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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Supply Chain Resilience: What can be done about it?

- **Firms**: Private sector incentives
  - Visibility, Redundancy, Agility
- **Policy-makers:** Public Sector Strategies
  - Correct market failures resulting from externalities
  - Particularly important upstream

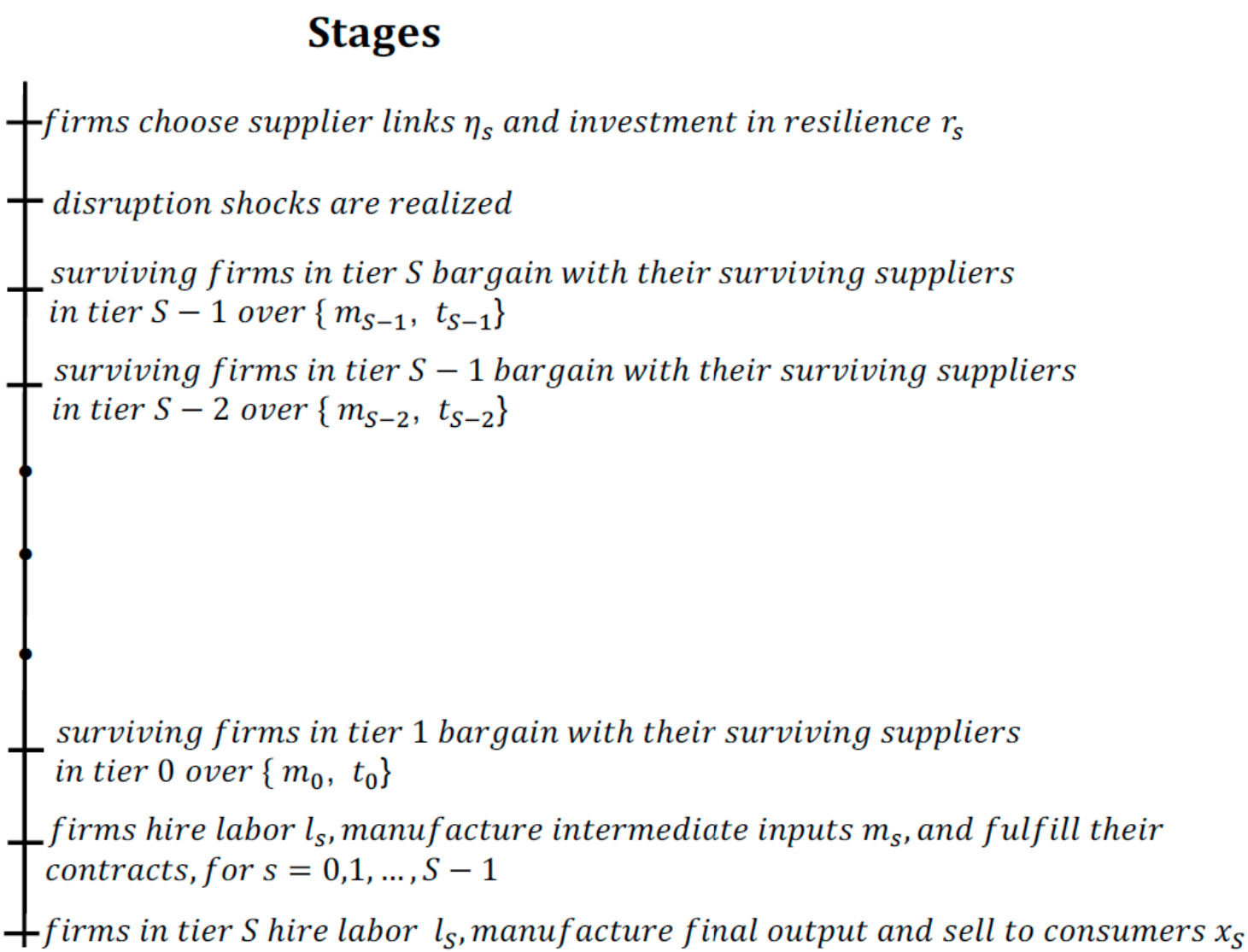
Questions Addressed in this Paper

- 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)

Sequence of Events and Decisions



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 η_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 & Markup Factor

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:

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

- β_s: bargaining weight of tier s buyer
- σ_s: elasticity of subsitution 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
- $\theta_0^* < 1$
- $\theta_s^* = \vartheta_s^* = \frac{1-\beta_{s+1}}{\tau_s^*} \gtrless 1 \rightarrow$ 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

Second-Best Policies

Setting where $\tau_s = 1$ for all s

Findings:

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

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: $\theta^\circ = \vartheta^\circ$

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