Optimal Monetary Policy in Production Networks

Jennifer La'O and Alireza Tahbaz-Salehi

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The Canonical New Keynesian Model

- Optimal monetary policy: price stability
  - implements flexible-price allocation
  - "Divine Coincidence:" price stability minimizes both inflation and the output gap

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  - price stability preserves productive efficiency.

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  - productive efficiency requires no relative price movement across **all firms**
  - price stability preserves productive efficiency.

- But once there are technological differences across firms (e.g., in an economy with a production network)
  - productive efficiency requires movements in relative quantities in response to producer-specific shocks
  - monetary policy may lose its ability to replicate flexible-price allocations

This Paper

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- Generalize the textbook New Keynesian model to a multi-sector economy with production networks, à la Long and Plosser (1983) and Acemoglu et al. (2012)

- Firms set their nominal prices under incomplete information about productivities (and before the realization of demand) ⇒ Nominal rigidities

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Formal Results

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▸ Formal Results

- Condition violated generically: impossible to simultaneously achieve
  - productive efficiency within each industry (zero price dispersion within each sector)
  - efficient relative price movement across industries

Part 2: Normative Results

- Characterize optimal monetary policy in terms of model primitives
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- Optimal policy is price index stabilization, with greater weight on
  (1) larger industries (as measured by Domar weights)
  (2) stickier industries
  (3) more upstream industries
  (4) industries with less sticky upstream suppliers
  (5) industries with stickier downstream customers

Related Literature

- Production networks
  - Long and Plosser (1983); Horvath (1998, 2000); Carvalho (2010); Acemoglu et al. (2012, 2017); Acemoglu, Akcigit, and Kerr (2016); Carvalho et al. (2016); Atalay (2017); Baqaee (2018), and many more...and in particular, Basu (1995), Christiano (2016), Pasten, et al. (2019, 2020) and Ozdagli and Weber (2020)
- Optimal policy in multi-sector New Keynesian models
  - Aoki (2001), Mankiw and Reis (2003), Woodford (2003, 2010), and Benigno (2004), Huang and Liu (2005), Wei and Xie (2019), Rubbo (2020)
- Misallocation and markups
  - Jones (2013), Baqaee and Farhi (2019), Liu (2019), Bigio and La'O (2020)

Framework

Standard model of production networks

$+$

nominal rigidities
(modeled as incomplete information)

- Generalizes the (static variant of) single-sector textbook New-Keynesian model to a multi-sector economy and a general class of nominal rigidities

Firms and Production

- n industries, each consisting of a unit mass of firms $k \in [0, 1]$
- Firms in industry i produce differentiated products using a CRS technology

$$y_{ik} = z_i \zeta_i \ell_{ik}^{\alpha_i} \prod_{j=1}^{n} x_{ij,k}^{a_{ij}}.$$

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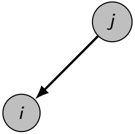
- Production network: $\mathbf{A} = [a_{ij}]$



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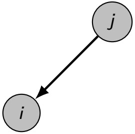

- Nominal profits:

$$\pi_{ik} = (1 - \tau_i)\, p_{ik} y_{ik} - w\ell_{ik} - \sum_{j=1}^{n} p_j x_{ij,k}$$

Firms and Production

- Firms in industry i produce differentiated goods $\rightarrow$ monopolistic competitors

- Competitive sectoral CES aggregator transforms the differentiated products into a uniform sectoral good:

$$y_i = \left(\int_0^1 y_{ik}^{(\theta_i - 1)/\theta_i} dk \right)^{\theta_i/(\theta_i - 1)} \qquad \theta_i > 1$$

