Financial systemic risk
in a world with known supply chain networks

Stefan Thurner

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team

Christian Diem, Tobias Reisch, Andras Borsos, Janos Kertesz, Johannes Stangl, Zlata Tabachova, and Stefan Thurner

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supply chains as a basis for economics?

supply chain networks allow us to see the economy at an **“atomistic”** scale

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supply chains as a basis for economics?

temporal resolution of supply chain networks allows us to watch what happens at the level where decisions are made

→ see **physical substrate** of practically all aspects of the economy

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what could benefit from atomic view?

- optimal allocation of resources?
- efficiency of markets vs planning: reopen Mises–Hayek debate
- price formation in various (limited) markets?
- where and how does wealth creation and distribution happen?
- systemic risks

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what is economics?

economics typically has to work with aggregates of agents (e.g. households, firms, buyers, sellers), their behavior, and their interactions

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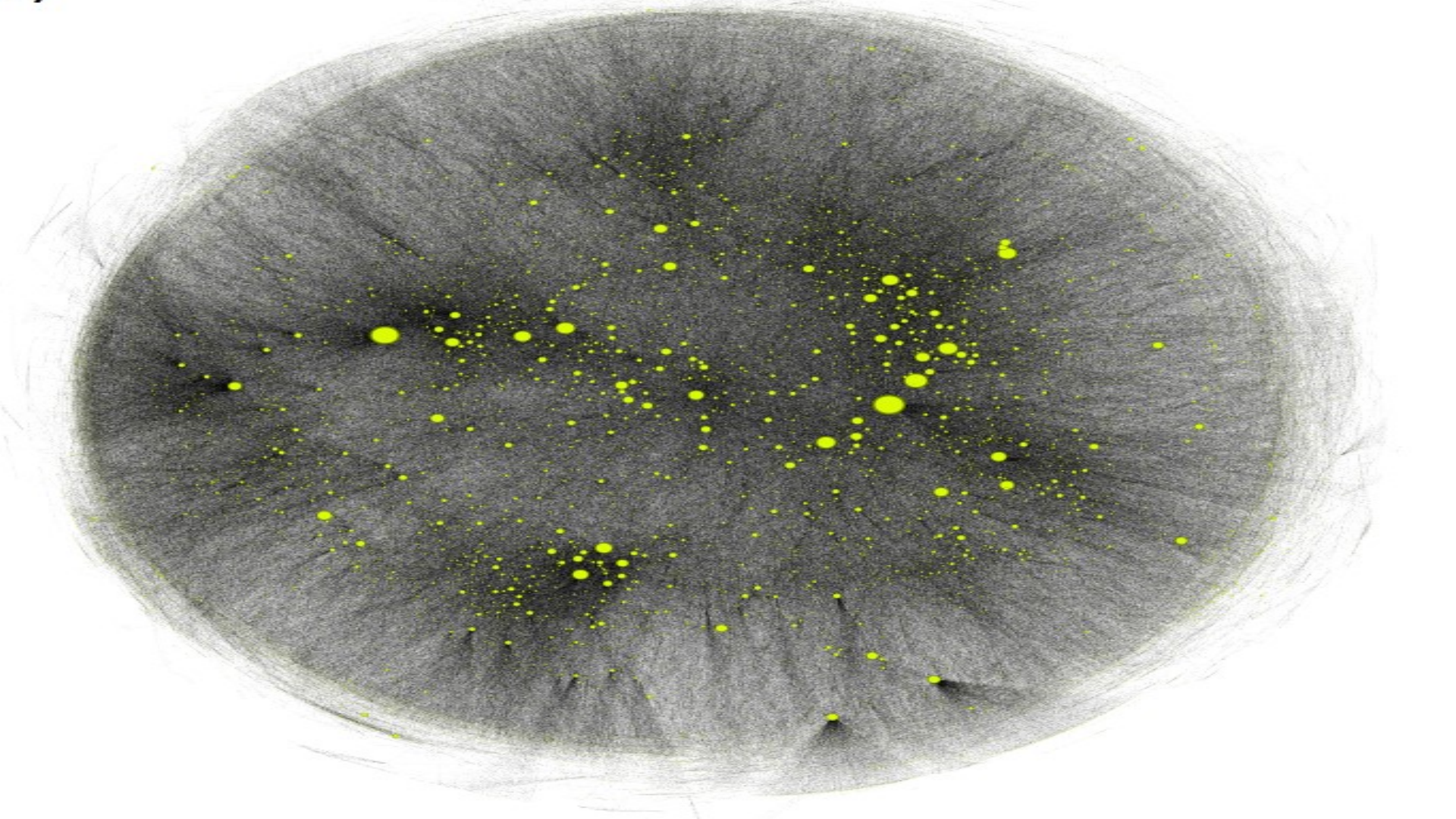

