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

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

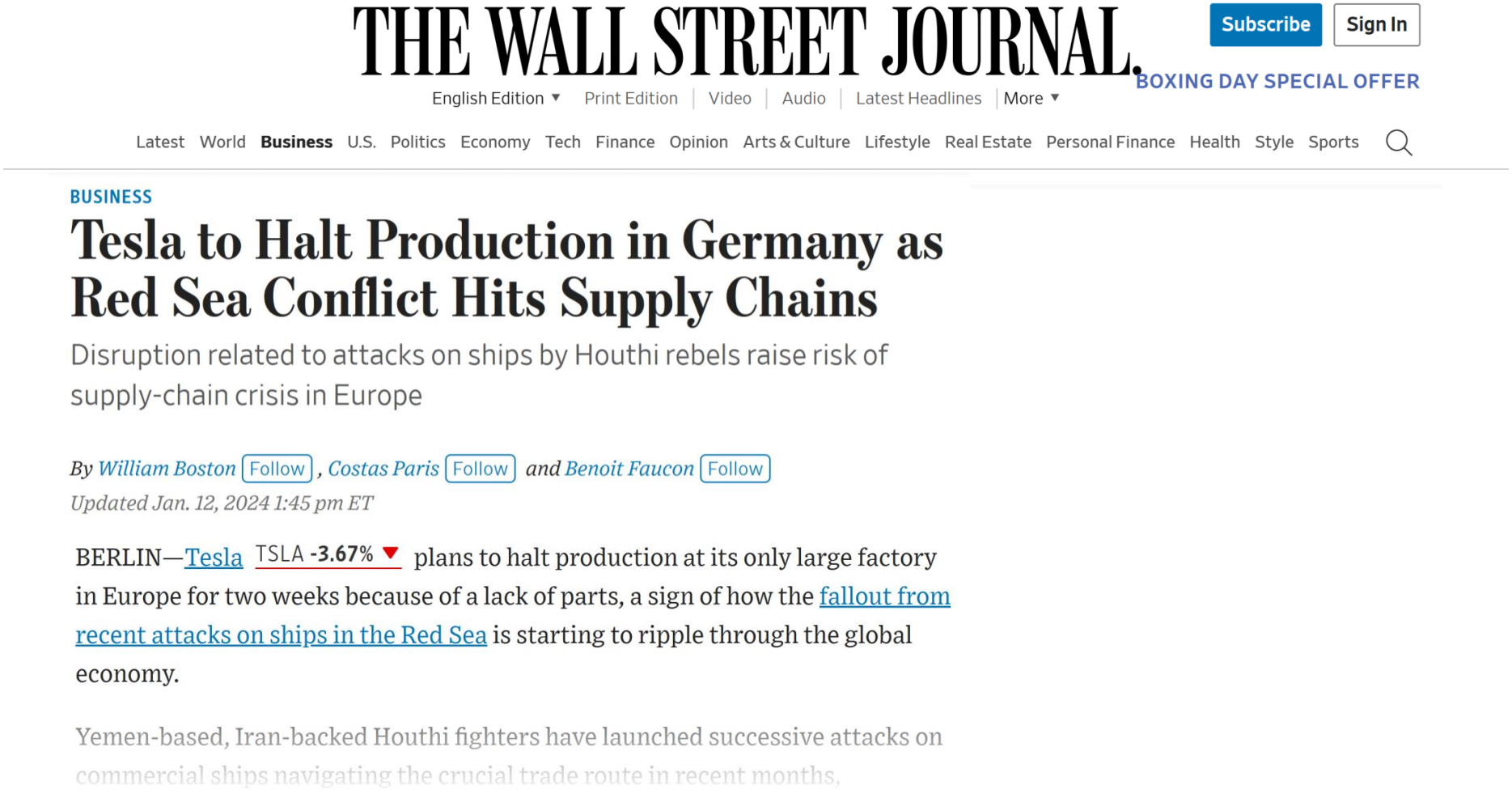
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By William Boston Follow *, Costas Paris* Follow *and Benoit Faucon* Follow

Updated Jan. 12, 2024 1:45 pm ET

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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

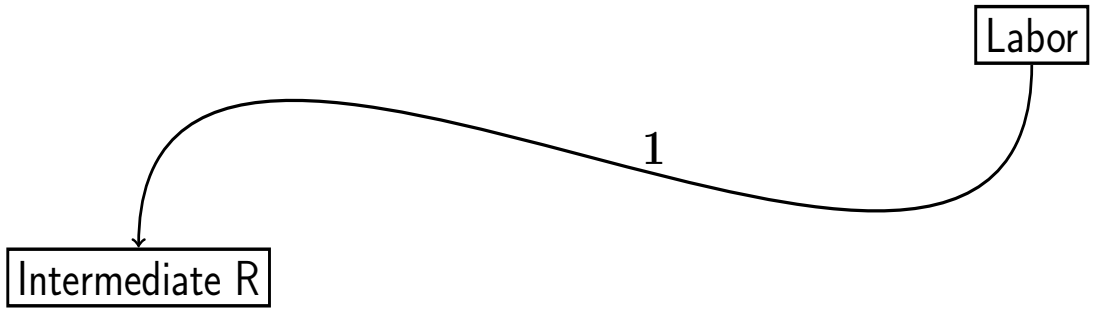
- **Foundational work:** Leontief (1936), Long Jr and Plosser (1983), Acemoglu et al. (2012)
- **Surveys:** Bernard (2018), Carvalho and Tahbaz-Salehi (2019), Baqaee and Rubbo (2022), Antràs and Chor (2022), Elliott and Golub (2022), Baldwin and Freeman (2022).
- **Production networks:** e.g., Brummitt 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)
- **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