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- Nominal profits

$$\hat{\pi}_i = p_i y_i - \int_0^1 p_{ik} y_{ik} dk$$

Representative Household

- Consumes the goods and provides labor to the firms
- Preferences:

$$W = \frac{C^{1-\gamma}}{1-\gamma} - \frac{L^{1+1/\eta}}{1+1/\eta}$$

where

$$\mathcal{C}(c_1, \ldots, c_n) = \prod_{i=1}^{n} (c_i/\beta_i)^{\beta_i}$$

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- Budget constraint:

$$\sum_{i=1}^{n} p_i c_i = wL + \sum_{i=1}^{n} \left(\int_0^1 \pi_{ik} dk + \hat{\pi}_i \right) + T$$

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- Cash-in-advance constraint:

$$\sum_{i=1}^{n} p_i c_i \leq m$$

The Government

- The government has the ability to set fiscal and monetary policies, with full commitment

- Fiscal instruments: a collection of industry-specific taxes/subsidies on the firms, leading to budget constraint

$$T = \sum_{i=1}^{n} \tau_i \int_0^1 p_{ik} y_{ik} \, dk$$

(set $\tau_i = 1/(1-\theta_i)$ so that the flexible-price equilibrium is efficient).

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- Monetary instrument: setting money supply/nominal aggregate demand:

$$m = \sum_{i=1}^{n} p_i c_i$$

Nominal Rigidities as Incomplete Information

- Firms do not observe the realized productivity shocks $z = (z_1, \ldots, z_n)$.
- Rather, firm k in industry i observes a signal $\omega_{ik} \in \Omega_{ik}$.

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$$\text{signals:} \quad \omega_{ij,k} = \log z_j + \epsilon_{ij,k} \qquad , \qquad \epsilon_{ij,k} \sim \mathcal{N}(0, \sigma_{ij,k}^2),$$

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- Model nominal rigidities as measurability constraint on nominal prices:

$$p_{ik}(s) = p_{ik}(\omega_{i1,k}, \ldots, \omega_{in,k})$$

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- Important special case: sticky information model of Mankiw and Reis (2002)

$$\sigma_{ij,k}^2 \in \{0, \infty\}$$

Price Stickiness/Flexibility

- Posterior mean and variance:

$$\text{var}[\log z_j | \omega_{ik}] = (1 - \phi_{ik})\text{var}[\log z_j],$$

where

$$\phi_{ik} = \frac{\sigma_z^2}{\sigma_z^2 + \sigma_{ik}^2}.$$

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The degree of price flexibility of industry i is

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Sticky-Price Equilibrium

Definition

A sticky-price equilibrium is triplet of allocation, prices, and policies such that

(i) firms set nominal prices $p_{ik}(\omega_{ik})$ to maximize expected real value of profits;

(ii) firms optimally choose inputs to meet realized demand;

(iii) the representative household maximizes her utility;

(iv) the government budget constraint is satisfied;

(v) all markets clear.

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Definition

A flexible-price equilibrium is a sticky-price equilibrium, except that all prices are measurable with respect to the aggregate state s.

Optimal Monetary Policy

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- Choose monetary policy $m(s)$ to maximize expected welfare

- Nominal rigidities result in "pricing errors":

$$e_{ik} = \log p_{ik} - \log p_{ik}^*$$

- cross-sectional average of pricing errors within industry i:

$$\bar{e}_i = \int_0^1 e_{ik} \, dk$$

Policy Objective

Proposition

The welfare loss due to the presence of nominal rigidities is given by

$$W - W^* = -\frac{1}{2}\left(\frac{1+1/\eta}{\gamma+1/\eta}\right)\Bigg[\sum_{i=1}^{n}\lambda_i\theta_i \mathrm{var}(e_{ik})$$

$$+ \sum_{i=0}^{n}\lambda_i\left[\sum_{j=1}^{n}a_{ij}\bar{e}_j^2 - \left(\sum_{j=1}^{n}a_{ij}\bar{e}_j\right)^2\right]$$

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- Three sources of welfare loss
  - (1) misallocation within industries
  - (2) misallocation across industries
  - (3) output gap volatility (labor wedge)

Sticky-Price Equilibrium

Lemma (Beauty Contest Representation)