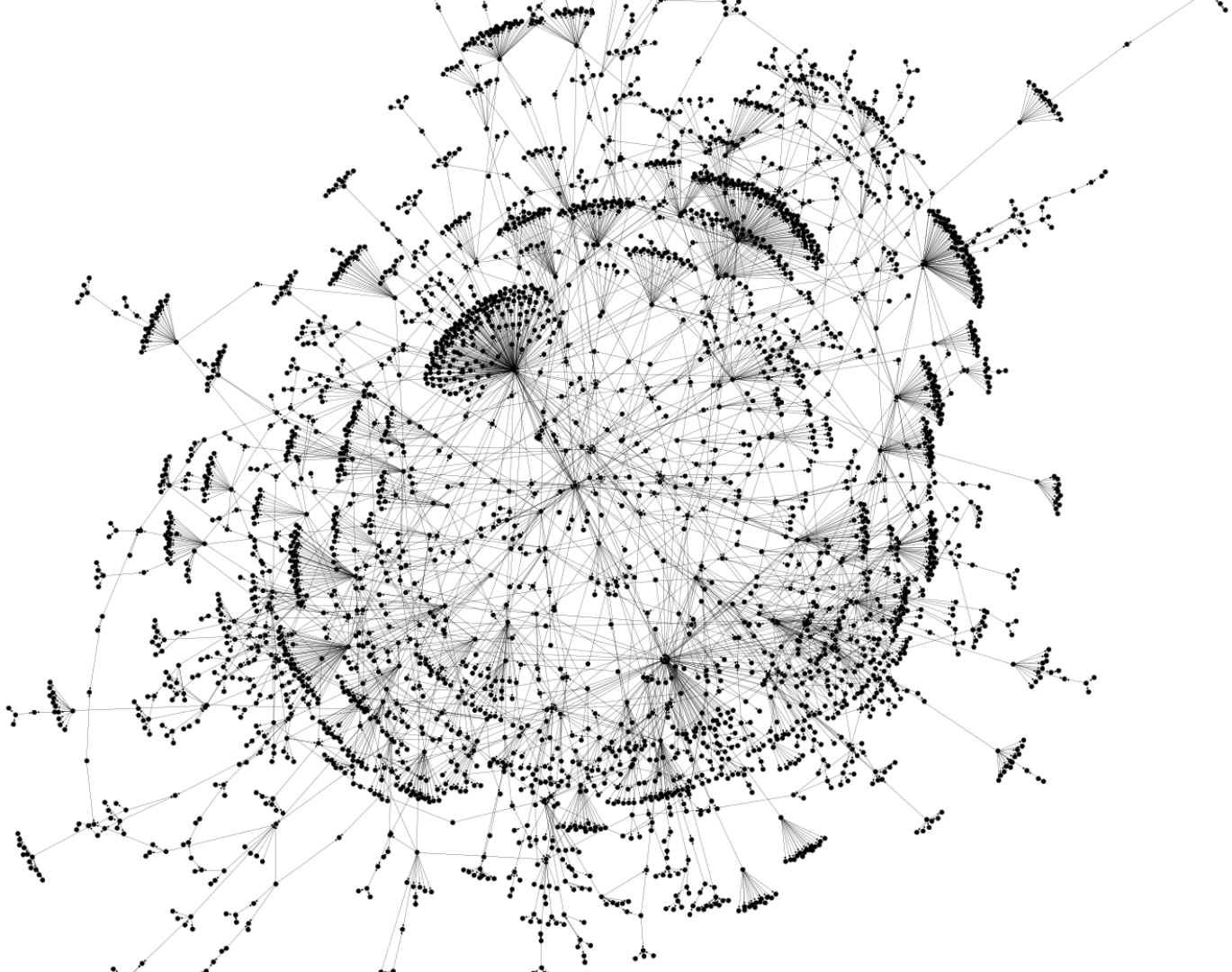

supply chain networks are **not yet** an economy

supply chain networks are only snapshots of networks

economy: constantly changing

→ have to understand the **dynamics** of supply networks

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how to arrive at an “atomistic” economics?

necessary ingredients:

1. **supply chain networks** / production networks
2. **production functions** of individual firms: must be estimated
3. **substitution/replacement dynamics** – how do firms substitute for lost suppliers? must be modeled
4. prices
5. believes / trends / hearding

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1. reconstruct supply chain-NWs

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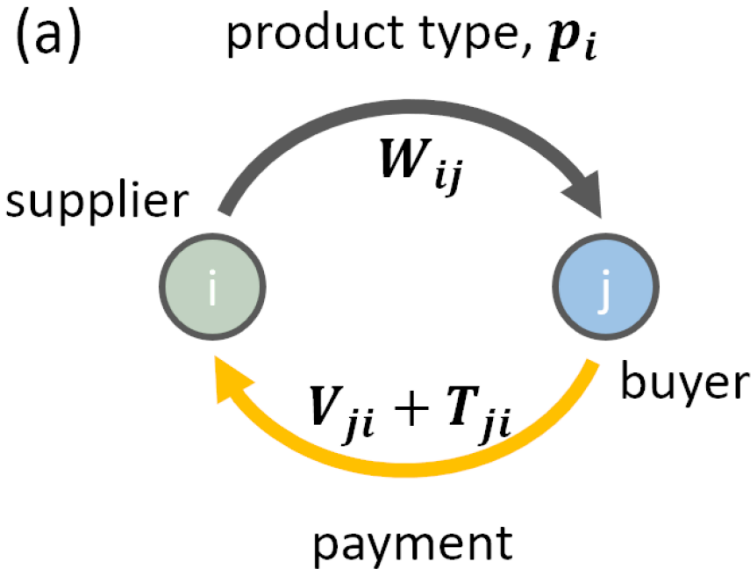
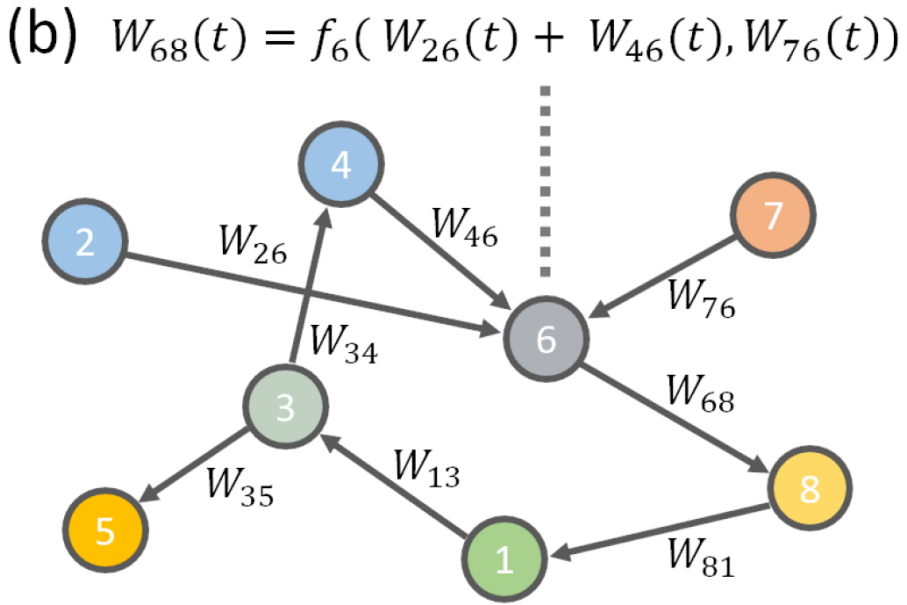
flows of goods and services





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data

- supply networks within countries are visible in national payment- or VAT data
- who ships what and how much to whom? (volume of suppler-buyer relations: monetary / real)

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how to reconstruct supply chains form other data?

a) from payment flows
b) from communication networks
c) from company information (linking data sets)
d) historical internet data (e.g. common crawl)
e) inference / entropy methods

