Resilience in Vertical Supply Chains

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The New (Ab)Normal: Supply Chain Disruptions

- Causes of disruptions:
  - COVID-19, natural disasters, cyber-attacks...

- Public attention has focused on supply chain resilience
  - International organizations, national governments, think tanks...
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  - Visibility, Redundancy, Agility
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- Policy-makers: Public Sector Strategies
  - Correct market failures resulting from externalities
  - Particularly important upstream
Questions Addressed in this Paper

- What are the relevant *externalities* in a canonical model of vertical supply chains?
- What are the *market distortions*?
- How do optimal policies vary along the supply chain?
- How do first-best policies for resilience and network formation differ from second-best policies?
A Novel Model of Vertical Supply Chains

- Arbitrary number $S + 1$ of tiers: tier $s$ firms purchase from tier $s - 1$ suppliers (snake across tiers)
- Each firm has many suppliers (continuum) in tier above (spider within each tier)
- Each firm has many customers (continuum) in tier below
- Quantities and payments determined by bilateral bargaining
  - Bargaining sequential moving up the supply chain
  - Lead firms in tier $S$ sign contracts with suppliers in $S - 1$.
  - Firms in $S - 1$ sign contracts with firms in $S - 2$...
- All bargaining between firms in tiers $s$ and $s + 1$ occurs simultaneously (Nash-in-Nash)
- Exogenous and independent risks of catastrophic supply chain disruptions
  - Endogenous networks (redundancy)
  - Endogenous resilience (agility)
Stages

- firms choose supplier links $\eta_s$ and investment in resilience $r_s$
- disruption shocks are realized
- surviving firms in tier $S$ bargain with their surviving suppliers in tier $S - 1$ over \{ $m_{S-1}$, $t_{S-1}$\}
- surviving firms in tier $S - 1$ bargain with their surviving suppliers in tier $S - 2$ over \{ $m_{S-2}$, $t_{S-2}$\}
- surviving firms in tier 1 bargain with their surviving suppliers in tier 0 over \{ $m_0$, $t_0$\}
- firms hire labor $l_s$, manufacture intermediate inputs $m_s$, and fulfill their contracts, for $s = 0, 1, ..., S - 1$
- firms in tier $S$ hire labor $l_s$, manufacture final output and sell to consumers $x_s$
Model Features

- **Production technology** in tier $s$: Cobb-Douglas across labor and bargained tier $s - 1$ intermediate inputs, CES across intermediate inputs
  - Tier 0: linear production function in labor

- **Demand**: derived from CES aggregate preferences over differentiated final goods

- **Ex-ante investment in agility** $r_s$ leads to survival probability $\phi_s(r_s)$

- **Ex-ante investment in link formation** $\eta_s \rightarrow$ match with fraction $\eta_s$ of surviving ex-ante formed links

- **Labor market clearing**: labor used for production of intermediate inputs, final goods, and for investments in agility and links.
Recursive Solution: we show that sequential Nash-in-Nash yields an intuitive and tractable solution for negotiated transfers and quantities

Markup factor: key result from recursive bargaining solution:

$$\mu_{s-1} = (1 - \beta_s) \frac{\sigma_s}{\sigma_s - 1} + \beta_s$$

- $\beta_s$: bargaining weight of tier $s$ buyer
- $\sigma_s$: elasticity of substitution of tier $s$ buyer across tier $s-1$ inputs
First-Best Policies

Need 3 sets of policy instruments to decentralize first-best allocation:

- Taxes/subsidies on input transactions \( \{\tau_s\}_{s=0}^S \)
- Taxes/subsidies on investment in agility \( \{\theta_s\}_{s=0}^S \)
- Taxes/subsidies on investment in link formation \( \{\vartheta_s\}_{s=1}^S \)

Find:

- \( \tau_0^* = \tau_S^* = 1 \rightarrow \) no subsidy at extremes
- \( \tau_s^* = \frac{1}{\gamma_s + (1-\gamma_s)\mu_{s-1}} < 1 \rightarrow \) subsidy on purchases in the middle to correct consumption distortion
- \( \theta_0^* < 1 \)
- \( \theta_s^* = \vartheta_s^* = \frac{1-\beta_{s+1}}{\tau_s^*} \geq 1 \rightarrow \) correct for excess incentives caused by transaction subsidies

**Key:** If \( \beta_s = \beta \) and \( \sigma_s \geq \sigma_{s+1} \) for all \( s \), resilience and link formation subsidies decrease as we go downstream
Setting where $\tau_s = 1$ for all $s$

Findings:

$$\theta_s^\circ = \frac{1 - \beta_{s+1}}{J \prod_{j=s+1}^{S-1} B_j} \geq 1 \text{ for } s \in \{0, 1, ..., S - 1\}$$

where $B_j = \gamma_j + (1 - \gamma_j)\mu_{j-1}$ and $J < 1$

Intuition: second-best subsidies increase with markups and input shares downstream from $s$ since markups reduce downstream sales and profits and depress incentives to invest

- If $\beta_s = \beta$ for all $s$, then second-best resilience subsidy is larger upstream
- Upstream firms create positive externalities for more downstream firms
- Second-best link subsidies same as second-best resilience subsidies: $\theta^\circ = \theta^\circ$
Conclusions

- New model of vertical supply chains with multiple tiers, endogenous networks, endogenous resilience, bilateral and sequential bargaining in general equilibrium

- Bilateral bargaining with shared surplus generates private cost of inputs greater than social cost

- First-best policy offsets effect of “markups” on perceived costs

- Second-best depends on accumulation of downstream conditions

- Under reasonable conditions on bargaining and production parameters, first and second-best resilience and link subsidies are larger upstream