Supply Chain Formation and Fragilities under Imperfect Information

Andrea Titton

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EEA-ESEM, 31 August 2023

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Motivation	Research Question	Setup	Equilibrium	Conclusion
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Hurricane Laura shuts 84% of US oil output in Gulf, one-third of SBR capacity

Hurricane Ida Threatens Global Plastic Markets

Peter C. Earle – August 30, 2021

Reading Time: 7 minutes

Image: A math a math

AIER >> Daily Economy >> Government >> Financial Markets >> Crisis

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Stylised facts:

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Stylised facts:

 Firms react to risk by multi-sourcing (Zhao and Freeman, 2019).



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Stylised facts:

- Firms react to risk by multi-sourcing (Zhao and Freeman, 2019).
- **2** The supply chain is *opaque* (Williams et al., 2013).

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Research Question

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Research Question

1 How do production networks form under opacity?

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Research Question

- 1 How do production networks form under **opacity**?
- 2 What are the implications for endogenous fragility?

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1 Vertical economy with $k \in \{0, 1, \dots, K\}$ goods / layers



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1 Vertical economy with $k \in \{0, 1, ..., K\}$ goods / layers 2 Identical firms $(k, 0), (k, 1) \dots (k, m)$

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- **1** Vertical economy with $k \in \{0, 1, \dots, K\}$ goods / layers
- 2 Identical firms $(k,0), (k,1) \dots (k,m)$
- 3 Production yields an exogenous payoff π

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- **1** Vertical economy with $k \in \{0, 1, \dots, K\}$ goods / layers
- **2** Identical firms $(k, 0), (k, 1) \dots (k, m)$
- 3 Production yields an exogenous payoff π
- **4** Firm contract with suppliers $S_{k,i}$ at a marginal cost $c |S_{k,i}|$

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- **1** Vertical economy with $k \in \{0, 1, \dots, K\}$ goods / layers
- **2** Identical firms $(k, 0), (k, 1) \dots (k, m)$
- 3 Production yields an exogenous payoff π
- **4** Firm contract with suppliers $S_{k,i}$ at a marginal cost $c |S_{k,i}|$
- **5** A firm is disrupted $(k, i) \in D_k$ if all its suppliers are disrupted $S_{k,i} \subset D_k$

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Opacity				

The upstream realisation of the production network $\mathcal{S}_{l,j}, l < k$ is not observable

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Problem of the firm

Choose a set of suppliers $S_{k+1,i}$ to maximise expected profits

$$\Pi(\mathcal{S}_{k+1,i}) = \left(1 - \mathbb{P}\big(\mathcal{S}_{k+1,i} \subset \mathcal{D}_k\big)\right) \, \pi - \frac{c}{2} |\mathcal{S}_{k+1,i}|^2$$

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Basal conditions

Assumption: The probability that a firm in the basal layer fails $p_{0,i}$ is sampled from a Beta with mean μ_0 and overdispersion ρ_0



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Overdispersion parameter



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Solution	trick I			

Let $X_{k,j} = \mathbb{1}\{\text{firm } (k,j) \text{ is disrupted}\}\$



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Let $X_{k,j} = \mathbb{1}\{\text{firm } (k,j) \text{ is disrupted}\}$

 $X_{k,0}, X_{k,1} \dots X_{k,m}$ are not independent.



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Opacity and *identical firms* \implies exchangeability!

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Opacity and *identical firms* \implies exchangeability!

 \implies what matters is the **number** of disrupted firms, $D_k = |\mathcal{D}_{k,i}|$

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Let
$$X_{k,j} = \mathbb{1}\{\text{firm } (k,j) \text{ is disrupted}\}$$

 $X_{k,0}, X_{k,1} \dots X_{k,m}$ are not independent.

Opacity and *identical firms* \implies exchangeability!

- \implies what matters is the **number** of disrupted firms, $D_k = |\mathcal{D}_{k,i}|$
- \implies optimise only on the **number** of suppliers, $s_{k+1} = |S_{k+1,i}|$

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How do disruptions propagate from suppliers to firms, $D_k \rightarrow D_{k+1}$?



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How do disruptions propagate from suppliers to firms, $D_k \rightarrow D_{k+1}$?

Borrow from Pólya's urns: if $D_k = D_0^{s_1 s_2 \dots s_k}$ with $D_0 \sim$ Beta, $D_{k+1} = D_0^{s_1 s_2 \dots s_k s_{k+1}}$.

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Problem of the firm (revisited)

Choose the number of sources s_k to maximise expected profits

$$\Pi(s_{k+1}) = \left(1 - p(s_{k+1}, D_k)\right) = \left(1 - \frac{c}{2}s_k^2\right)$$

where $D_k = D_0^{s_1 s_2 \dots s_k}, D_0 \sim \text{Beta}.$

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Optimal Number of Sources

Firms stop adding sources whenever doing so yields a negative marginal payoffs

$$\Pi(s_{k+1}+1) - \Pi(s_{k+1}),$$

this depends crucially on μ_0 and ρ_0 .

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Optimal Number of Sources





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Endogenous Fragility



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directly generates tail risk,



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1 Overdispersion with opacity

- directly generates tail risk,
- **indirectly** changes the firms' incentives.



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1 Overdispersion with opacity

- directly generates tail risk,
- indirectly changes the firms' incentives.
- 2 Common externalities are exacerbated

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1 Overdispersion with opacity

- directly generates tail risk,
- indirectly changes the firms' incentives.
- 2 Common externalities are exacerbated
- 3 Self organised criticality: worse than we thought