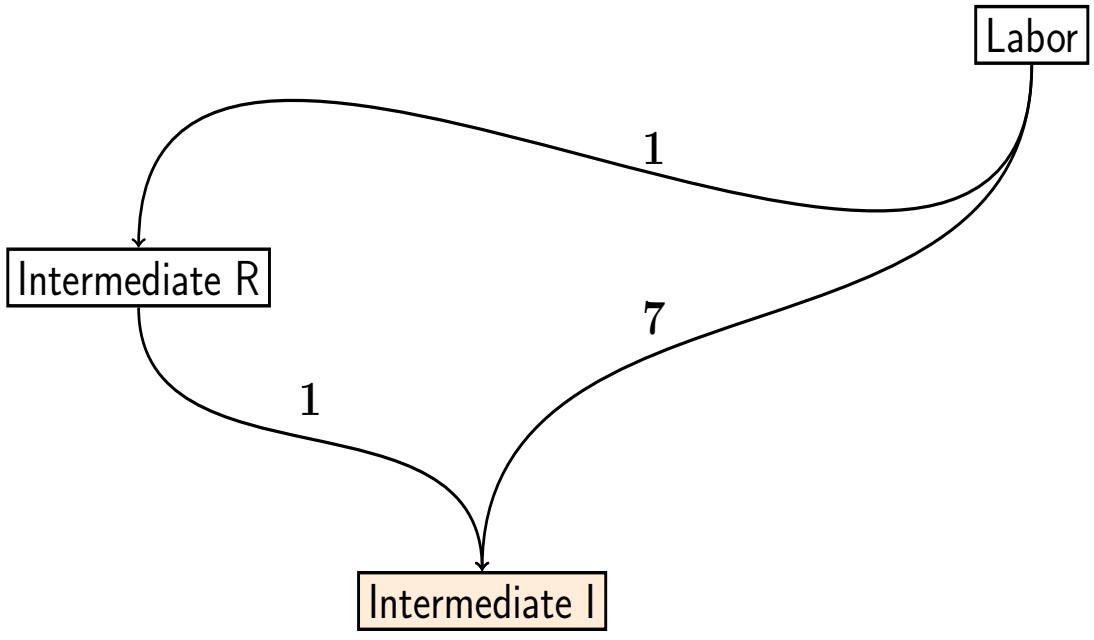
1 Introduction

2 Model

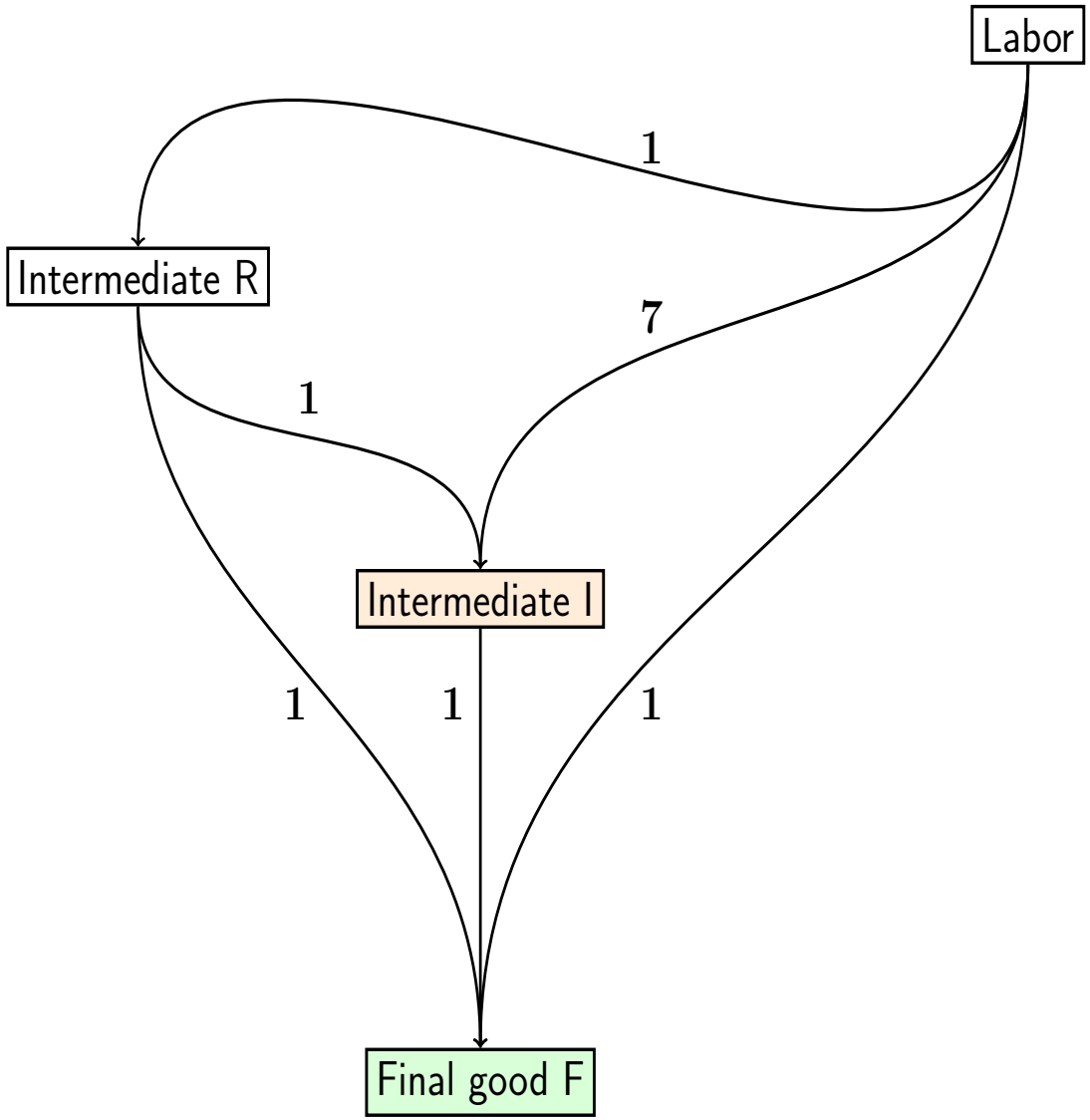
Example: Technologies



Example: Technologies



Example: Technologies



Arrow-Debreu (1954) Technologies

Constant returns to scale technologies $\tau \in \mathbb{R}^{1+M+F}$.

