−0.080**	−0.126***	−0.147***
	(0.040)	(0.024)	(0.040)	(0.073)	(0.039)	(0.038)	(0.039)
Downstream effects $t-1$	0.060***	0.062***	0.060***	0.077**	0.039*	0.027	0.027
	(0.020)	(0.021)	(0.020)	(0.034)	(0.020)	(0.018)	(0.019)
Upstream effects $t-1$	0.024**	0.024**	0.025**	0.054***	0.021*	0.017	0.020
	(0.011)	(0.011)	(0.011)	(0.016)	(0.011)	(0.012)	(0.013)
Own effects $t-1$	0.004		0.005	0.025*	0.010	0.014**	0.012**
	(0.007)		(0.007)	(0.014)	(0.006)	(0.006)	(0.005)
Observations	6,560	6,560	6,560	6,560	6,560	6,560	6,560
P-value: Downstream = own	0.005		0.007	0.303	0.198	0.623	0.171
		B. Δ Log Employment					
Δ Dependent variable $t-1$	0.141***	0.154***	0.146***	0.252***	0.081***	0.020	−0.015
	(0.021)	(0.021)	(0.021)	(0.032)	(0.021)	(0.019)	(0.020)
Downstream effects $t-1$	0.016*	0.025***	0.016*	0.024*	0.002	0.011	0.013
	(0.009)	(0.009)	(0.009)	(0.012)	(0.009)	(0.010)	(0.011)
Upstream effects $t-1$	0.009	0.012**	0.009	0.022***	0.007	0.010	0.010
	(0.006)	(0.006)	(0.006)	(0.008)	(0.006)	(0.007)	(0.007)
Own effects $t-1$	0.006***		0.006***	0.003	0.007***	0.008***	0.009***
	(0.002)		(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Observations	6,560	6,560	6,560	6,560	6,560	6,560	6,560
P-value: Downstream = own	0.041		0.045	0.026	0.712	0.312	0.314

E. Foreign Patenting Shocks

These foreign patents quantify technology changes in the world tech-nology frontier external to the US economy (e.g., patents filed by car manufacturers in Germany and Japan signal advances in automobile technologies).

- market competition and technology spillovers
- the lagged log change in USPTO-granted patents filed by overseas inventors associated with the industry.
- $\text{Downstream}_{i,t}^{\text{ForeignPatent}} = \sum_j \left(\text{Input } \%_{j \to i}^{1991} - \mathbf{1}_{j=i} \right) \cdot \Delta \ln \text{Patents}_{j,t}^{\text{Foreign}}$

Table 5A
Foreign Patent Shock Analysis

	Δ Log Real Value Added		Δ Log Employment		Δ Log Real Labor Productivity	
	(1)	(2)	(3)	(4)	(5)	(6)
Δ Dependent variable $t-1$	0.020	0.020	0.159***	0.138***	–0.117***	–0.120***
	(0.025)	(0.025)	(0.021)	(0.020)	(0.030)	(0.036)
Δ Dependent variable $t-2$		0.051**		0.117***		–0.057
		(0.023)		(0.020)		(0.038)
Δ Dependent variable $t-3$		0.037*		0.100***		–0.003
		(0.021)		(0.016)		(0.035)
Downstream effects $t-1$	0.043***	0.044***	0.018***	0.018***	0.027***	0.028***
	(0.011)	(0.011)	(0.006)	(0.006)	(0.009)	(0.009)
Upstream effects $t-1$	–0.000	0.000	–0.001	–0.000	0.001	0.002
	(0.005)	(0.005)	(0.003)	(0.003)	(0.004)	(0.004)
Own effects $t-1$	–0.006	–0.007*	–0.008***	–0.006**	0.003	0.002
	(0.004)	(0.004)	(0.003)	(0.003)	(0.003)	(0.004)
Observations	6,543	5,761	6,543	5,761	6,543	5,761
P-value: Downstream = own	0.000	0.000	0.001	0.002	0.029	0.026