The nominal price set by firm k in industry i satisfies

$$\log p_{ik} = \mathbb{E}_{ik}[\log \mathrm{mc}_{ik}]$$

$$= \mathbb{E}_{ik}[\alpha_i \log w - \log z_i] + \sum_{j=1}^{n} a_{ij} \mathbb{E}_{ik}[\log p_j].$$

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- The economy is isomorphic to a beauty contest game of incomplete information over the production network (Bergemann, Heumann, and Morris, 2017)
- Strategic complementarities: increase in the price set by firms increases the incentive of firms in its customer industries to raise theirs (Blanchard, 1983, Basu, 1995)
- Plays a key role in the optimal conduct of monetary policy

Optimal Monetary Policy

Theorem

Optimal monetary policy is a price-stabilization policy of the form

$$\sum_{s=1}^{n} \psi_s^* \log p_s = 0,$$

where

$$\psi_s^* = \psi_s^{o.g.} + \psi_s^{within} + \psi_s^{across}$$

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and

$$\begin{aligned}
\psi_s^{o.g.} &= \lambda_s (1/\phi_s - 1) \left(\frac{1-\rho_0}{\gamma + 1/\eta} \right) \\
\psi_s^{within} &= \lambda_s (1/\phi_s - 1) \theta_s \rho_s \phi_s \\
\psi_s^{across} &= \lambda_s (1/\phi_s - 1) \left[\rho_0 - \rho_s + \sum_{i=1}^{n} (1-\phi_i) \lambda_i \rho_i \ell_{is} / \lambda_s \right],
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and $\rho_i = \alpha_i + \sum_{j=1}^{n} a_{ij}\phi_j \rho_j$ *is the degree of upstream flexibility of industry* i.

Optimal Policy Comparative Statics

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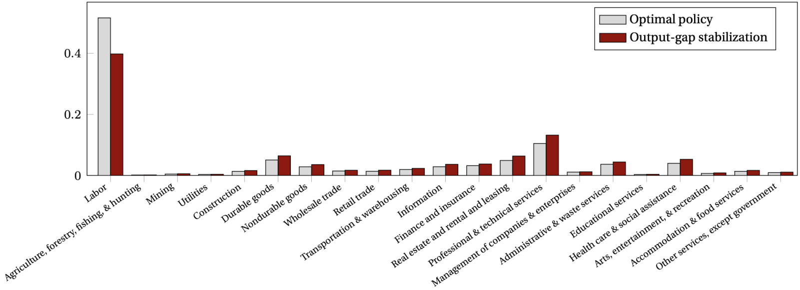
Formal Results

Quantitative Exercise: Welfare Loss under Various Policies

	optimal policy (1)	output-gap stabilization (2)	consumption weighted (3)	Domar weighted (4)	stickiness weighted (5)
Welfare loss (fully nonlinear model)	0.65	0.67	1.95	1.58	3.31
Welfare loss (quadratic approximation)	0.67	0.68	1.08	0.87	1.25
within-industry misallocation	0.53	0.54	0.73	0.64	0.83
across-industry misallocation	0.14	0.14	0.15	0.14	0.14
output gap volatility	10^{-5}	0	0.20	0.08	0.27
Cosine similarity to optimal policy	1	0.9931	0.1181	0.1649	0.2749

Quantitative Exercise: Policy Weights



Summary

- A New-Keynesian model with production networks
- Positive analysis:
  - characterization of the set of allocations monetary policy can implement
  - first-best allocation is not implementable (generically)
- Normative analysis:
  - optimal monetary policy as a function of model primitives
  - general insights about the policy weights
- Future direction:
  - Empirical investigation of production network's role as a mechanism for the propagation of monetary policy shocks

Sticky-Price Equilibrium

Proposition

A feasible allocation is sticky-price implementable if and only if there exist $(\chi_1^s, \ldots, \chi_n^s)$, *policy function* $m(s)$, *and wedges* $\varepsilon_{ik}(s)$ *such that*

