Supply Chain Disruptions, the Structure of Production Networks, and the Impact of Globalization

Matthew Elliott
Cambridge

Matthew O. Jackson
Stanford

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BUSINESS

Tesla to Halt Production in Germany as Red Sea Conflict Hits Supply Chains

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By William Boston Follow , *Costas Paris* Follow *and Benoit Faucon* Follow

Updated Jan. 12, 2024 1:45 pm ET

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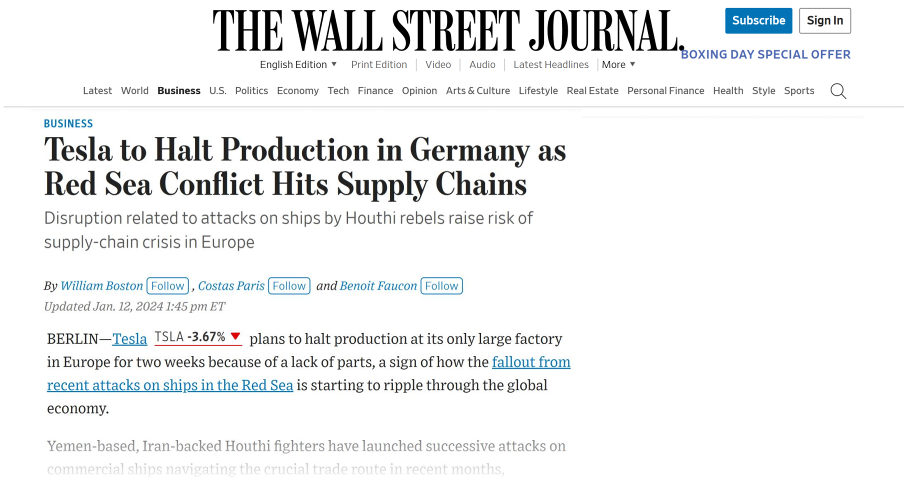

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This paper: tractable model of (global, complex) supply chains to:

- characterize short-run impact of a shock,
- contrast with long-run impact,
- investigate how impact depends on complexity,
- examine impact of globalization on fragility.

Some Related Literature

- **Foundational work:** Leontief (1936), Long Jr and Plosser (1983), Acemoglu et al. (2012)
- **Surveys:** Bernard (2018), Carvalho and Tahbaz-Salehi (2019), Baqaee and Rubbo (2022), Antràs and Chor (2022), Elliott and Golub (2022), Baldwin and Freeman (2022).
- **Production networks:** e.g., Brummitt et al. (2017),Baqaee (2018), Oberfield (2018), Acemoglu and Tahbaz-Salehi (2020), Acemoglu and Azar (2020), Baqaee and Farhi (2021), Kopytov et al. (2021), Elliott et al. (2022), Bui et al. (2022), König et al. (2022), Pellet and Tahbaz-Salehi (2023), Grossman et al. (forthcoming), Grossman et al. (2023a), Grossman et al. (2023b)
- **Trade networks:** e.g., Chaney (2014), Bernard et al. (2019)
- **Micro network structure:** e.g., Bimpikis et al. (2018), Bimpikis et al. (2019), Amelkin and Vohra (2020)

Outline

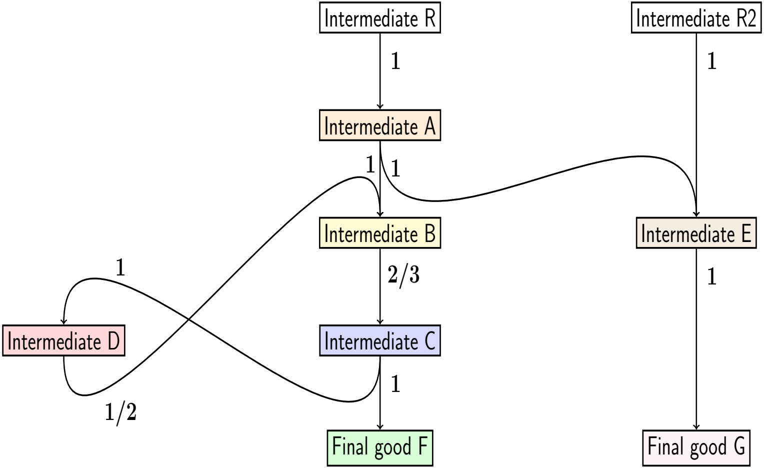
Arrow-Debreu (1954) Technologies

Constant returns to scale technologies τ

$$\left(\text{labor}, \quad \underbrace{m_1, \ldots, m_M}_{\text{intermediate}}, \quad \underbrace{f_1, \ldots, f_F}_{\text{final goods}}\right)$$

e.g., $(-2, 0, -3, 0, 1)$: 2 units labor & 3 units m_2 make 1 unit f_2.

