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The fragmentation of production amplifies systemic risk in supply chains

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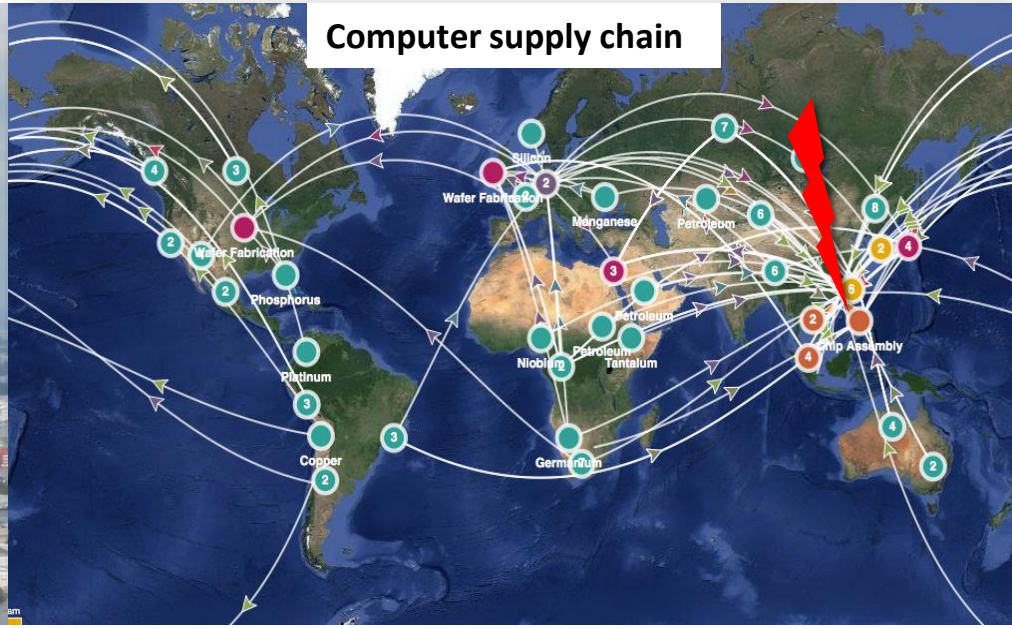
Disruptions can propagate through supply chains



- Production disruptions **propagate through supply chains**
  - Empirical evidence (e.g., Barrot & Sauvagnat 2016)
  - Indirect losses of natural disasters often exceed direct loss (Hallegatte 2014)

- For businesses, a perception of rising **systemic risk**
  - Managers and insurers loosing track of risk propagation (e.g., Goldin 2010 & pers. commun.)
  - A quest for *supply chain resilience* in the business management literature (e.g., Sheffi 2005)

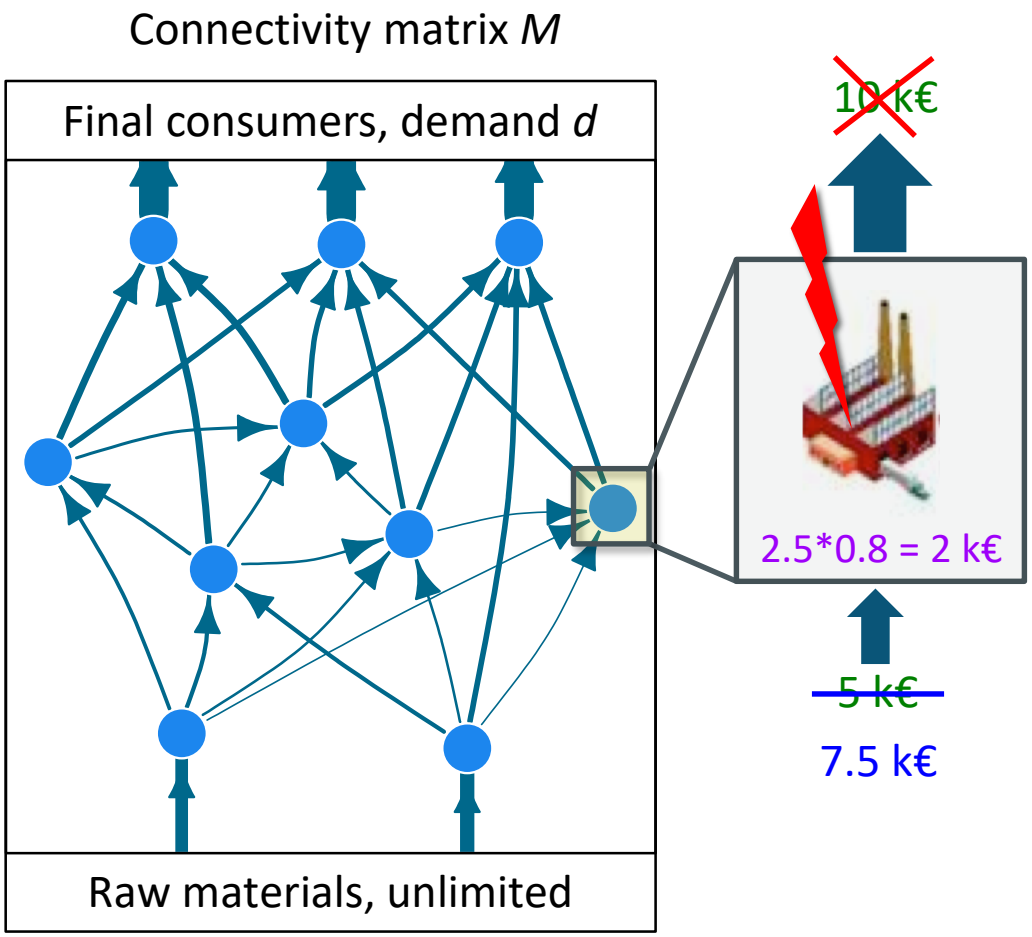
How fragmentation affect systemic risks?