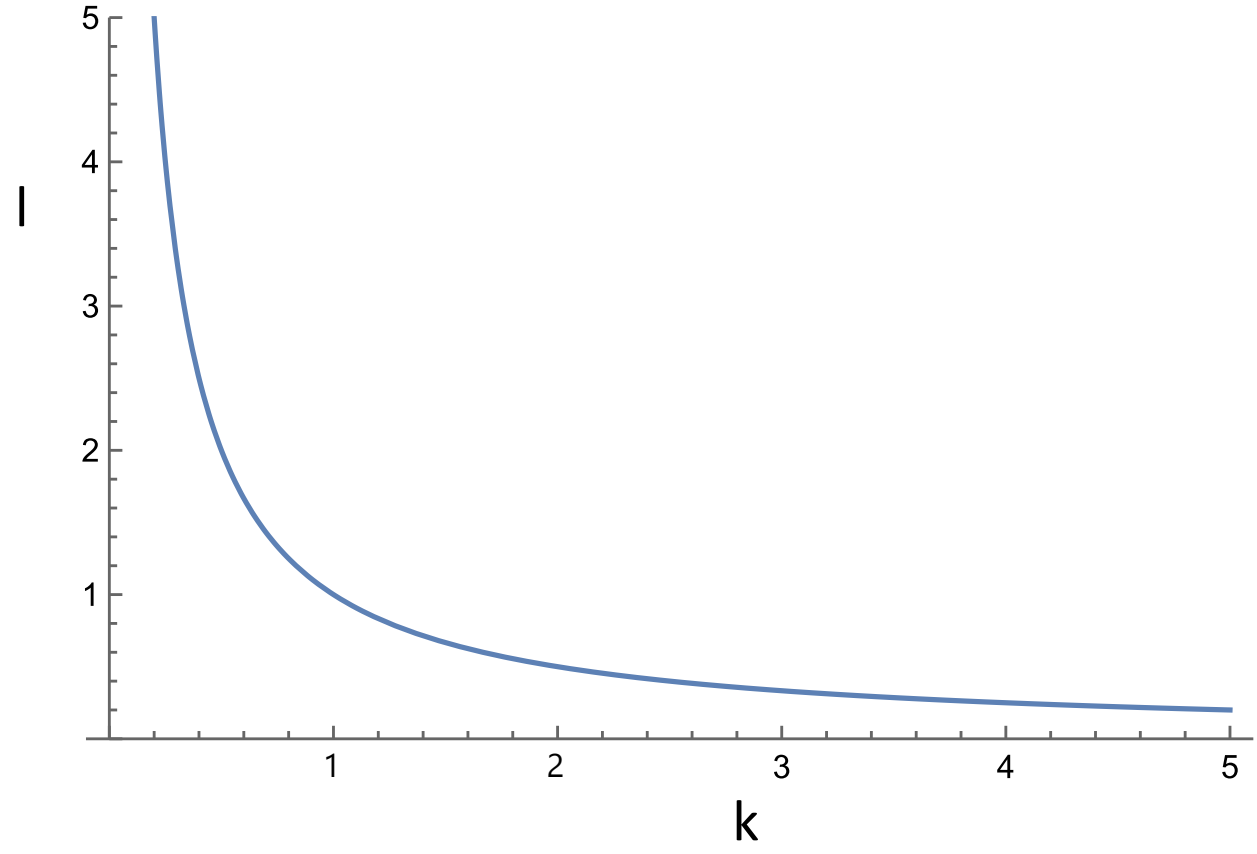
$$\Big(\text{labor},\quad \underbrace{m_1,\ldots,m_M}_{\text{intermediate}},\quad \underbrace{f_1,\ldots,f_F}_{\text{final goods}}\Big)$$

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

Arrow-Debreu (1954) Technologies

Suppose country n can produce according to $y = L^{\alpha}K^{1-\alpha}$

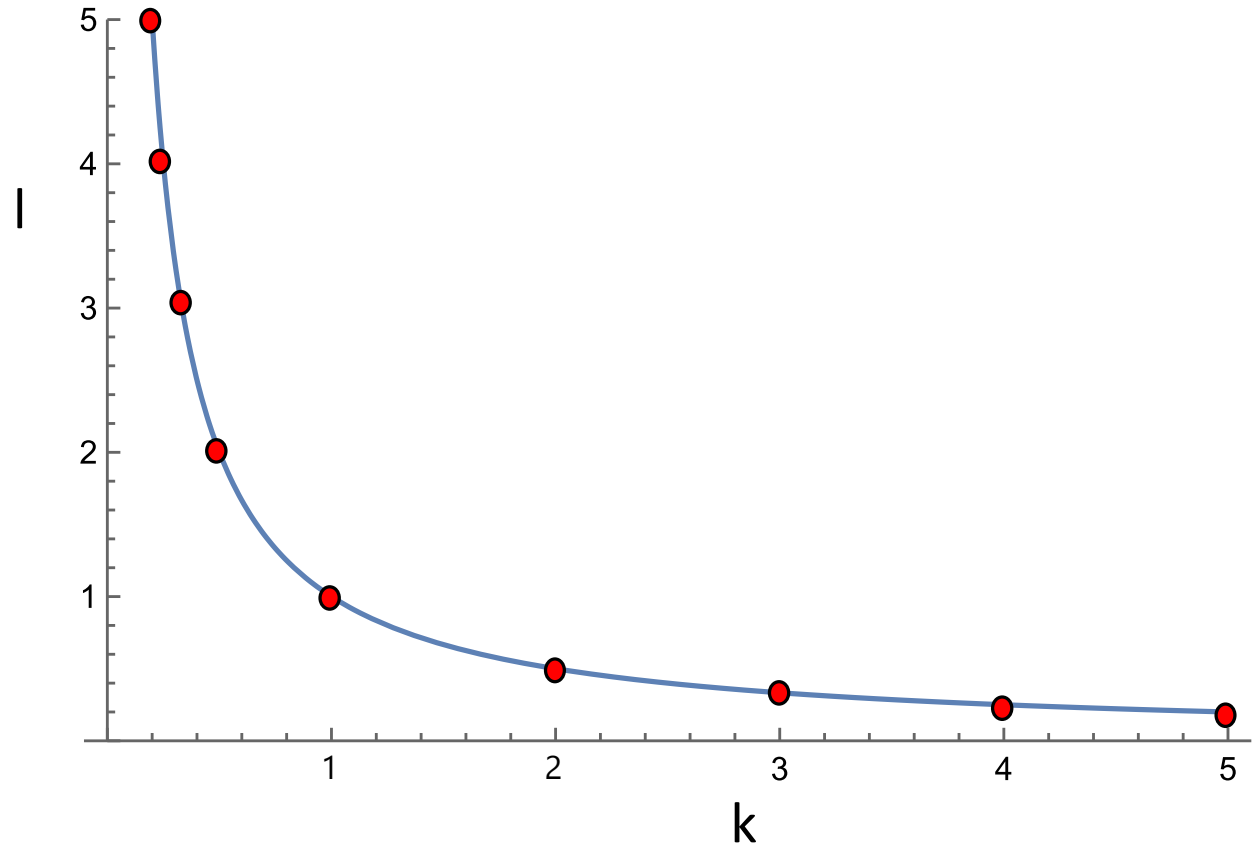
Then $T_n = \{(-l, -k, 1) : l^{\alpha}k^{1-\alpha} = 1\}$