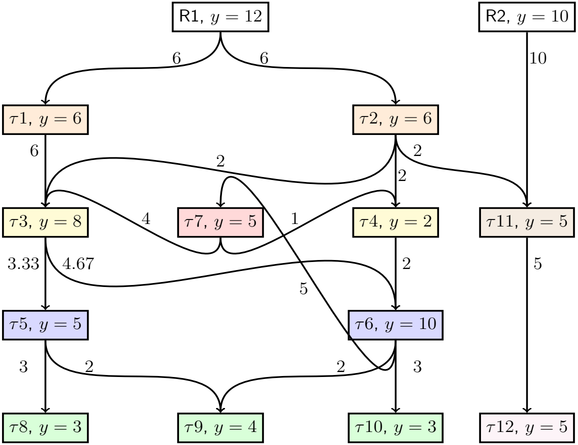
Example: Technologies



Equilibrium (in Paper)

- Laborers
  - supply labor inelastically
  - have homothetic preferences for final goods
- Producers maximize profits (price takers)
- Markets clear - Standard Arrow Debreu equilibrium

Example: Equilibrium Flows (Can Include Cycles)



Shock Impact

For τ, with output k, normalized $\tau_k = 1$.

Let's vary τ_k to capture shocks/disruptions

Analyze/contrast:

- **Long run**: new equilibrium using shocked technologies,
- **Short run**: work with existing supplies/shortages.

Long-Run: Hulten's Theorem

Proposition (Hulten's Theorem)

Consider a (generic) equilibrium and technology τ, with $O(\tau) = k$, used in positive amounts in equilibrium. Then

$$\frac{\partial \log(U)}{\partial \log(\tau_k)} = \frac{\partial \log(GDP)}{\partial \log(\tau_k)} = \frac{p_\tau y_\tau}{GDP}.$$

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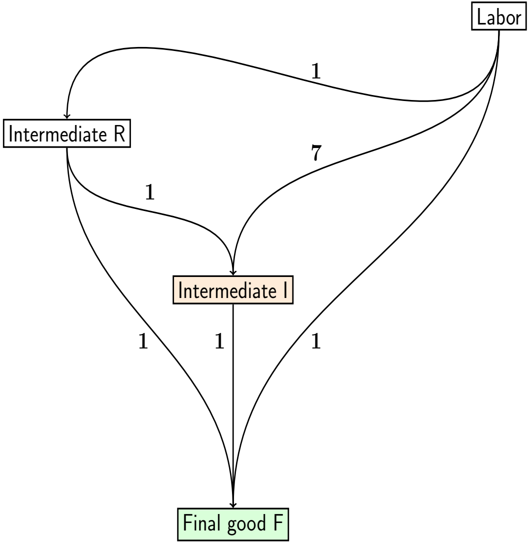
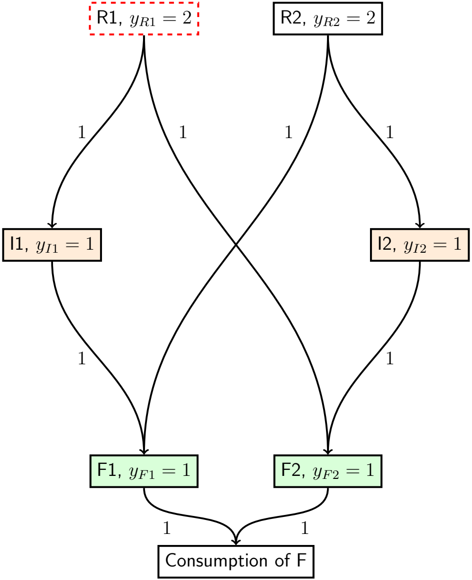
- Sufficient statistic: spending on shocked technology.
- Intuition—adjust by sourcing more inputs at the margin.
- Network matters in background as it determines equilibrium
  - but don't need to see network to estimate long-run impact.