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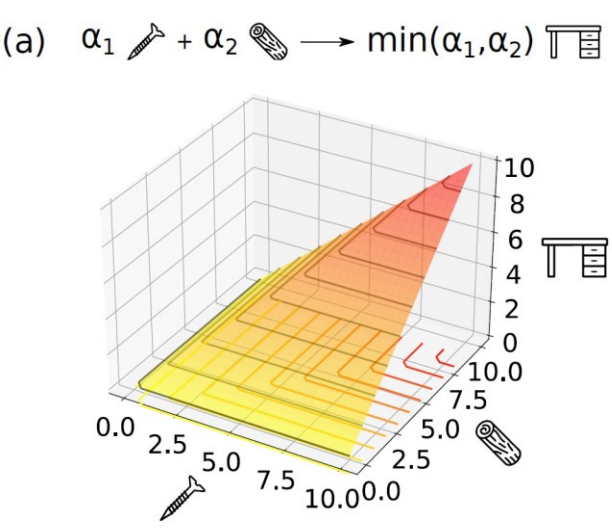
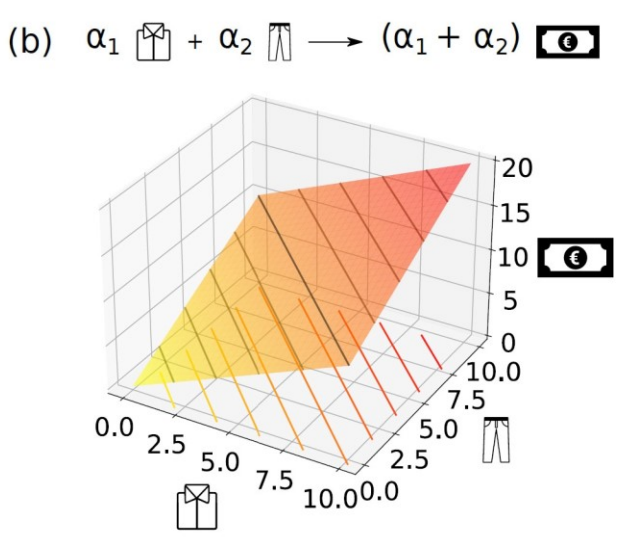
2. production functions

production functions = powergraphs

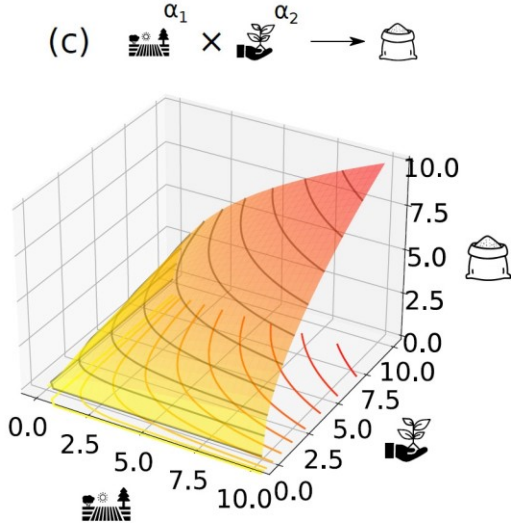
sets of inputs → set of outputs



Leontieff



linear



Cobb-Douglas

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every firm has production function

we use a **Generalized Leontieff Production Function**

$$x_i = \min\left[\min_{k\in\mathcal{I}_i^{\text{es}}}\left[\frac{1}{\alpha_{ik}}\Pi_{ik}\right],\ \beta_i + \frac{1}{\alpha_i}\sum_{k\in\mathcal{I}_i^{\text{ne}}}\Pi_{ik},\ \frac{1}{\alpha_{l_i}}l_i,\ \frac{1}{\alpha_{c_i}}c_i\right]$$

- α_{ik} technologically determined coefficients
- β_i production level possible without non-essential inputs, $k\in\mathcal{I}_{\text{ne}}$
- α_i chosen to interpolate between full production level (with all inputs) and β_i
- α and β determined by W, $\mathcal{I}_{\text{es}}$ and $\mathcal{I}_{\text{ne}}$

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production functions

depend on industry (e.g. at NACE 4 level)

parameters taken from data

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3. replacement dynamics

how do companies substitute lost suppliers?

assume: companies with low market share easy to replace; firms with high market share hard to replace

inverse “substitutability”

$$\sigma_j(t) = \min\left[\frac{s_j^{\text{out}}(0)}{\sum_{l=1}^{n} s_l^{\text{out}}(0) h_l^d(t) \delta_{p_l,p_j}}, 1\right]$$

- proxy for how replaceable firm *j* is for its customers
- firms with low market share are replaceable to certain extent
- firms with market shares >50% not replaceable in short term

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models of virtual economy

→ can now turn supply chain data into “1:1 agent-based model”

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what can be done better now – with 1:1 model?

- non-linear IO analysis on most granular level
- growth predictions
- origin of inflation (once price info is included)
- **quantify efficiency / resilience / collapse**
- basic provisions planning vs. markets
- planning change: green transition
- inflation of financial risks (e.g. credit default risk)
- **identify systemic risks**
- global flows of systemic risk
- potential of circular economy
- link to labor economics
- link to complexity economics (e.g. more realistic “product space”)

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resilience of economy: systemic risk

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with “atomistic” economy

compute a Systemic Risk Index: **ESRI** for all firms

ESRI quantifies effect of default of one firm on all other firms in the supply chain network:

upstream: suppliers, suppliers of suppliers, etc.

downstream: customers, customers of customers, etc.

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Economic Systemic Risk Index

$$\mathrm{ESRI}_j = \sum_{i=1}^{n} \frac{s_i^{\mathrm{out}}}{\sum_{l=1}^{n} s_l^{\mathrm{out}}} \left(1 - h_i(T)\right)$$

S_i^{out} … proxy for volume of sales

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with…

$$h_i^u(t+1) = \min\left[\sum_{j=1}^{n} \Lambda_{ji}^{\mathrm{u}} h_j^{\mathrm{u}}(t), \psi_i\right] \qquad h_i^{\mathrm{d}}(t+1) = \min\left[\min_{k \in \mathcal{F}_i^{\mathrm{es}}} \left(\tilde{\Pi}_{ik}(t)\right), \tilde{\Pi}_{ik'}(t), \psi_i\right]$$

$$\tilde{\Pi}_{ik}(t) = 1 - \sum_{j=1}^{n} \sigma_j(t) \Lambda_{ji}^{d} \left(1 - h_j^{\mathrm{d}}(t)\right) \delta_{p_j,k}$$

$$\tilde{\Pi}_{ik'}(t) = 1 - \sum_{k \in \mathcal{F}_i^{\mathrm{ne}}} \sum_{j=1}^{n} \sigma_j(t) \Lambda_{ji}^{d} \left(1 - h_j^{\mathrm{d}}(t)\right) \delta_{p_j,k}$$