- A trend towards global **outsourcing**
  1. **Complex** supply chains: more firms, more interconnected (Osadchiy et al. 2016)
     - Models linking network structure and disruption propagation (e.g., Coluzzi et al. 2011)
  2. **Fragmented** supply chains: production stages split between many firms (Hummels et al. 2001)
     - Gap: **How does fragmentation influence systemic risks**?

- Risk-management decisions are **interdependent** in supply chains
  - Decisions taken by one firm modify the risk exposure of the other firms
  - Operation-research models use **game theory** to elicit optimal strategies (Snyder et al. 2016)
  - Method limited to very small supply chains

- A stylized model with **evolutionary** dynamics
  - Supply chains subject to random disruption (e.g., Weisbuch & Battiston 2009)
  - Firms adapt their risk-mitigating strategy to the level of fragmentation
  - Evolutionary game on networks (Szabó & Fáth 2009) with coalitions

Model formulation, I — Input–output network



Technology: Linear production function with productivity $z > 1$:
$z = 2$

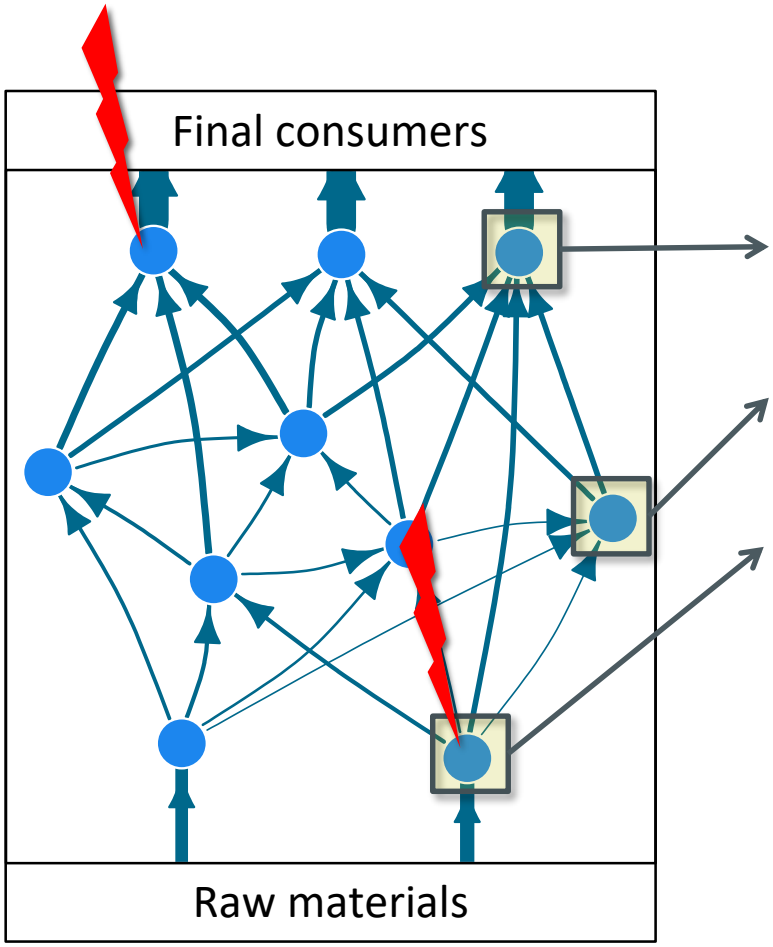
Orders are equally split among suppliers (full substitutability).