Figure: Technologies



Labor endowment: 20

Figure: Equilibrium flow network



$$p = \left(\underbrace{\frac{1}{10}}_{\text{labor}}, \underbrace{\frac{1}{10}}_{R}, \underbrace{\frac{4}{5}}_{I}, \underbrace{1}_{F} \right)$$

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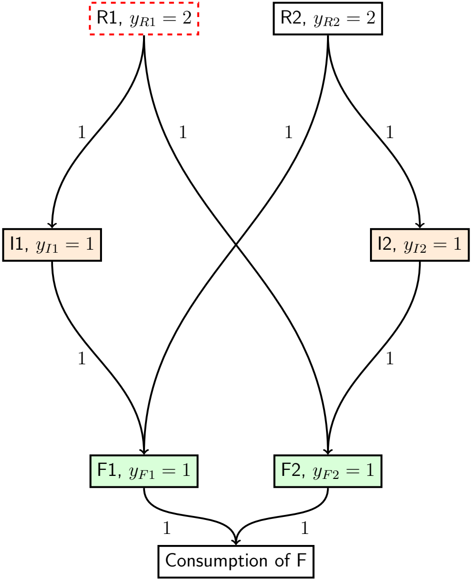


$$p = \left(\underbrace{\frac{1}{10}}_{\text{labor}}, \underbrace{\frac{1}{10}}_{R}, \underbrace{\frac{4}{5}}_{I}, \underbrace{1}_{F} \right)$$

$GDP = \sum_f p_f c_f = 2.$

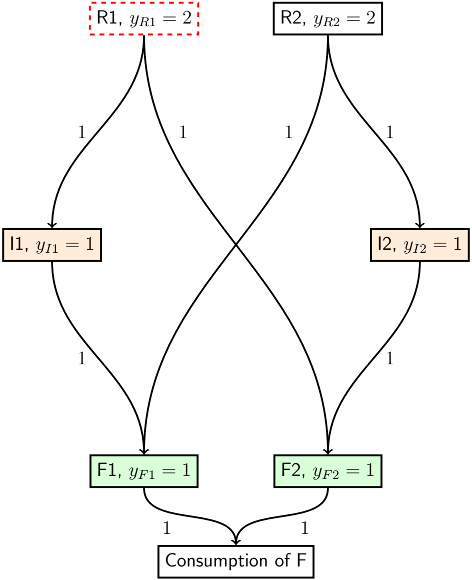
$p_{R1} = 1/10$

$y_{R1} = 2$

Marginal impact:

$$\frac{p_{R1} y_{R1}}{\text{GDP}} = \frac{1}{10}$$

Figure: Equilibrium flow network



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Extrapolating for a 50% shock,

Total impact: $1/20$th of GDP

Larry Summers 2013

"There would be a set of economists who would sit around explaining that electricity was only 4% of the economy, and so if you lost 80% of electricity, you couldn't possibly have lost more than 3% of the economy...[However,] *we would understand that* [...] *when there wasn't any electricity, there wasn't really going to be much economy."*

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Limitations:

- Result at the *margin* (relies on Envelope Theorem)
  - Baqaee and Farhi (2019)—second order effects can matter
- *Long-Run* re-optimization of production
  - Takes time—different impact in the short run.

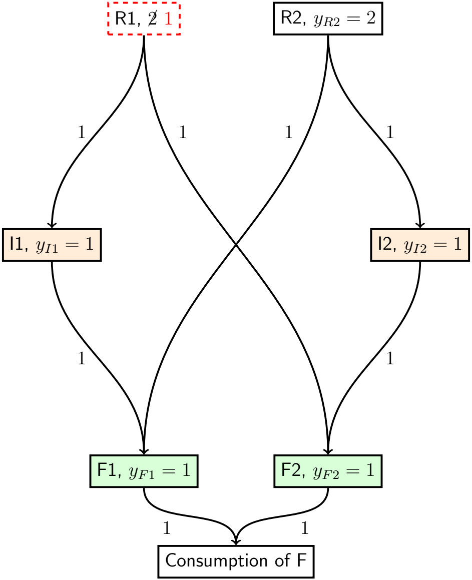
Short-Run Impact of a Shock

Hulten: Production is perfectly flexible and fully adjusts.
(Marginal result.)

Now: Opposite benchmark with no adjustments.
(Our result holds away from the margin.)

- Cannot adjust the technologies being used.
- Cannot source additional units from alternative suppliers.
- Prices cannot adjust—rationing of disrupted goods is proportional

Figure: Shock Propagation



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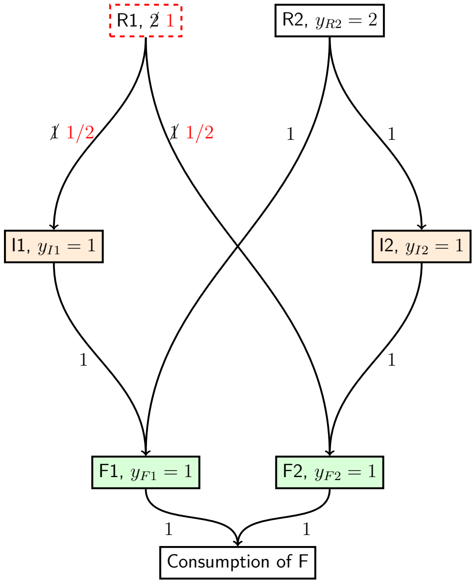