IV. Results: The Input-Output Network

D. Roreign Patenting Shocks–Robust

Table 5B
Robustness Checks on Foreign Patent Shock Analysis

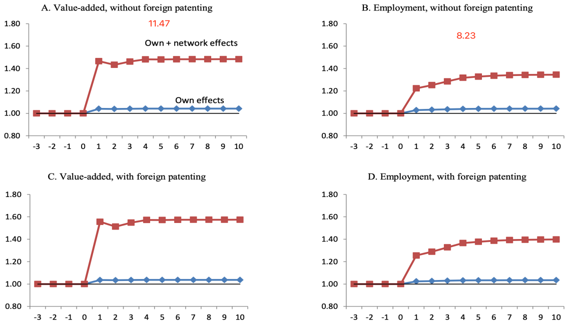
	Baseline Estimation (1)	Excluding Own Lagged Shock (2)	Weighting by 1991 Log Value Added (3)	Weighting by 1991 Employees (4)	Adding SIC2 Fixed Effects (5)	Adding SIC3 Fixed Effects (6)	Adding SIC4 Fixed Effects (7)
			A. Δ Log Real Value Added				
Δ Dependent variable $t-1$	0.020	0.020	0.024	0.120*	–0.012	–0.042*	–0.075***
	(0.025)	(0.025)	(0.026)	(0.070)	(0.025)	(0.024)	(0.021)
Downstream effects $t-1$	0.043***	0.039***	0.042***	0.044**	0.040***	0.038***	0.038***
	(0.011)	(0.011)	(0.011)	(0.021)	(0.011)	(0.011)	(0.011)
Upstream effects $t-1$	–0.000	0.000	0.000	0.007	0.000	0.000	0.000
	(0.005)	(0.005)	(0.004)	(0.007)	(0.005)	(0.004)	(0.005)
Own effects $t-1$	–0.006		–0.006	0.004	–0.003	–0.003	–0.004
	(0.004)		(0.004)	(0.007)	(0.004)	(0.004)	(0.004)
Observations	6,543	6,543	6,543	6,543	6,543	6,543	6,543
P-value: Downstream = own	0.000		0.000	0.354	0.001	0.001	0.000
			B. Δ Log Employment				
Δ Dependent variable $t-1$	0.159***	0.160***	0.163***	0.270***	0.099***	0.044**	0.012
	(0.021)	(0.021)	(0.021)	(0.034)	(0.020)	(0.019)	(0.020)
Downstream effects $t-1$	0.018***	0.013**	0.018***	0.014*	0.015**	0.014**	0.013**
	(0.006)	(0.006)	(0.006)	(0.007)	(0.006)	(0.006)	(0.006)
Upstream effects $t-1$	–0.001	–0.000	–0.001	0.001	–0.001	–0.000	–0.000
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Own effects $t-1$	–0.008***		–0.007***	–0.004	–0.004	–0.003	–0.003
	(0.003)		(0.002)	(0.003)	(0.003)	(0.002)	(0.003)
Observations	6,543	6,543	6,543	6,543	6,543	6,543	6,543
P-value: Downstream = own	0.001		0.001	0.238	0.008	0.016	0.023

IV. Results: The Input-Output Network

G. Combined Shock Analysis–simultaneously: why?

- we would like to verify that our downstream and upstream effects indeed capture network-based propagation of different types of shocks rather than some other omitted characteristics.
- it is important to quantify whether the simultaneous operation of all of these networked effects creates attenuation, which is relevant for our quantitative evaluation.

Appendix Figure 2: Combined response to joint one standard-deviation shocks



Notes: See Figure 1a. Figure plots estimated response to joint one-time standard-deviation shocks. Panels A and B exclude foreign patenting, which has a negative own effect, while Panels C and D include it.

IV. Results: The Input-Output Network
G. Combined Shock Analysis

Table 7
Joint Analysis of Shocks

		Δ Log Real Value Added		Δ Log Employment	
		(1)	(2)	(3)	(4)
Δ Dependent variable $t-1$		–0.043	–0.050	0.125***	0.105***
		(0.041)	(0.041)	(0.020)	(0.020)
Δ Dependent variable $t-2$			0.040*		0.108***
			(0.022)		(0.020)
Δ Dependent variable $t-3$			0.032		0.089***
			(0.021)		(0.016)
Trade:	Downstream effects $t-1$	–0.059	–0.042	–0.016	0.008
		(0.082)	(0.080)	(0.044)	(0.040)
	Upstream effects $t-1$	0.106***	0.107***	0.066***	0.054***
		(0.030)	(0.031)	(0.020)	(0.019)
	Own effects $t-1$	0.032***	0.030***	0.022***	0.017***
		(0.009)	(0.009)	(0.005)	(0.004)
Federal:	Downstream effects $t-1$	–0.006	–0.003	–0.008	0.001
		(0.023)	(0.025)	(0.017)	(0.014)
	Upstream effects $t-1$	0.035**	0.040***	0.020**	0.023***
		(0.014)	(0.014)	(0.009)	(0.008)
	Own effects $t-1$	0.001	0.004	0.001	0.005*
		(0.003)	(0.004)	(0.003)	(0.003)
TFP:	Downstream effects $t-1$	0.062***	0.051**	0.019*	0.014
		(0.021)	(0.021)	(0.010)	(0.010)
	Upstream effects $t-1$	0.030**	0.028**	0.013*	0.011
		(0.013)	(0.014)	(0.008)	(0.008)
	Own effects $t-1$	0.007	0.009	0.007***	0.008***
		(0.007)	(0.007)	(0.002)	(0.002)
Patent:	Downstream effects $t-1$	0.043***	0.043***	0.017***	0.016**
		(0.011)	(0.011)	(0.006)	(0.007)
	Upstream effects $t-1$	0.002	0.002	0.000	0.000
		(0.005)	(0.005)	(0.003)	(0.003)
	Own effects $t-1$	–0.007*	–0.007*	–0.007***	–0.006**
		(0.004)	(0.004)	(0.003)	(0.003)
Observations		6,543	5,761	6,543	5,761

V. Additional Results: The Geographic Network

how shocks to an industry can also propagate regionally because they expand or depress economic activity, impacting the decisions of other industries in the area.