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Model

- $n \in \{1, \ldots, N\}$ countries,
- $m \in \{1, \ldots, M\}$ intermediate goods,
- $f \in \{1, \ldots, F\}$ final goods,
- L_n units of labor country n,
- T_n (finite) set technologies country n.

Iceberg costs, Prices

- $\theta_{\tau\tau'} \geq 1$ units of $O(\tau)$ shipped from τ for 1 unit to get to τ'.
- Iceberg cost on labor $\theta^L_{nn'} \geq 1$.
- No iceberg costs on final goods.
- Local prices before iceberg costs $p \in \mathbb{R}_+^{N+|T|}$

Preferences

- Laborers are the consumers, preferences $U(c_1, \ldots, c_F)$:
  - increasing, strictly quasi-concave, homogeneous of degree 1.
- Laborers all consume multiples of same bundle.
- Normalize price of final bundle to 1 (GDP).

Equilibrium

- p prices
- $L_{n\tau}$ labor used for each n, τ
- $(x_{\tau\tau'})_{\tau\tau'}$ intermediates shipped
- $y_\tau \in \mathbb{R}_+$ output for each τ
- c_{nf} consumption for each n, f

such that: consumers and producers optimize, and markets clear.

Equilibrium

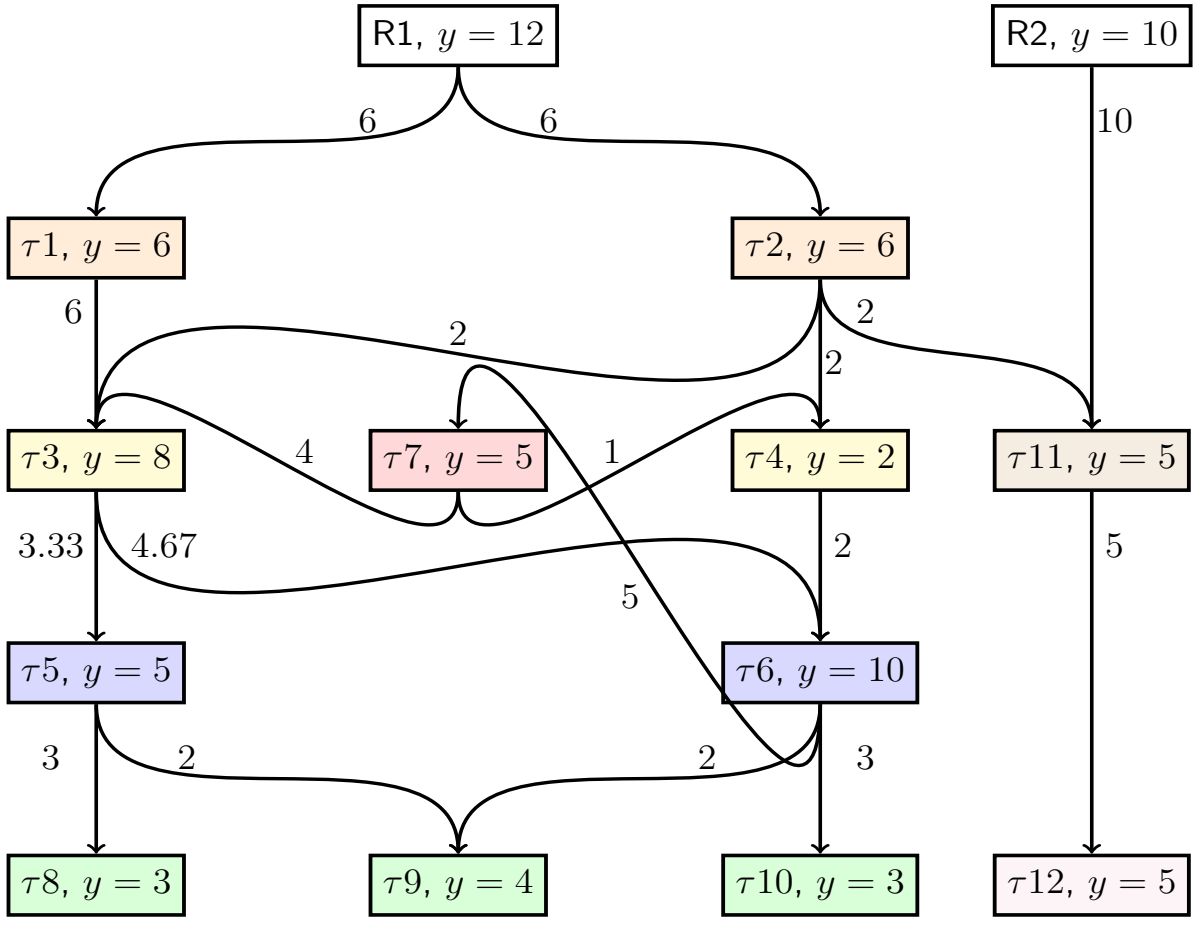
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Lemma

There exists a (generically unique) equilibrium. The same amount of each final good is produced in all equilibria.

Example: Equilibrium Flows (Can Include Cycles)



Long-Run Shock Impact

Recall: for τ, with output k, normalized $\tau_k = 1$.