Risk mitigation: Overorder at rate $\eta \geq 0$:
$\eta = 50\%$

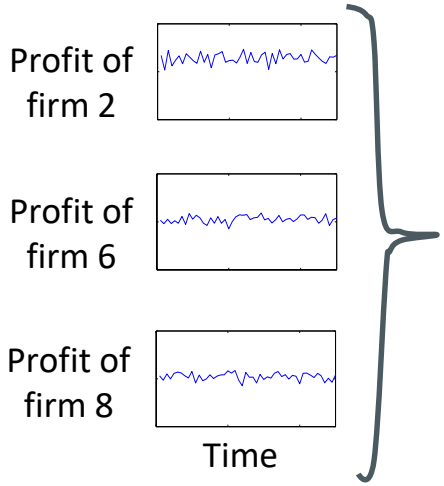
Inventory with durability δ : A fraction $\delta \geq 0$ of unused inputs is stored:
$\delta = 80\%$

Shocks: At each time step, firms get perturbed with probability f, called the failure rate

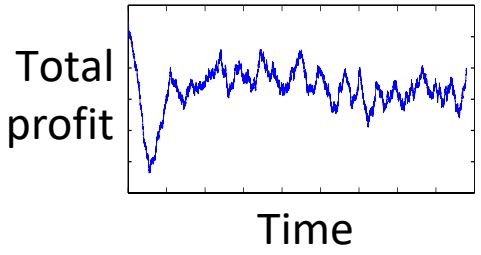
Model formulation, II — Supply disruptions



Firm level



Supply-chain level



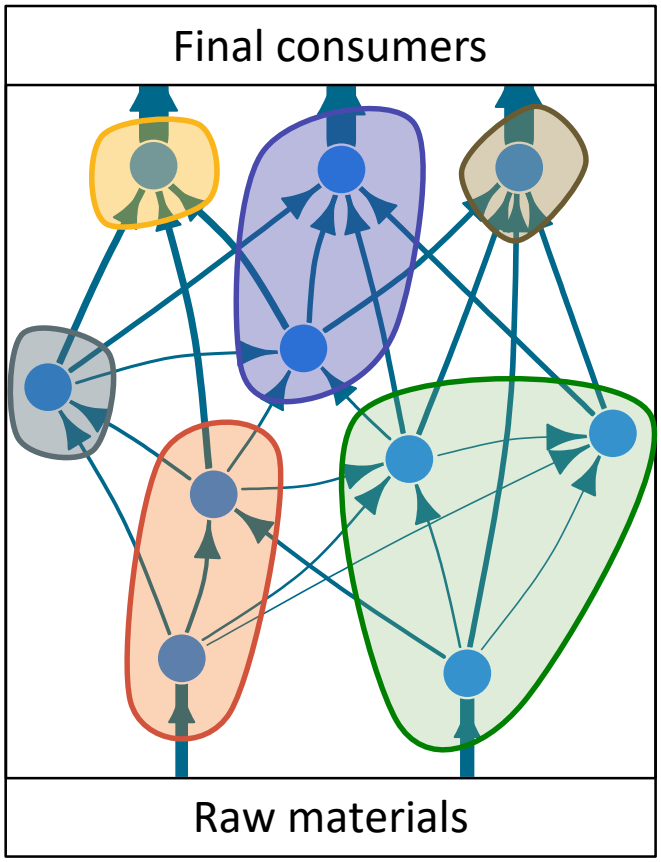
We evaluate the **average profit loss *L*** of the supply chain compared to a no-risk scenario

L* = *Direct Loss* + *Indirect Loss

Loss incurred by firms that are externally perturbed

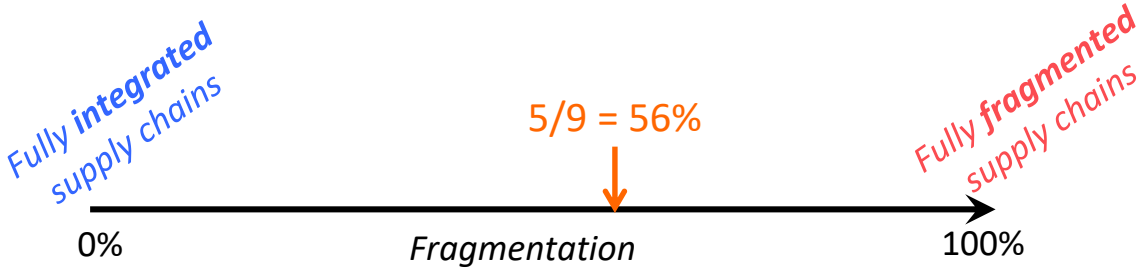
Loss due to the propagation of supply disruptions