Table 8
Geographic and Networks Analysis

		Δ Log Real Value Added		Δ Log Employment	
		(1)	(2)	(3)	(4)
Δ Dependent variable $t-1$		−0.028	−0.047	0.130***	0.124***
		(0.040)	(0.041)	(0.021)	(0.020)
Trade:	Geographic effects $t-1$	0.125***	0.113***	0.055***	0.049***
		(0.035)	(0.034)	(0.018)	(0.017)
	Downstream effects $t-1$		−0.048		−0.014
			(0.078)		(0.045)
	Upstream effects $t-1$		0.095***		0.061***
			(0.029)		(0.019)
	Own effects $t-1$	0.032***	0.033***	0.023***	0.023***
		(0.009)	(0.009)	(0.005)	(0.005)
Federal:	Geographic effects $t-1$	0.112***	0.101***	0.046***	0.040***
		(0.032)	(0.031)	(0.015)	(0.014)
	Downstream effects $t-1$		−0.036		−0.018
			(0.023)		(0.017)
	Upstream effects $t-1$		0.026**		0.017**
			(0.012)		(0.009)
	Own effects $t-1$	0.001	−0.001	0.002	0.001
		(0.004)	(0.004)	(0.003)	(0.003)
TFP:	Geographic effects $t-1$	0.032***	0.027***	0.014***	0.012**
		(0.010)	(0.010)	(0.005)	(0.005)
	Downstream effects $t-1$		0.055***		0.016*
			(0.019)		(0.010)
	Upstream effects $t-1$		0.024*		0.011
			(0.013)		(0.008)
	Own effects $t-1$	0.008	0.007	0.008***	0.007***
		(0.006)	(0.006)	(0.002)	(0.002)
Patent:	Geographic effects $t-1$	0.005***	0.004***	0.001	0.001
		(0.001)	(0.001)	(0.001)	(0.001)
	Downstream effects $t-1$		0.039***		0.016**
			(0.011)		(0.006)
	Upstream effects $t-1$		0.002		0.000
			(0.005)		(0.003)
	Own effects $t-1$	−0.002	−0.006*	−0.005**	−0.007***
		(0.004)	(0.004)	(0.003)	(0.003)
Observations		6,543	6,543	6,543	6,543

V. Additional Results: The Geographic Network

Robust? NO!

Appendix Table 9b: Geographic effects and networks analysis with single shocks

		Δ Log real value added							
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Δ Dependent variable t-1		0.022	0.019	0.018	0.017	-0.013	-0.024	0.021	0.020
		(0.025)	(0.025)	(0.024)	(0.024)	(0.040)	(0.040)	(0.025)	(0.025)
Trade:	Geographic effects t-1	0.001	0.002						
		(0.007)	(0.007)						
	Downstream effects t-1		-0.142*						
			(0.086)						
	Upstream effects t-1		0.076***						
			(0.024)						
	Own effects t-1	0.032***	0.034***						
		(0.009)	(0.009)						
Federal:	Geographic effects t-1			0.021**	0.018**				
				(0.009)	(0.009)				
	Downstream effects t-1				0.005				
					(0.021)				
	Upstream effects t-1				0.018**				
					(0.008)				
	Own effects t-1			0.004	0.003				
				(0.003)	(0.003)				
TFP:	Geographic effects t-1					0.005	0.003		
						(0.005)	(0.005)		
	Downstream effects t-1						0.060***		
							(0.020)		
	Upstream effects t-1						0.023**		
							(0.011)		
	Own effects t-1					0.007	0.004		
						(0.007)	(0.007)		
Patent:	Geographic effects t-1							0.004***	0.003***
								(0.001)	(0.001)
	Downstream effects t-1								0.041***
									(0.011)
	Upstream effects t-1								-0.001
									(0.004)
	Own effects t-1							-0.002	-0.006
								(0.004)	(0.004)
Observations		6560	6560	6560	6560	6560	6560	6543	6543

V. Conclusion

supply-side (productivity) shocks **propagate downstream**

- downstream customers of directly hit industries are affected more strongly than their upstream suppliers.
- supply-side shocks **change the prices** faced by customer industries, creating powerful downstream propagation

demand shocks (from imports or government spending) **propagate upstream**

- upstream suppliers of directly hit industries are affected more strongly than their downstream customers.
- propagate upstream as affected industries adjust their **production** levels and thus input **demands**.

geographic: industries with substantial exchanges frequently locate near each other to

- reduce transportation costs and facilitate information transfer.

Notes: Many details omitted....why? **unimportance**

感谢大家的聆听！
请大家批评指正！