Now vary τ_k to capture shocks/disruptions

First, long-run:

- new equilibrium using new version(s) of technologies

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

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

Long-Run: Hulten's Theorem

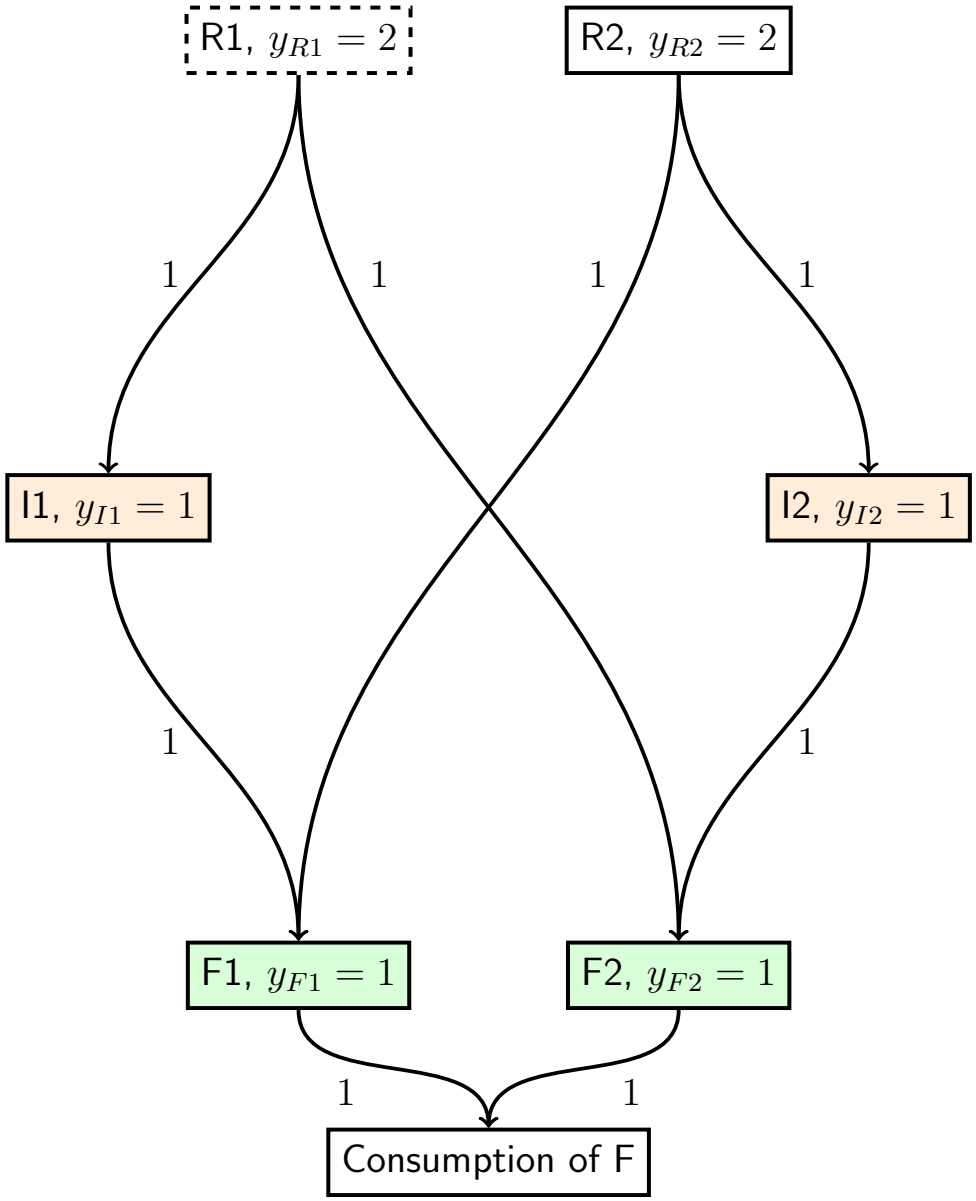
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- Sufficient statistic: spending on shocked technology.
- Intuition—adjust by sourcing more inputs at the margin.
- Network matters in background as it determines equilibrium
  - but don't need to see network to estimate long-run impact.