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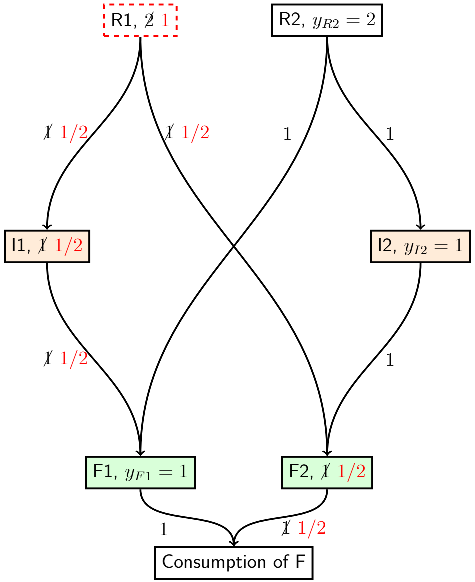

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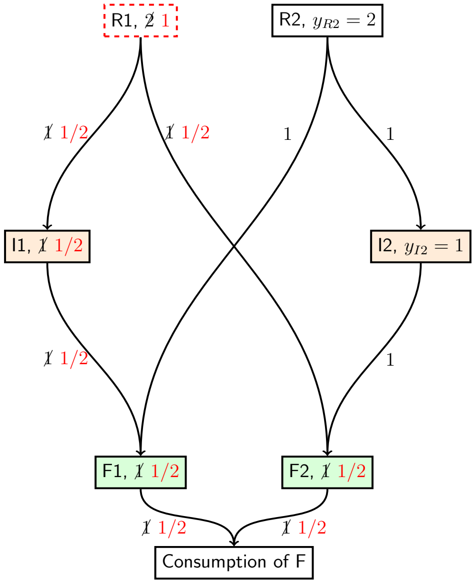

Total impact: $1/2$ of GDP

(versus $1/20$th in long run)

Shock Propagation Algorithm

Define an algorithm that traces shock (like example): it converges to the unique solution of a minimum disruption problem (in paper).

Shock Propagation Algorithm

Define an algorithm that traces shock (like example): it converges to the unique solution of a minimum disruption problem (in paper).

Let $F(\Psi)$ be the final goods that can be affected by shocks

Proposition (Upper Bound)

Consider a shock that reduces the output of technologies $\tau \in \Psi$ to $\lambda < 1$ of their original levels. The proportion of lost GDP is bounded above by

$$(1 - \lambda) \left(\frac{\sum_{f \in F(\Psi)} p_f c_f}{GDP} \right).$$

Hulten's Theorem Comparison

Long Run, Hulten's Theorem,

$$\frac{\partial \log(U)}{\partial \log(\tau_k)} = \frac{\partial \log(GDP)}{\partial \log(\tau_k)} = \frac{p_\tau y_\tau}{GDP}.$$

Short Run, when bound binds

$$\frac{\Delta \log(U)}{\Delta \log(\lambda)} = \frac{\Delta \log(GDP)}{\Delta \log(\lambda)} = \frac{(1-\lambda)\sum_{f \in F(\tau)} p_f c_f}{GDP}.$$

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- Long Run: shocking more expensive technologies has a larger impact.
  - Might expect these to be more *downstream*.
- Short Run: shocking technologies that are used in more final goods has a larger impact.
  - Might expect these to be more *upstream*.

Sufficient Conditions for Bound to Bite

- All producers of given good and any "substitute" for it in a supply chain are shocked.
- Globalization: for low iceberg costs generically get unique technologies used.
- Other sufficient conditions in paper.

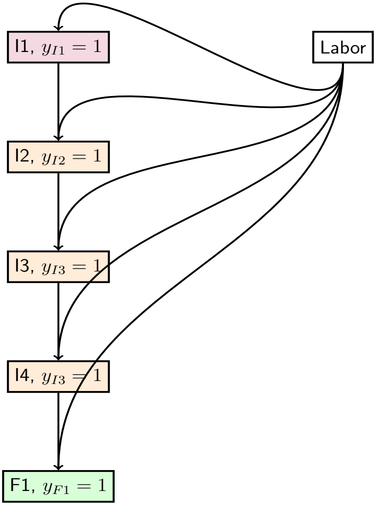
Supply Chain Complexity and Disruption

Under the bound, randomly disrupt technology to $\lambda < 1$:

- Probability π disrupt any given technology, independent.
- $S =$ average $\#$ technologies used produce a final good.
- $q =$ E[(cost of random input)$/$(final good cost)].