ψ_i … fraction of company remaining after shock

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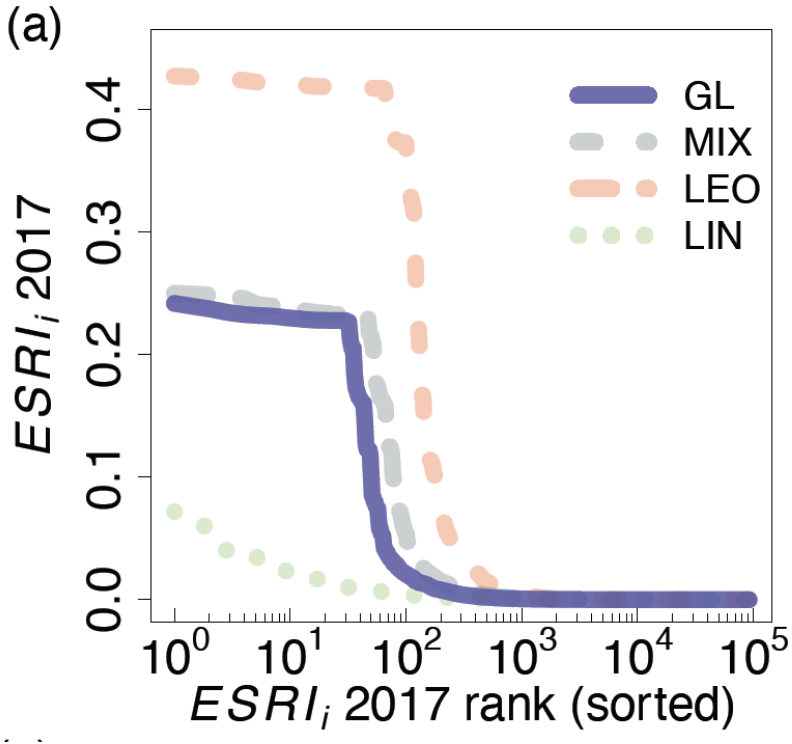
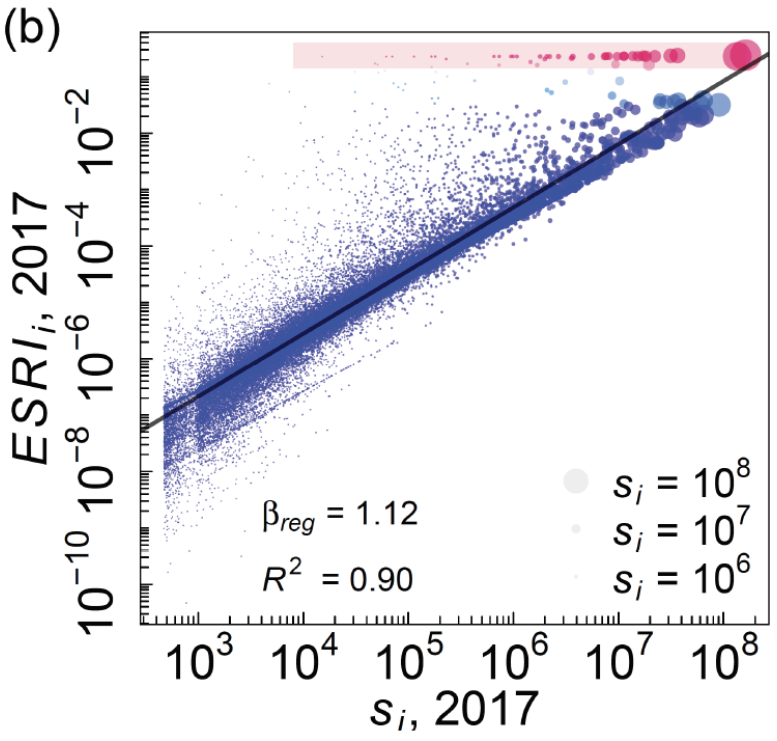
systemic relevance / resilience of economy





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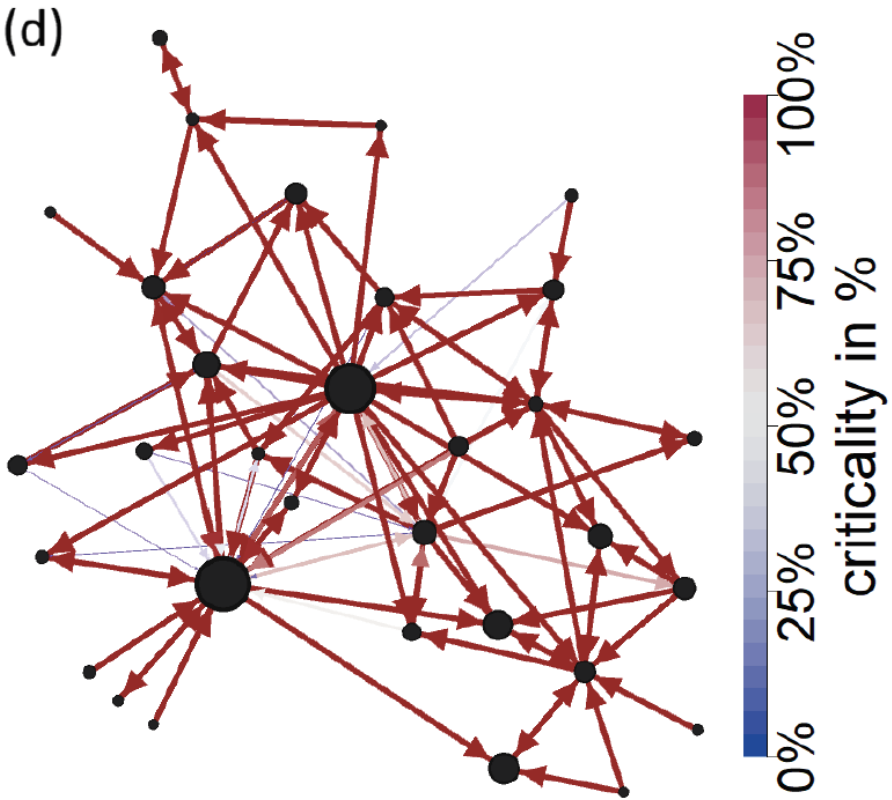
“systemic core” of the economy



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financial risk from firm-loans