(i)

$$V'(L(s)) = \varepsilon_{ik}(s)\chi_i^s U'(C(s)) \frac{\mathrm{d}\mathcal{C}}{\mathrm{d}c_i}(s) z_i \frac{\mathrm{d}F_i}{\mathrm{d}l_{ik}}(s) \left(\frac{y_{ik}(s)}{y_i(s)}\right)^{-1/\theta_i}$$

$$\frac{\mathrm{d}\mathcal{C}/\mathrm{d}c_j}{\mathrm{d}\mathcal{C}/\mathrm{d}c_i}(s) = \varepsilon_{ik}(s)\chi_i^s z_i \frac{\mathrm{d}F_i}{\mathrm{d}x_{ij}}(s) \left(\frac{y_{ik}(s)}{y_i(s)}\right)^{-1/\theta_i}$$

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(ii) *policy function $m(s)$ induces wedge functions $\varepsilon_{ik}(s)$ given by*

$$\varepsilon_{ik}(s) = \frac{\mathrm{mc}_i(s)\mathbb{E}_{ik}[v_{ik}(s)]}{\mathbb{E}_{ik}[\mathrm{mc}_i(s)v_{ik}(s)]}$$

where

$$\mathrm{mc}_i(s) = m(s)\frac{V'(L(s))}{C((s))U'(C(s))}\left(z_i\frac{\mathrm{d}F_i}{\mathrm{d}\ell_i}(s)\right)^{-1}$$

$$v_{ik}(s) = U'(C(s))\frac{\mathrm{d}\mathcal{C}}{\mathrm{d}c_i}(s)y_i(s)\left(\frac{y_{ik}(s)}{y_i(s)}\right)^{(\theta_i-1)/\theta_i}$$

The Power of Monetary Policy

- Let g_i be the marginal product of labor in the production of commodity i under the first-best allocation.

Theorem

A flexible-price allocation indexed by $(\chi_1^f, \ldots, \chi_n^f)$ is implementable as a sticky-price equilibrium if and only if

$$\frac{1}{w(s)} \cdot g_i(\chi_1^f z_1, \ldots, \chi_n^f z_n) \in \sigma(\omega_{ik}) \qquad \text{for all } ik.$$

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controlled by the policy — technology — information structure

- Joint restriction on the technology, information structure, and policy.
- Need to use $w(s)$ as an instrument to make all firms' marginal costs measurable with respect to their information sets.

Characterization: Flexible- and Sticky-Price-Implementable Allocations

Corollary

The sets of sticky- and flexible-price equilibria are generically disjoint.

Corollary

Generically, no monetary policy can implement the first-best optimal allocation.

- Impossible to simultaneously achieve:
  - productive efficiency within each industry (zero price dispersion within each sector)
  - efficient relative price movement across industries

back

Comparative Statics

Definition

industries i and j are

- upstream symmetric if $a_{ir} = a_{jr}$ for all r.
- downstream symmetric if $a_{ri} = a_{rj}$ for all r and $\beta_i = \beta_j$.

"Stickiness Principle"

Proposition

Suppose industries i and j are upstream and downstream symmetric. Then,

$$\psi_i^* > \psi_j^* \qquad \text{if and only if} \qquad \phi_i < \phi_j .$$

- All else equal, monetary policy should **stabilize the price of stickier industries** (Eusepi, Hobijn, and Tambalotti, 2011)

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Suppose industries i and j are upstream and downstream symmetric. Then,

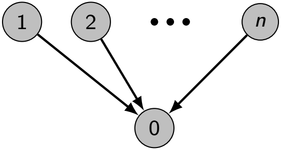
$$\psi_i^* > \psi_j^* \qquad \textit{if and only if} \qquad \phi_i < \phi_j.$$

- All else equal, monetary policy should **stabilize the price of stickier industries** (Eusepi, Hobijn, and Tambalotti, 2011)