Model formulation, III — Evolution of strategy



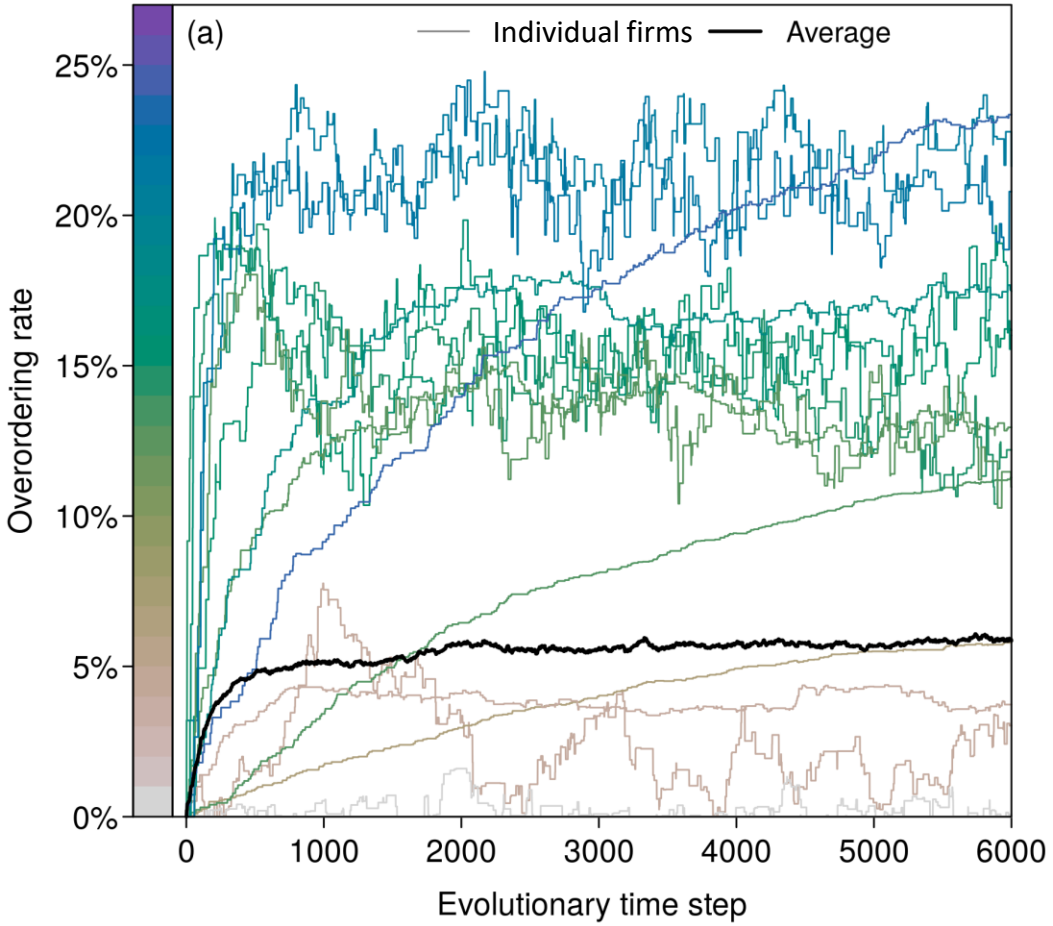
Example of group configuration

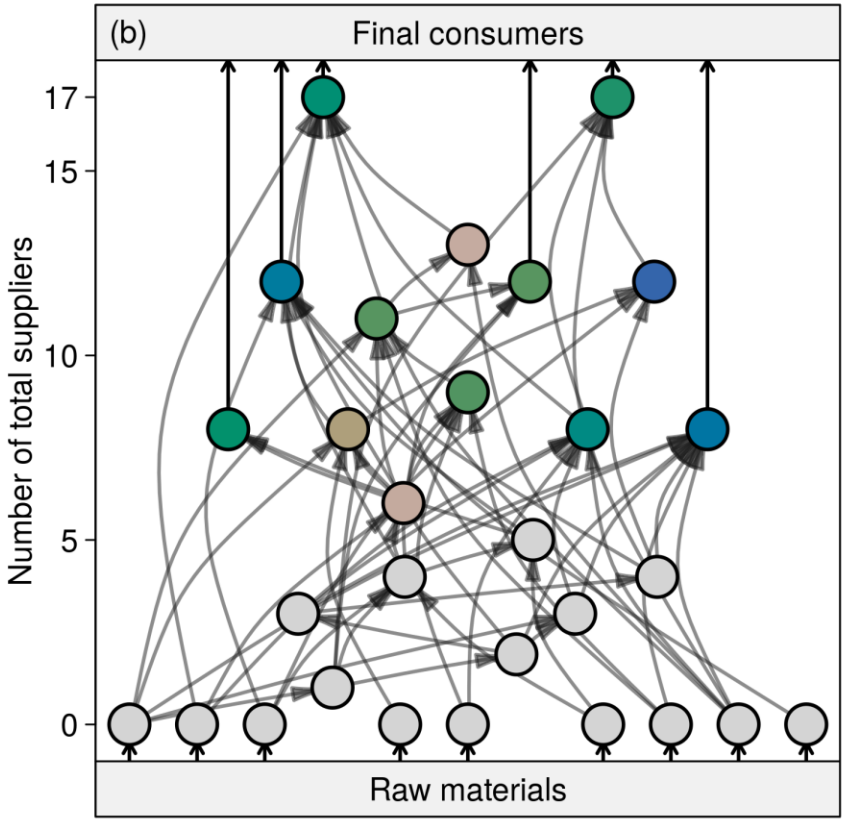
- The n firms are allocated to g groups
  - Fragmentation = $(g-1)/(n-1)$