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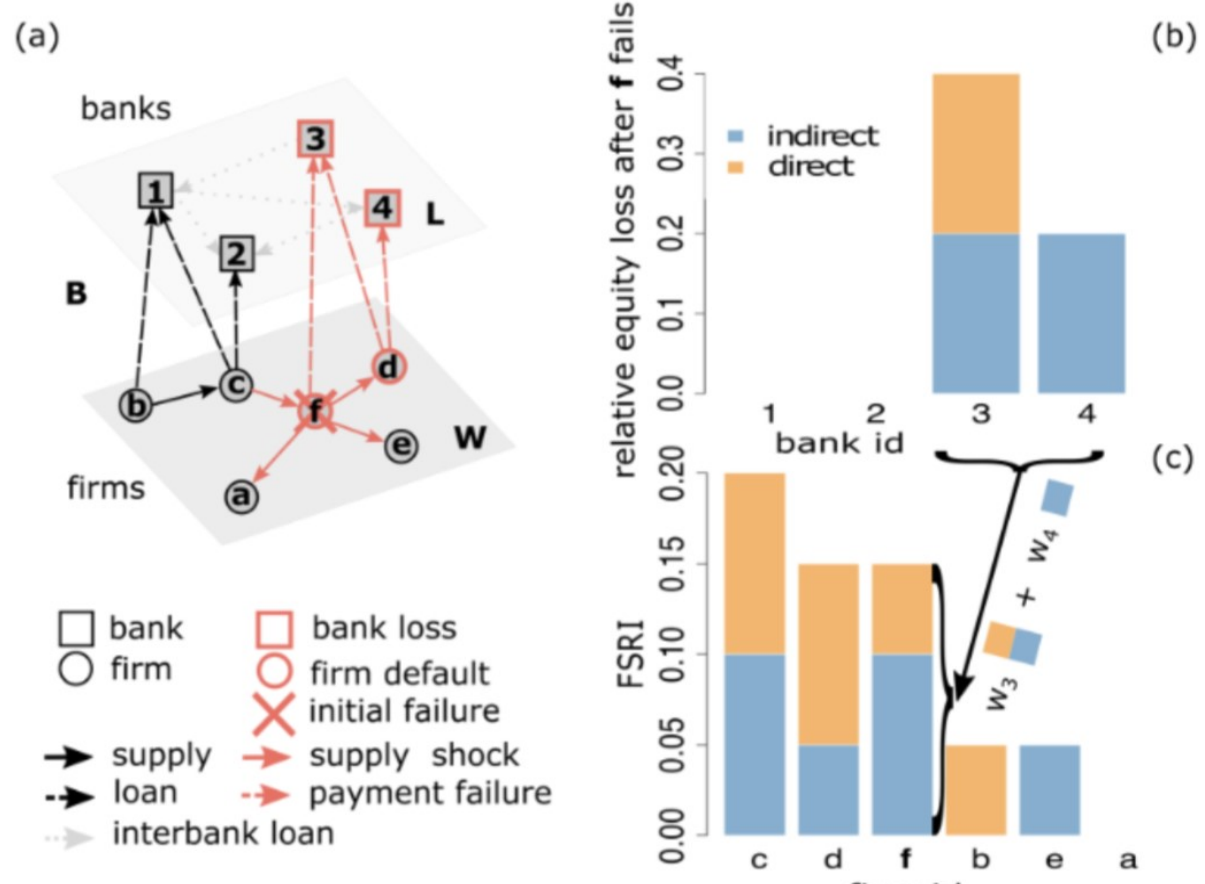
multi-layer: economic & financial NWs



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multi-layer data

four micro-data sets of the *Central Bank of Hungary*

1. VAT data of supplier-buyer relations between all firms in HUN
2. balance sheets and income statements of firms
3. loans of banks to firms
4. CET1 equity of banks

240,000 firms, 27 banks, 1.1 million supply links, 25,000 loans for 2019

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balance sheets

Table 1: Stylized balance sheet and income statement of firm, i.

Assets	**Liabilities**
Short term assets (a_i)	Accounts payable (s_i)
Inventory	Other liabilities
Fixed assets	**Equity** (z_i)
Other assets	Profit (p_i)
	Other equity
Total Assets	**Total Liabilities**

Operational profit
+ Revenues (r_i)
− Material costs (c_i)
Non-operational profit (o_i)
+ Other income
− Other costs
Net Profit (p_i)

profit-change due to supply chain effect

$$\Delta p_i\left(h_i(T)\right) = p_i - \tilde{p}_i = \left(1 - h_i(T)\right)\left(r_i - c_i\right)$$

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default → FSRI

default indicator

$$\chi_i = \begin{cases} 1 & \text{if} \quad (z_i - \Delta p_i) \leq 0 \quad \text{or} \quad (a_i - s_i - \Delta p_i) \leq 0 \\ 0 & \text{if} \quad (z_i - \Delta p_i) > 0 \quad \text{and} \quad (a_i - s_i - \Delta p_i) > 0 \end{cases}$$

→ specify LGD, κ

→ losses for specific shock scenario, Ψ

$$\mathcal{L}(\psi, \kappa) \equiv \frac{\sum_{k=1}^{m} \mathcal{L}_k(\psi, \kappa) e_k}{\sum_{\ell=1}^{m} e_\ell}$$

→ $$\mathrm{FSRI_j} \equiv \sum_{k=1}^{m} \frac{e_k}{\sum_{\ell=1}^{m} e_\ell} \min\left[1, \mathcal{L}_k\left(\psi^{S,j}, \kappa\right)\right]$$