Figure: Equilibrium flow network



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

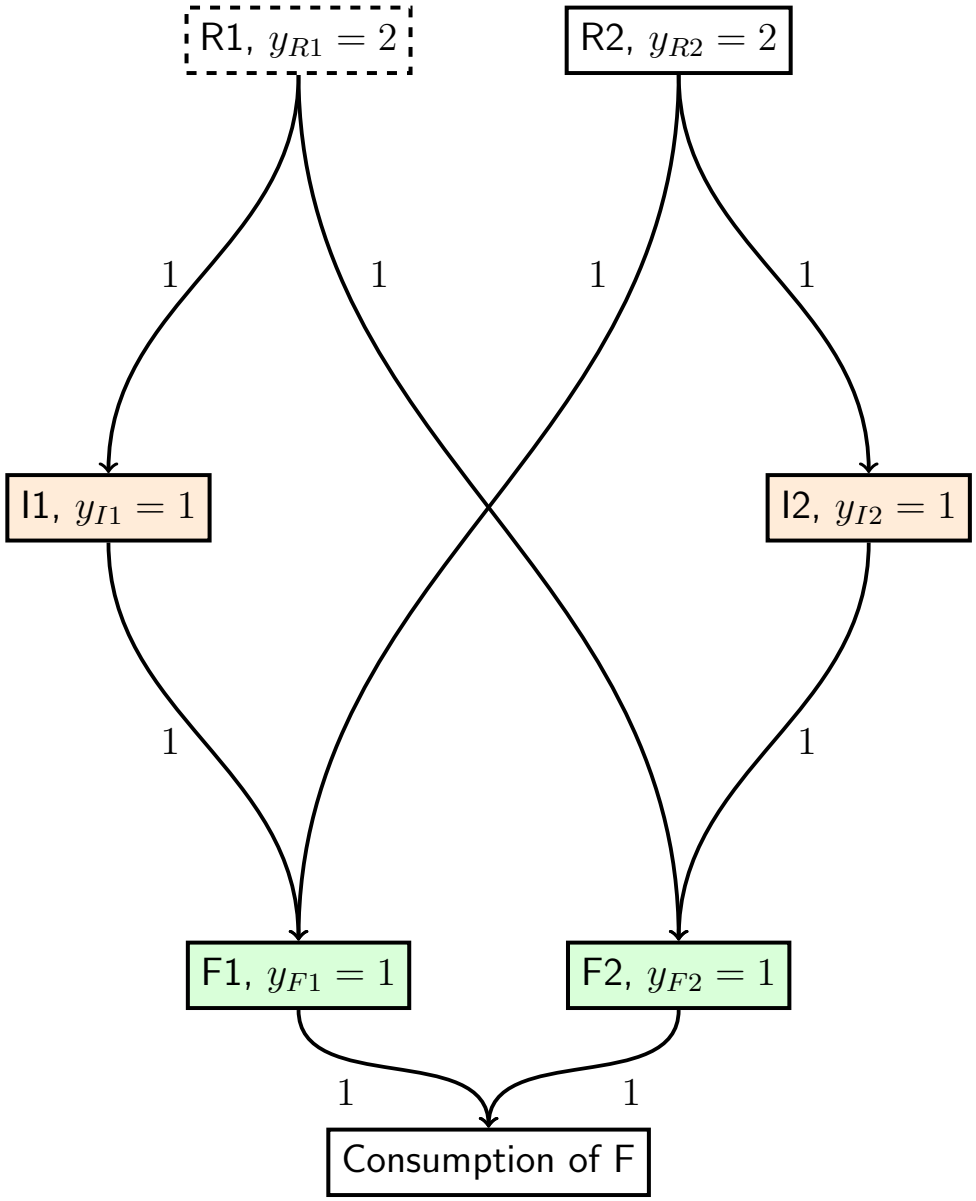
$GDP = \sum_f p_f c_f = 2.$

$p_{R1} = 1/10$

$y_{R1} = 2$

Marginal impact: $(2/10)/2 = 1/10$

Figure: Equilibrium flow network



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$p_{R1} = 1/10$

$y_{R1} = 2$

Marginal impact: $(2/10)/2 = 1/10$

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.)

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Shock set of technologies $\Psi \subset T$, reducing their output to $\lambda < 1$ of initial level.

What is the maximum value of final goods that can be produced after a shock—without changing technologies or supply chains—with proportional rationing?

Minimum disruption problem

$$\max_{(\hat{y}_\tau)_\tau} \sum_{\tau : O(\tau) \in F} p_\tau \hat{y}_\tau$$

subject to

1. shocks: $\hat{y}_\tau \leq \lambda y_\tau$ for all $\tau \in \Psi$,
2. technologies fixed: $\hat{y}_\tau \leq \left(\min_{\text{inputs to } \tau} \frac{\text{New input level}}{\text{Original input level}} \right) y_\tau$,
3. proportional rationing: $\hat{x}_{\tau\tau'} = x_{\tau\tau'} \left(\frac{\hat{y}_\tau}{y_\tau} \right)$.