- Intuition:
  - downstream symmetry: i and j are equally important for downstream customers.
  - upstream symmetry: $\text{mc}_i = \text{mc}_j$.
  - $\phi_i < \phi_j$: firms in i respond more sluggishly to changes in productivity

$\Rightarrow$ stabilize the stickier industry i

"Stickiness Principle": Example



$$\psi_i^{\text{across}} \propto (1/\phi_s - 1)\beta_s$$
$$\psi_i^{\text{within}} = (1 - \phi_s)\beta_s\theta_s$$
$$\psi_i^{\text{o.g.}} \propto (1/\phi_s - 1)\beta_s$$

Upstream Stickiness

Proposition

Suppose i and j are downstream symmetric and $\phi_i = \phi_j$.

$$\psi_i^* \geq \psi_j^* \qquad \textit{if and only if} \qquad \rho_i \geq \rho_j.$$

- All else equal, the optimal target price index **stabilizes the industry with more flexible upstream suppliers**.

Upstream Stickiness

Proposition

Suppose i and j are downstream symmetric and $\phi_i = \phi_j$.

$$\psi_i^* \geq \psi_j^* \qquad \text{if and only if} \qquad \rho_i \geq \rho_j.$$

- All else equal, the optimal target price index **stabilizes the industry with more flexible upstream suppliers**.

- Intuition:
  - $\rho_i > \rho_j$ means that j's marginal cost responds more sluggishly to shocks, making the lack of complete information about the realized shocks less material for price-setting by firms in j compared to those in i.

$\Rightarrow$ stabilize the industry with more flexible suppliers

Downstream Stickiness

Proposition

Suppose i and j are upstream symmetric, $\phi_i = \phi_j$ and $\lambda_i = \lambda_j$. Then,

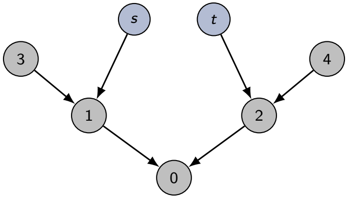
$$\psi_i^* \geq \psi_j^* \qquad \textit{if and only if} \qquad \sum_{s=1}^{n} (1-\phi_s)\lambda_s \rho_s \left(\ell_{si} - \ell_{sj}\right) \geq 0.$$

differential importance of i and j as direct or indirect input suppliers to s

- All else equal, industry i receives a higher weight in the optimal price index if
  - (i) it is a more **important supplier to stickier industries**
  - (ii) **its customers have a higher degree of upstream flexibility**

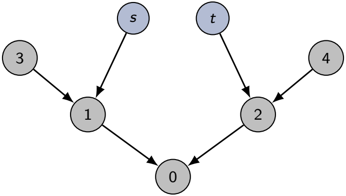
Example

- Suppose s and t are identical ($\phi_s = \phi_t$ and $\lambda_s = \lambda_t$)



Example

- Suppose s and t are identical ($\phi_s = \phi_t$ and $\lambda_s = \lambda_t$)



- Suppose $\phi_3 = \phi_4$. Then,

$$\psi_s^* > \psi_t^* \qquad \text{if and only if} \qquad \phi_1 < \phi_2$$

  - Stabilizing the industry with the stickier customer reduces the need for the firms in the customer industry to adjust their nominal price.

Example

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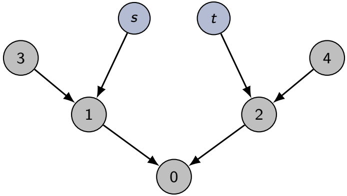

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- Suppose $\phi_1 = \phi_2$. Then,

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  - A higher degree of upstream flexibility means that firms in industry face a more volatile nominal marginal cost and hence, on average, have to adjust their nominal price by more. Therefore, stabilizing the price of one of their inputs would reduce the need for such price adjustment and hence reduce the welfare loss arising from nominal rigidities.

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