Figure: Vertical supply chain

(All flows equal 1)



Labor endowment: 5

$$p = \left(\underbrace{\frac{1}{5}}_{\text{labor}}, \underbrace{\frac{1}{5}}_{I1}, \underbrace{\frac{2}{5}}_{I2}, \underbrace{\frac{3}{5}}_{I3}, \underbrace{\frac{4}{5}}_{I4}, \underbrace{1}_{F} \right)$$

Complexity: $S = 5$.

Average input cost: $1/2$

Average input cost / final good cost: $q = 1/2$

Figure: Vertical supply chain

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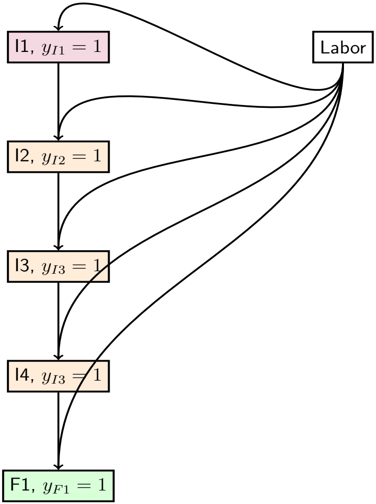

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Complexity: $S = 5$.

Average input cost: $1/2$

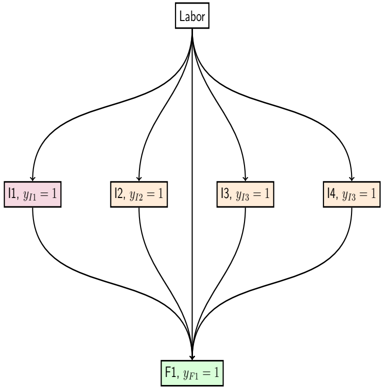
Average input cost / final good cost: $q = 1/2$

SR marginal impact of shock to inter.: 1

LR Av. marginal impact of shock to inter.: $1/2$

Figure: Horizontal supply chain

(All flows equal 1)



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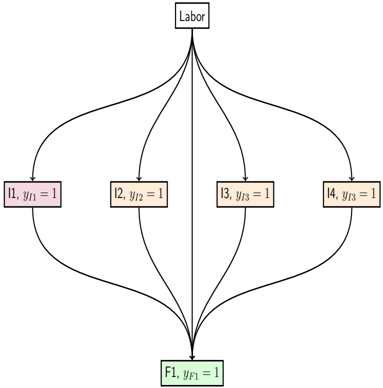
Average input cost: $1/S = 1/5$

Average input cost / final good cost: $q = 1/5$

Figure: Horizontal supply chain

(All flows equal 1)



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Average input cost / final good cost: $q = 1/5$

SR marginal impact of shock to inter.: 1

LR Av. marginal impact of shock to inter.: $1/5$

Supply Chain Complexity and Disruption

Proposition (Complexity and Fragility)

For small π

$$\text{Short-Run} \quad \mathbb{E}\left[\frac{\Delta GDP}{GDP}\right] \approx -(1-\lambda)\pi S,$$

$$\text{Long-Run} \quad \mathbb{E}\left[\frac{\Delta GDP}{GDP}\right] \approx -(1-\lambda)\pi S q.$$

Supply Chain Complexity and Disruption

Short Run:

- Increased number of goods (S) per supply chain to disrupt,
- Each would disrupt the final good fully (by $1-\lambda$).
- Overall effect $(1-\lambda)\pi S$.

Long Run:

- Increased number of goods (S) per supply chain to disrupt,
- But each has a fractional value (q) relative to final good.
- Overall effect $(1-\lambda)\pi Sq$.

Supply Chain Complexity and Disruption

Short Run — *shape (breadth vs depth) of supply chain is irrelevant*:

- Increased number of goods (S) per supply chain to disrupt,
- Each would disrupt the final good fully (by $1-\lambda$),
- Overall effect $(1-\lambda)\pi S$.

Long Run — *shape of supply chain matters*:

- Supply chains are horizontal, $q \approx 1/S$: overall effect $(1-\lambda)\pi$.
- Supply chains are vertical, $q \approx 1/2$: overall effect $(1-\lambda)\pi S/2$.

Concluding remarks

- Short and long run can differ dramatically, both very tractable.
- Range of outcomes between the short and long run.
- Anticipation, inventories, buffers, not in model.
- Diversity is good (rather than globalization is bad).
- Policy implications (within model): subsidize diversity and shallow supply chains.

Discussion

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