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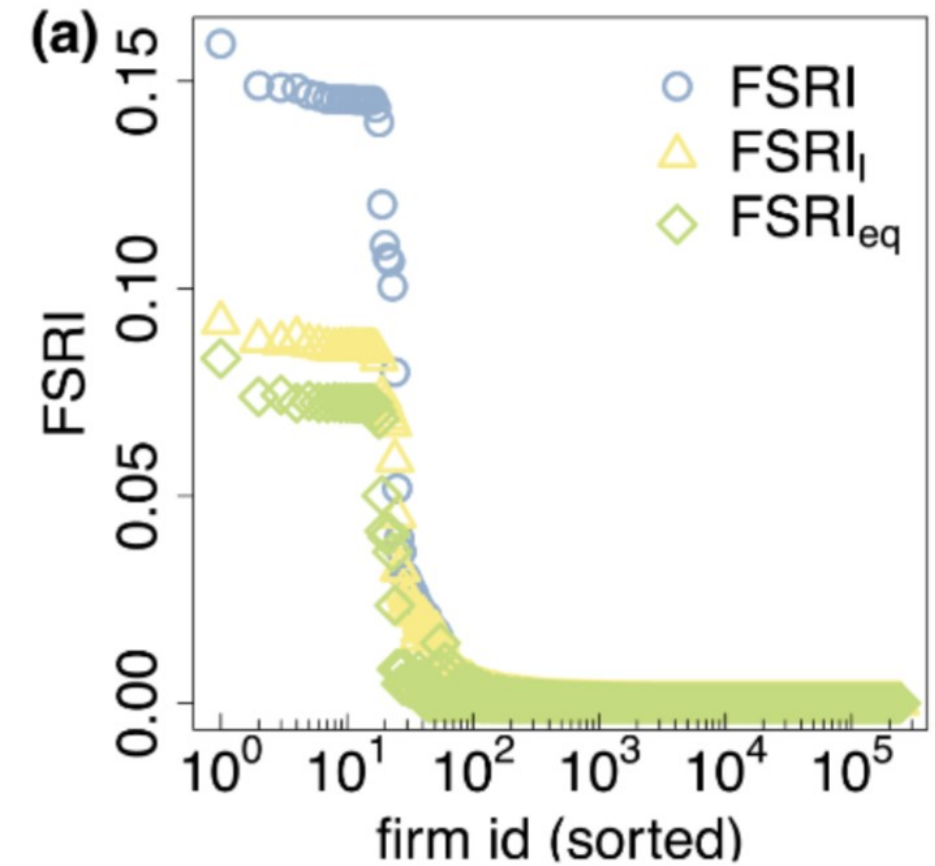
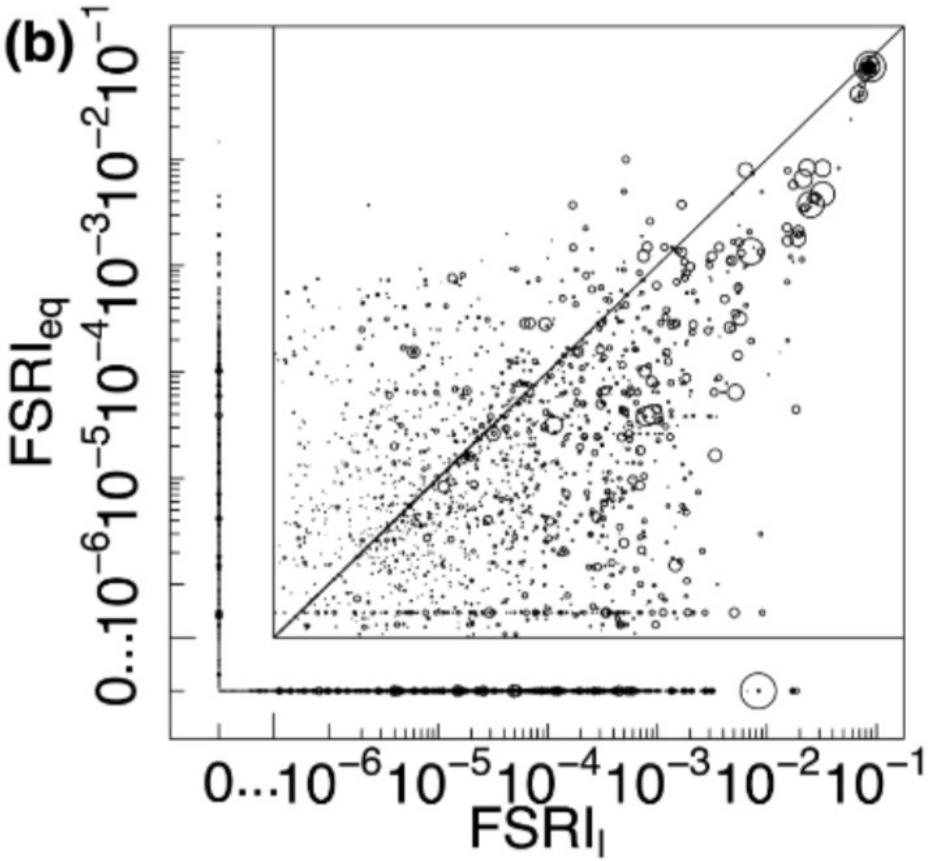
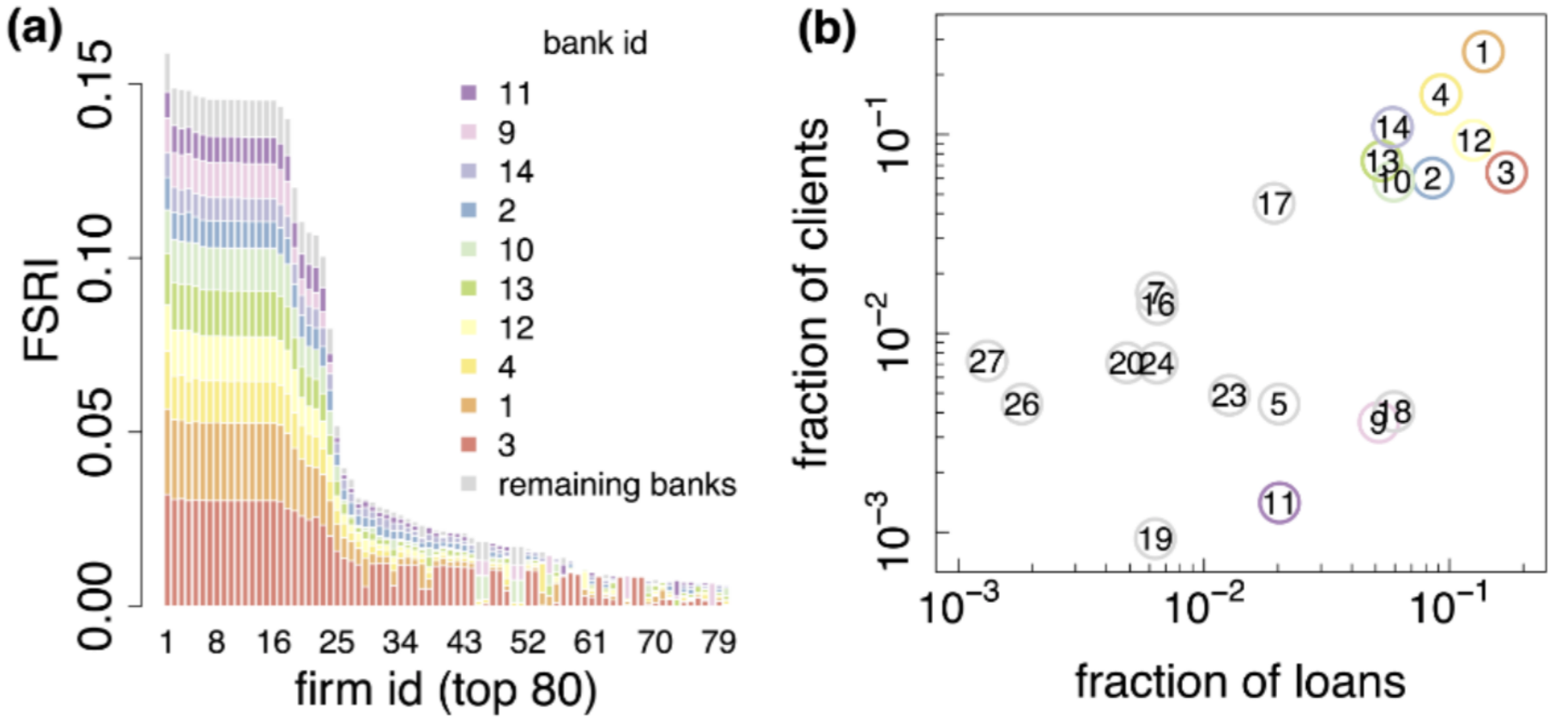
Financial Systemic Risk Index