Figure: Shock Propagation

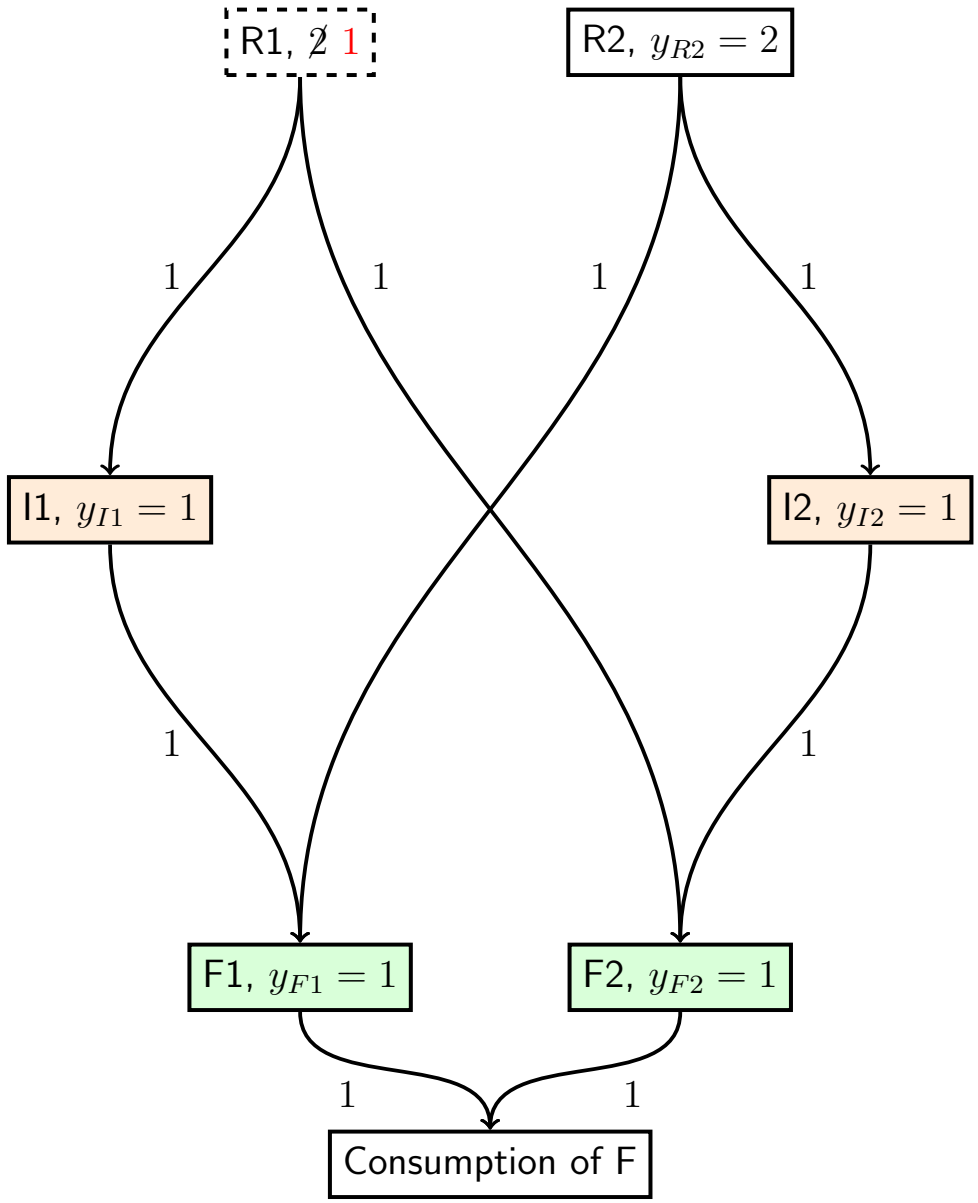


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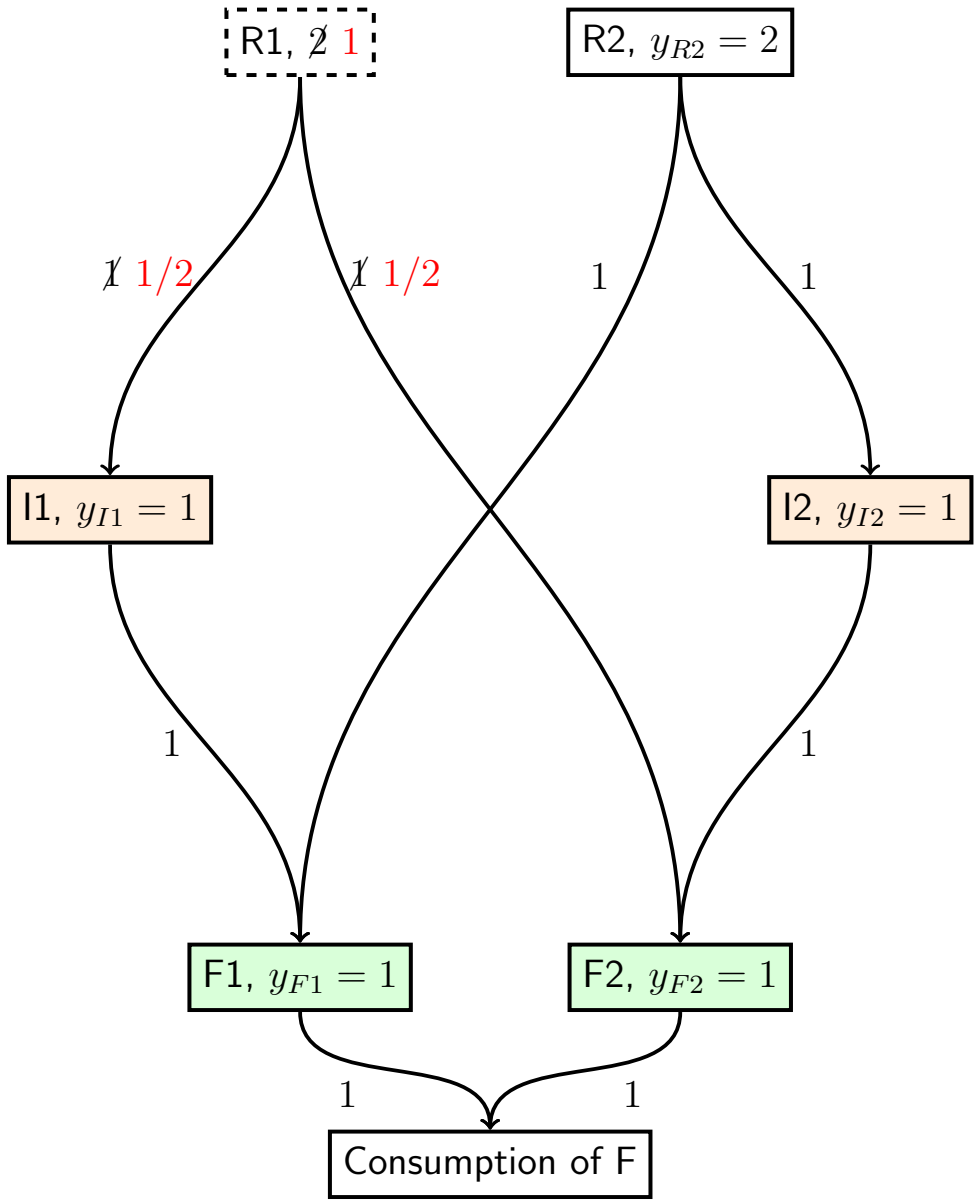