- Each firm **adjust its overordering rate** η_i to increase the profit of its group
  - **Evolutionary** process based on gradient ascent
  - Each firm **tries and tests** different rates and picks the one that increases profits
  - The process is **iterated** until a stationary state is reached

Example of a fragmented chain, I — Differentiated strategies

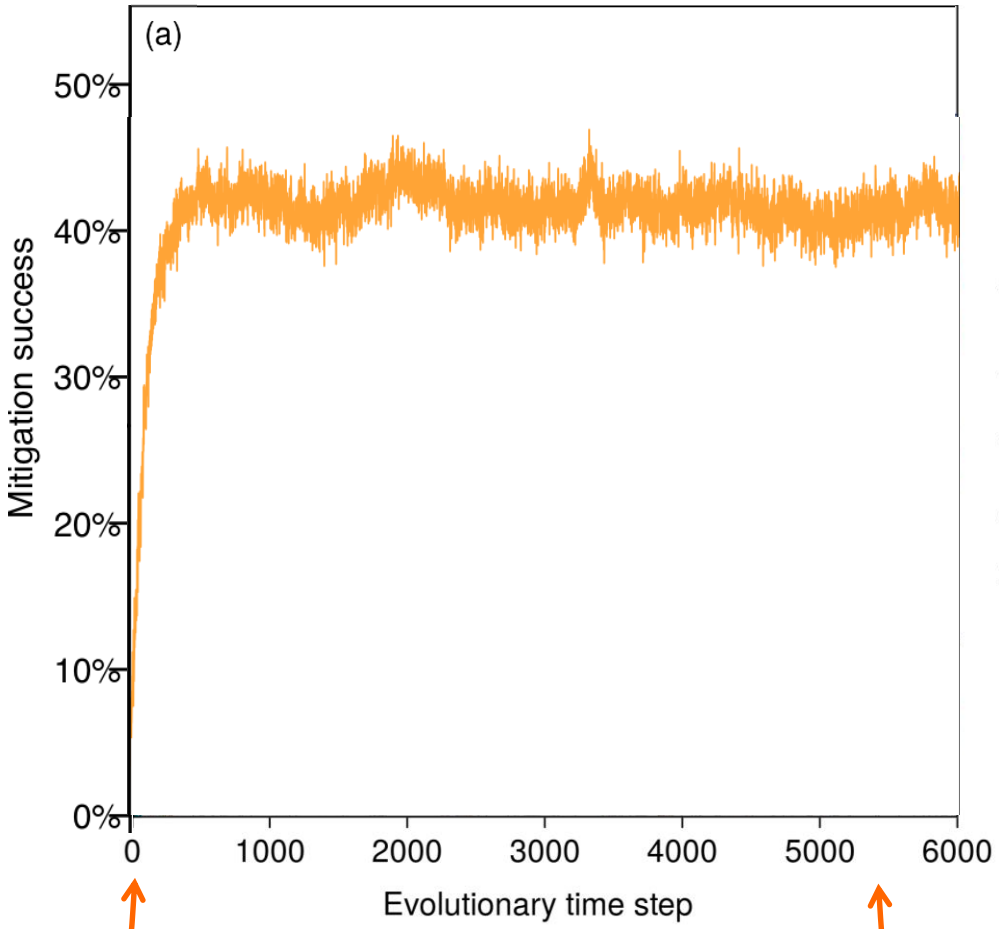




Productivity $z = 2$
Durability of inventory $\delta = 50\%$
Failure rate $f = 10\%$