(a)
FSRI
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8
16
25
34
43
52
61
70
79
firm id (top 80)
bank id
11
9
14
2
10
13
12
4
1
3
remaining banks
(b)
fraction of clients
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10^{-2}
10^{-3}
fraction of loans
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COVID-19 shock scenario

COVID-19 shock: reduce firms' production levels in Q1 of 2020, as in monthly firm-level employment data. Data contains monthly information about the number of employees for 160,000 firms

Synthetic COVID-19 shock: generate 1000 independent scenarios wher individual firms are shocked randomly under the constraint that at the NACE 2 aggregation level the shock is equivalent to the real reduction

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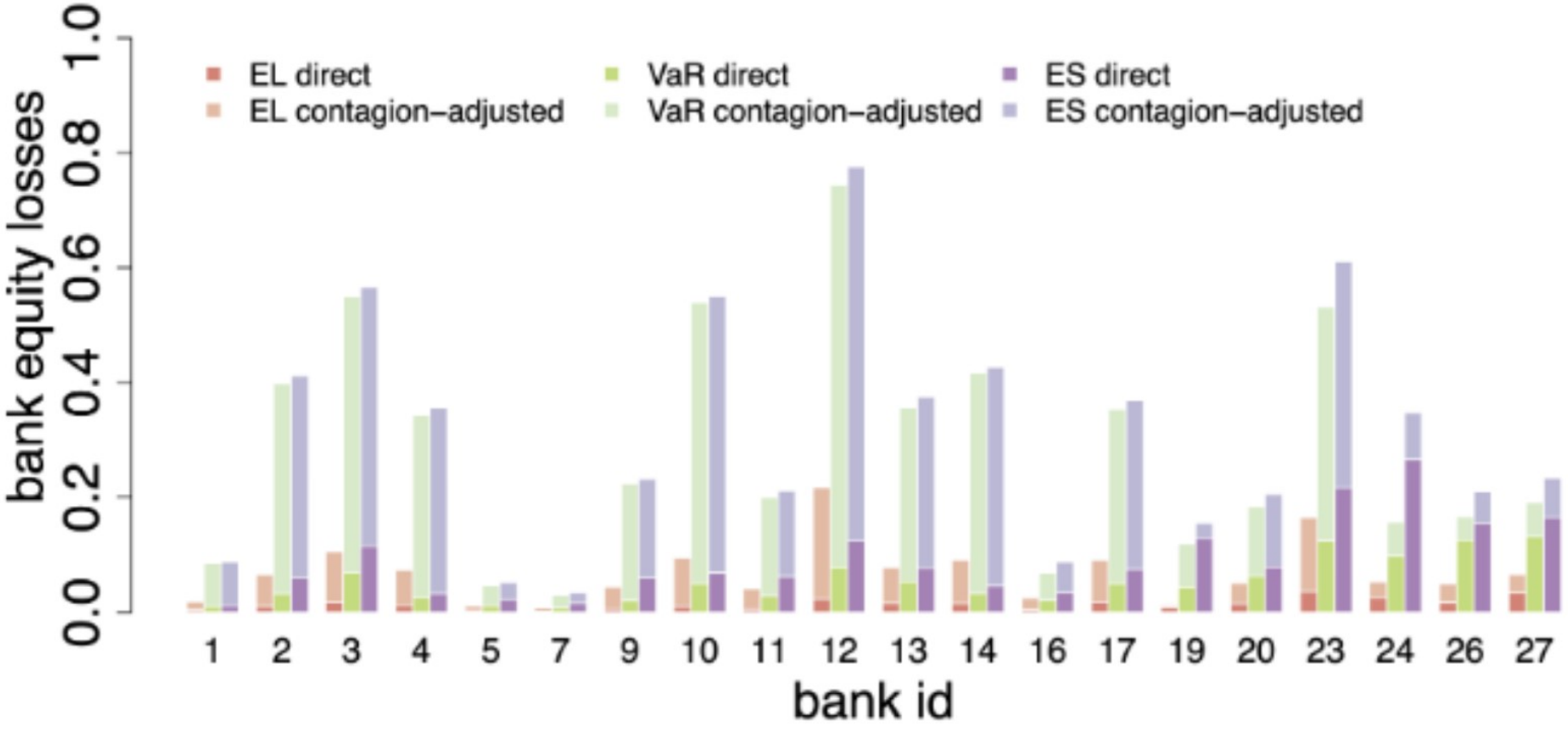
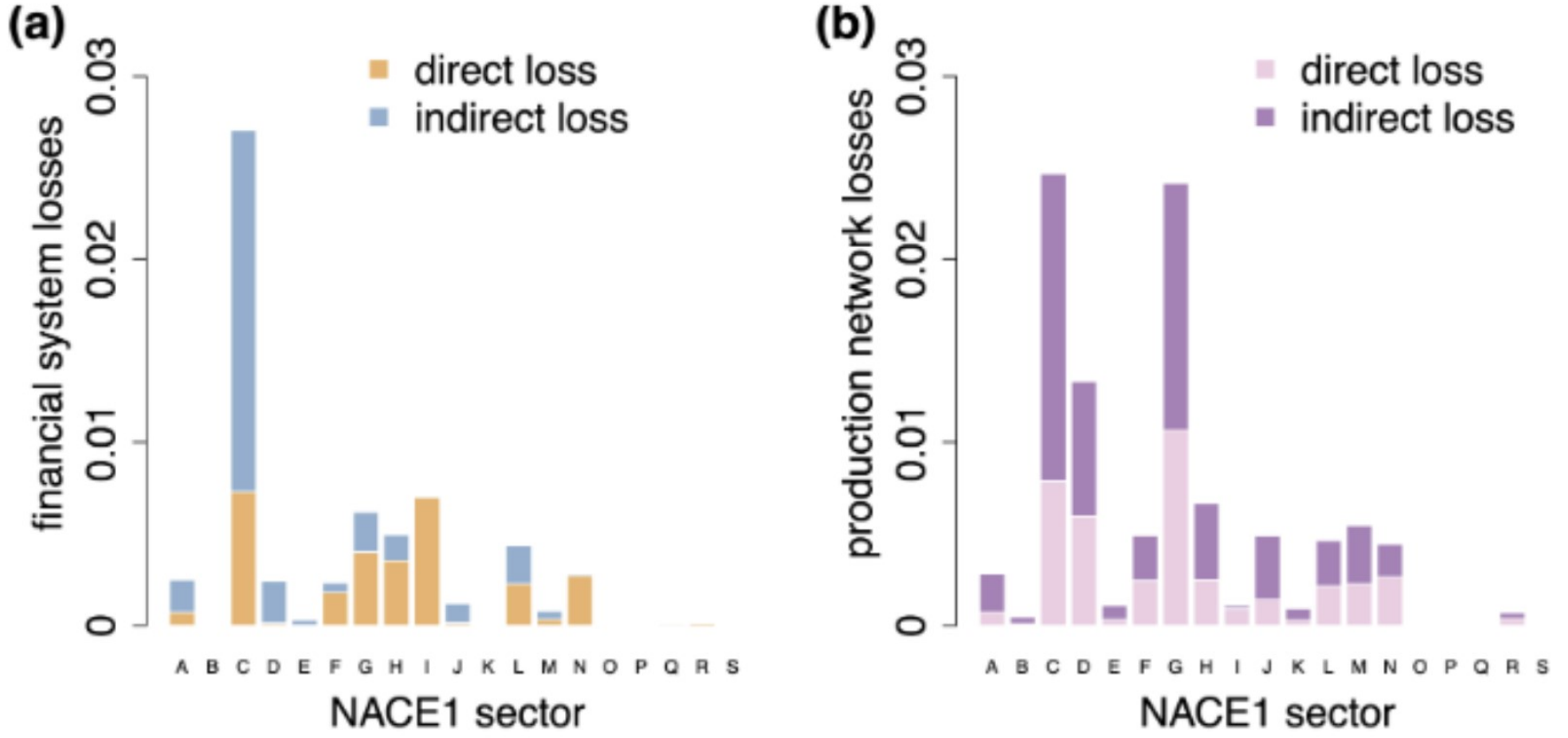
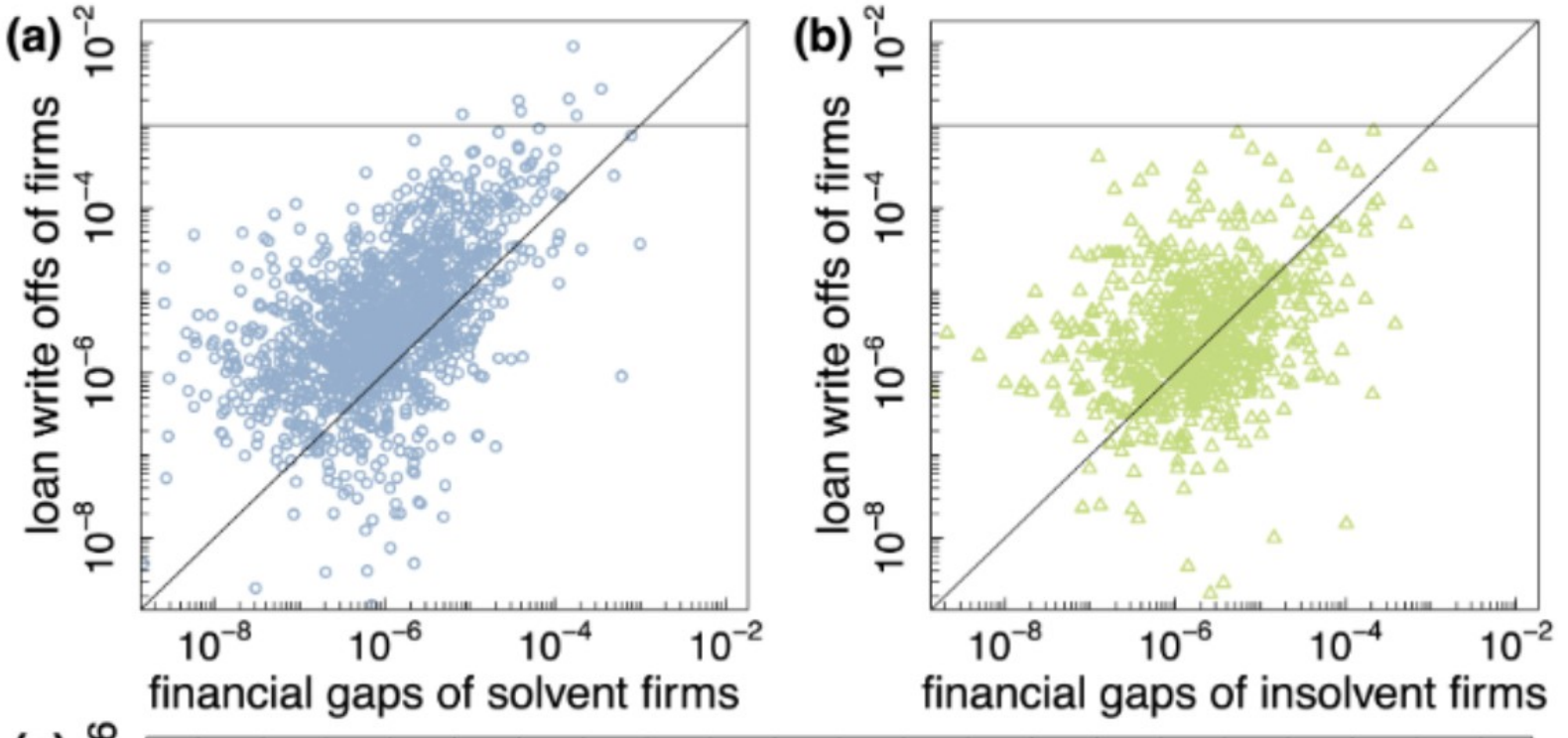
massive risk amplification due to SCN



financial vs production losses in sectors



how beneficial is rescuing firms?



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summary

- networks **do** matter in the economy: real and financial
- relevant scale: firms
- markets do not necessarily make economy resilient – might create SR
- some level of planning might be necessary to tackle big challenges ahead
- → realistic predictive models of economy are necessary
- ingredients: value creation NWs of all agents, production functions, substitution dynamics
- in combination with understanding ”human factor” and institutions → rethinking economics possible
- many applications: basic provisioning, economic planning, green transition, defense
- combining with other data: labor markets, trade, waste, material flows, …

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multi-layer contagion spreading

1. quantify propagation of production disruptions in SCN after firm failure
2. update equity and liquidity buffers of firms in response to reduced production levels. Check if firms are illiquid/insolvent and default on loans
3. update bank equity buffers by writing off the loans of initially failed firms, and those defaulted due to SCN contagion

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need for new institutions?

supply-chain institutes on international level that create space for this symbiosis

- data / technology
- policy / legal
- science

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