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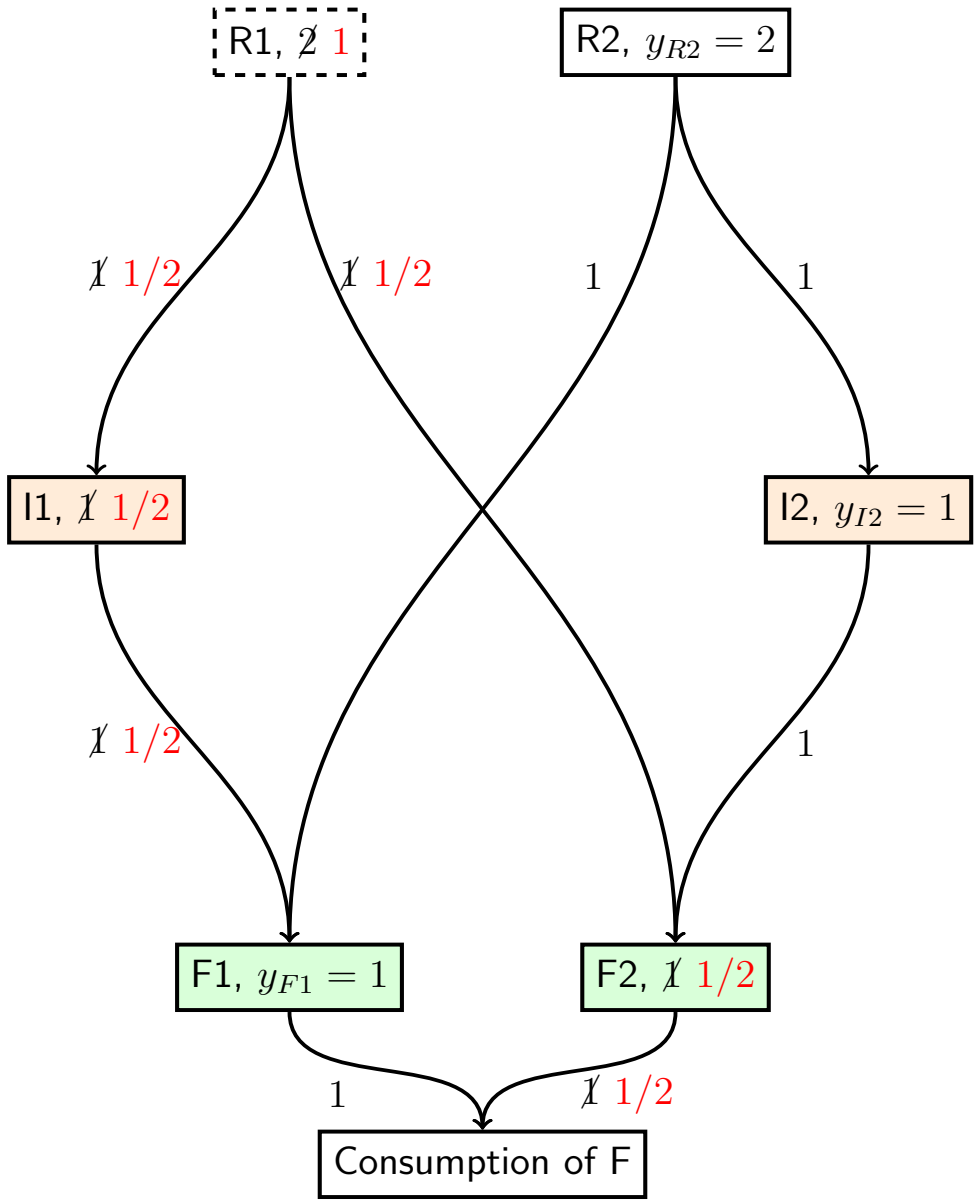
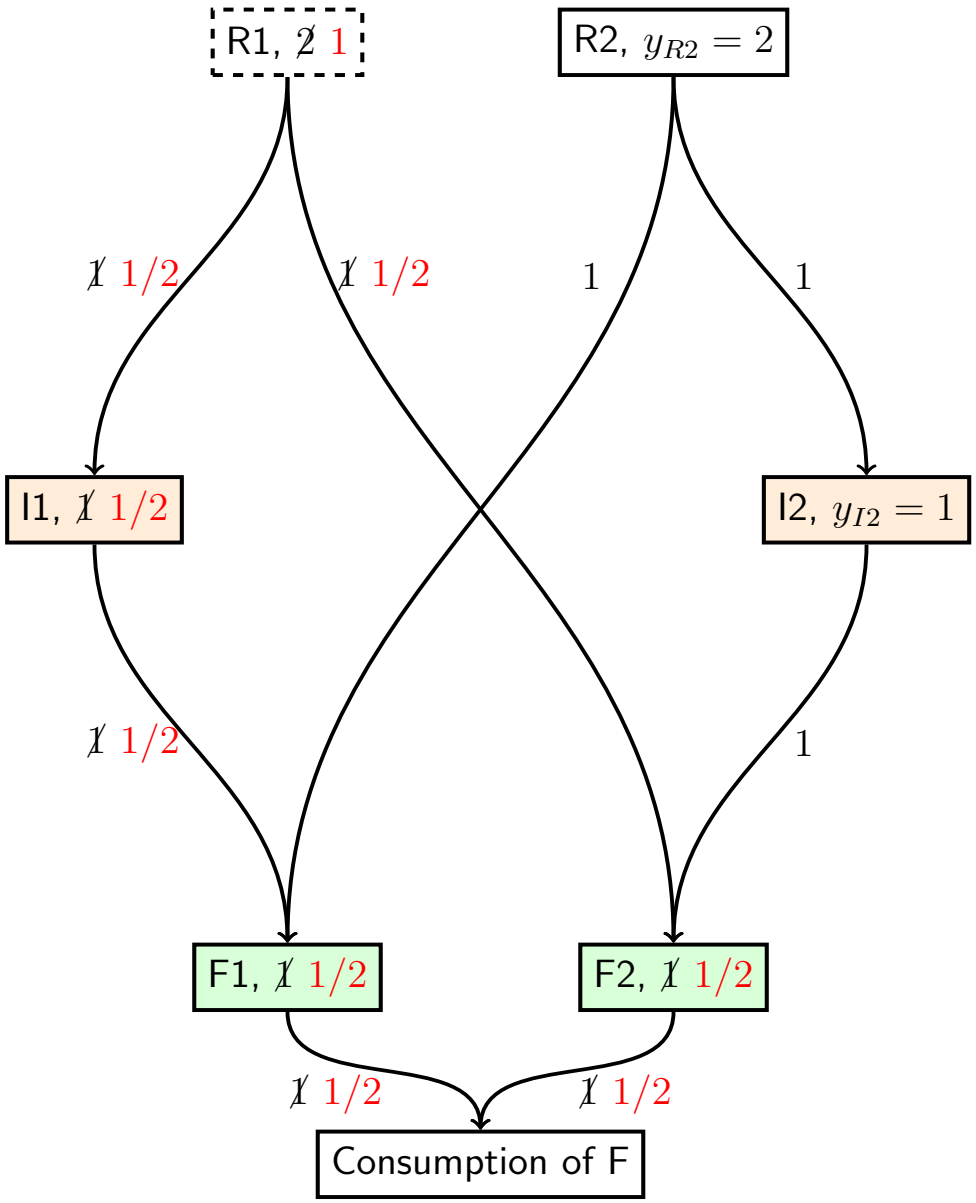


Figure: Shock Propagation



Total impact: $1/2$ **of GDP**

Shock Propagation Algorithm

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

Shock Propagation Algorithm

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

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

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

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.

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

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

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Short Run

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

- Long Run: shocking *downstream* technologies has a larger impact because they are more expensive.
- Short Run: shocking *upstream* technologies has a larger impact because they affect more final goods.

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)].

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 $(1 - \lambda)\pi S q$.

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 $(1-\lambda)\pi S/2$.
- Long-run is at most half of short-run disruption.

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