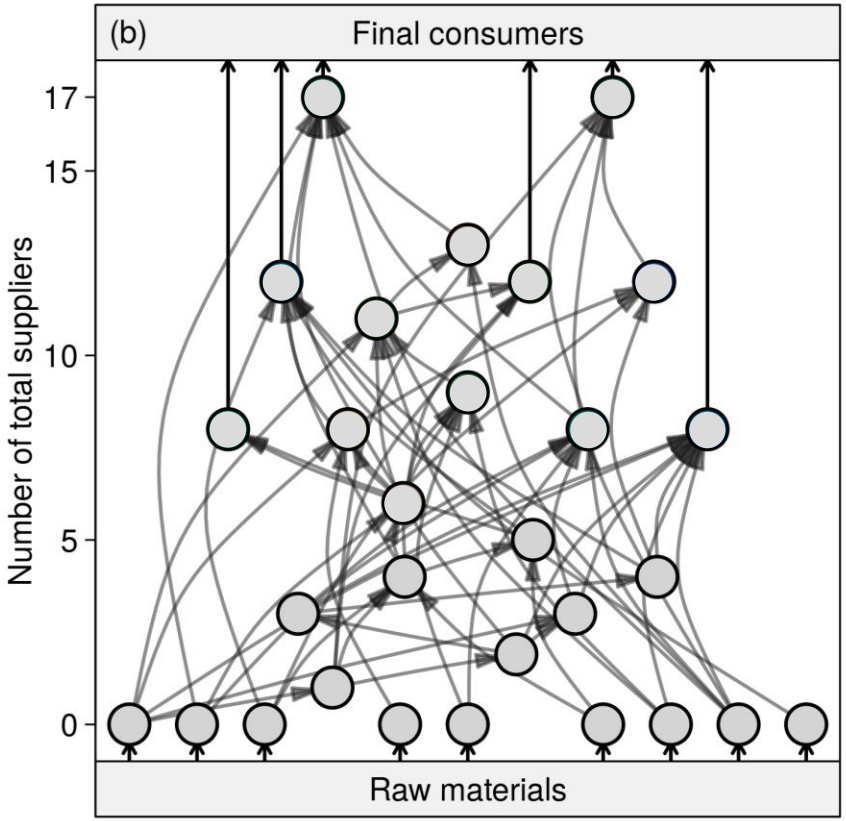
Example of a fragmented chain, II — Risk mitigation

Relative reduction in indirect loss



Indirect loss ≈ 2*(Direct loss)

Indirect loss ≈ 1.2*(Direct loss)



Productivity $z = 2$

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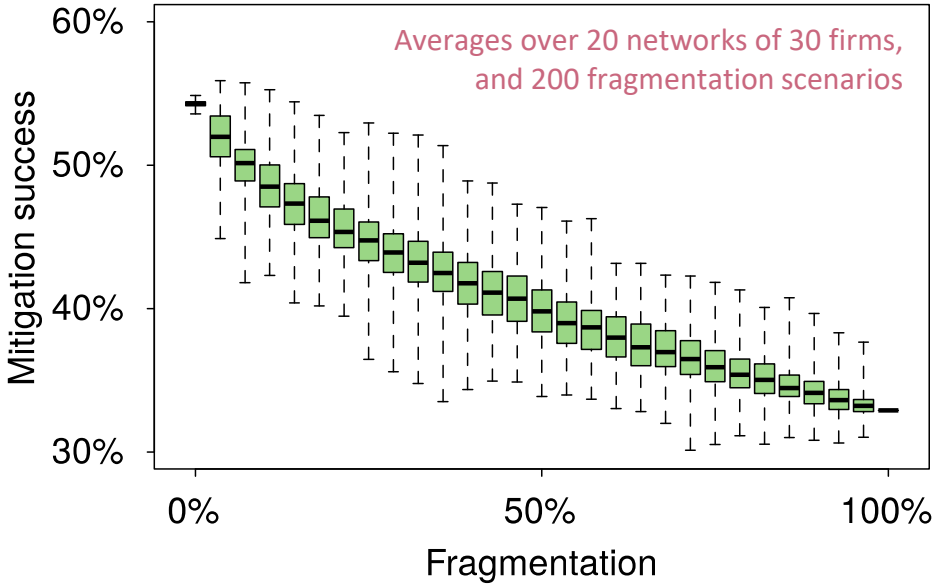
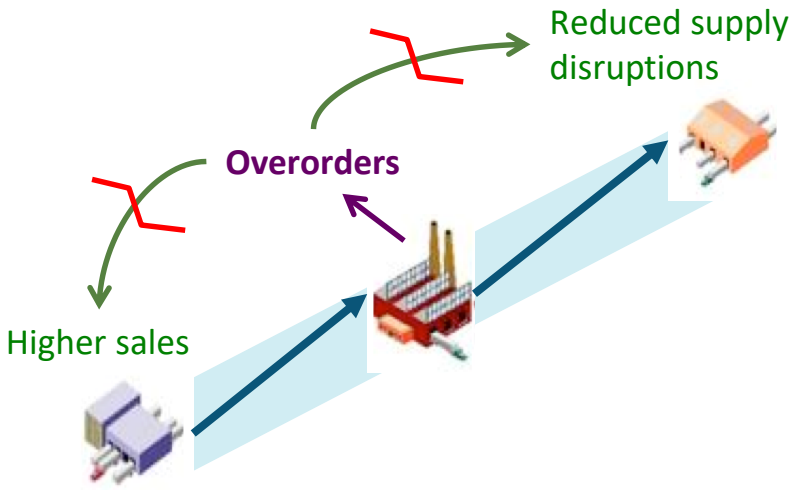
Fragmentation amplifies systemic risks

Fragmentation diminishes risk mitigation…

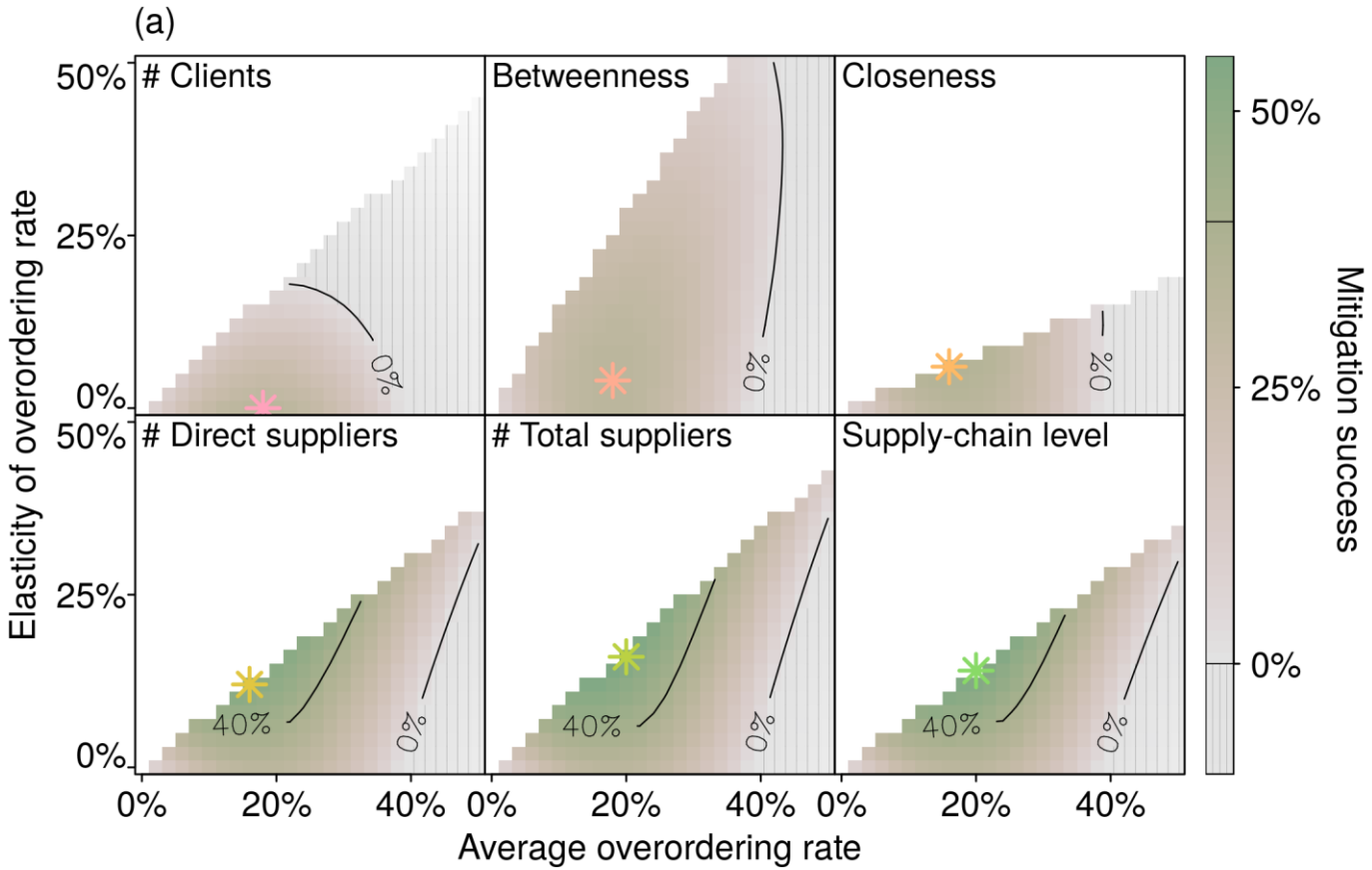


…by reducing incentives to overorder



Supply chain mapping helps identify mitigation benchmarks

Suppose a decision-maker could impose the overordering rate based on objective criteria, what level of mitigation success could be reached?



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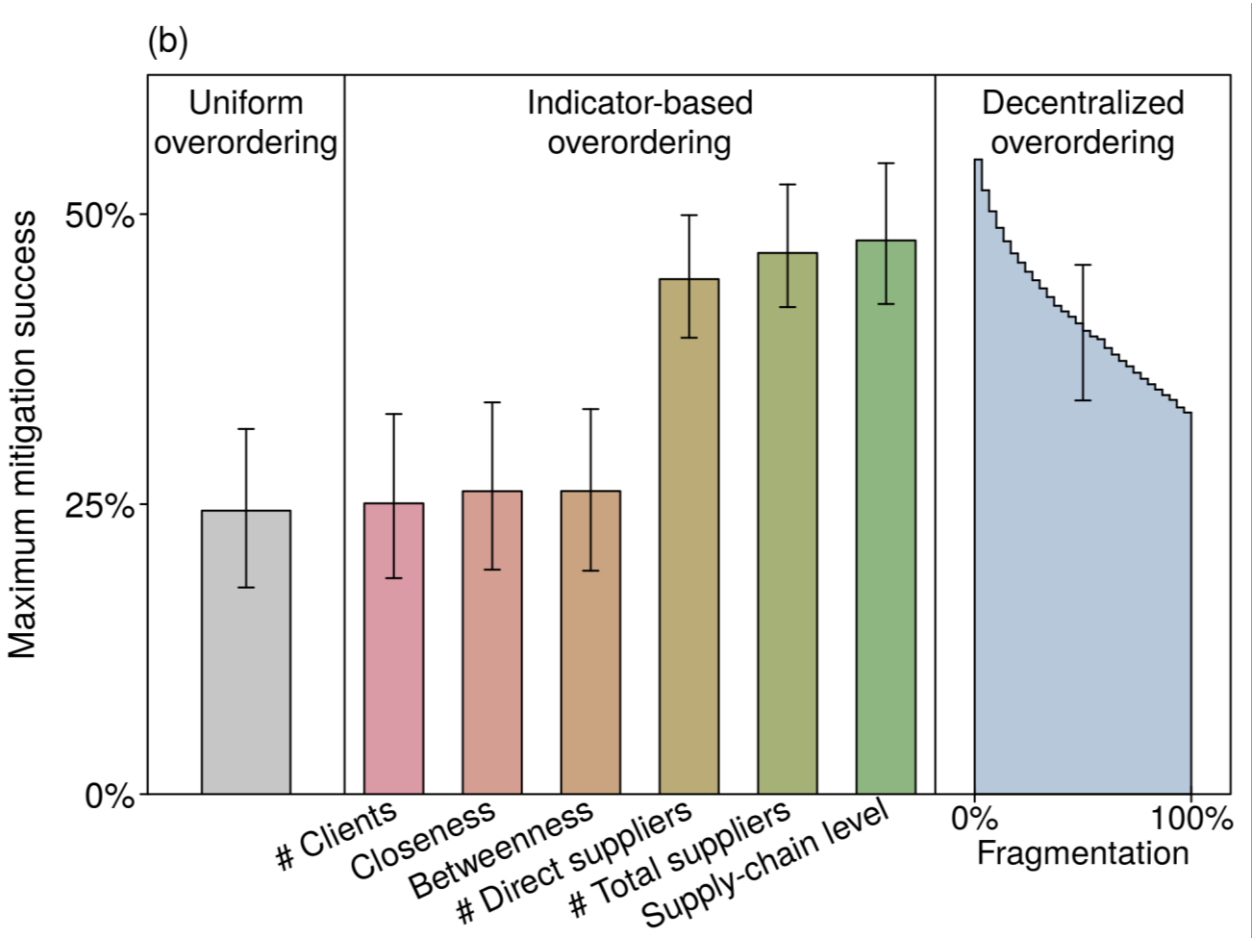

Concluding remarks

- Fragmentation, inventories and risks
  - More fragmented supply chains (Hummels et al. 2001) & lower inventories (Goldin 2010)
  - Our model suggests that **both trends may be linked**: fragmentation disincentivises inventories.
  - **Risks are transferred** from individual firms to the production system.
- A coming role for insurers?
  - There is a growing demand for **supply chain insurance** (Munsch 2013 & pers. com.)
  - Insurers inherit the complexity of the system.
  - **Supply chain mapping** helps provide benchmarks for mitigating risks.