Universität Konstanz

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Economic Complexity 2

Network Science of Socio-Economic Systems

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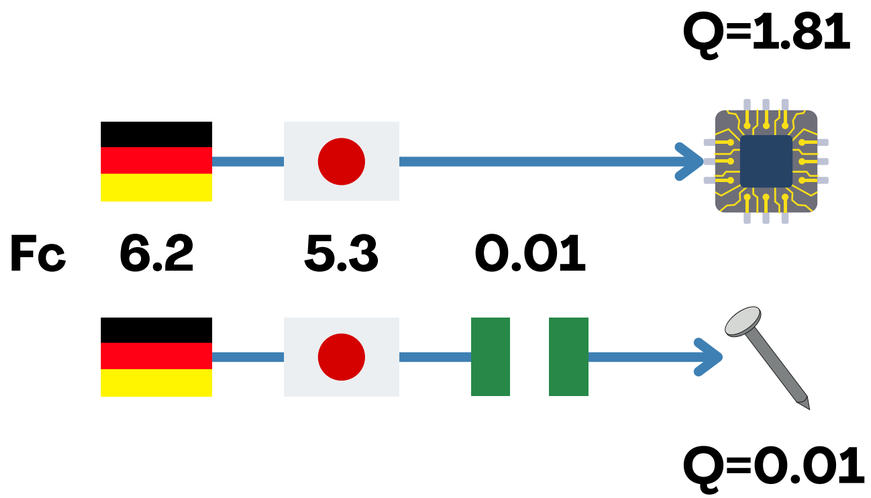


Recap

Economic Complexity

Economic Complexity studies economic with data-driven network-based methods. We introduced the EFC algorithm.

Product Progression

Economic Complexity techniques allow to forecast industrial progression, with machine learning outperforming networks.

Economic Complexity at Different Scales

Economy is a hierarchical system with many different scales. We observe a similar nested structure at almost all scales.

Outline

1. Firms Output Networks
2. Ownership and Directors Networks
3. Supply Chains

Firms Output Networks

Looking at Firms with Networks

We mostly focused on countries

- countries are very large entities
- they evolve regularly
- statistical fluctuations are not very relevant

However economic complexity can be applied to firms also

- firms vary extremely in size
- large companies can be as large as small countries
- we may expect similar regularities with respect to countries

Different Perspectives

Different types of firms networks can be considered. Each one of them allows to study firms under a different perspective

- **Output Networks**
  - firm-product/technology bipartite network
  - firm-activities bipartite network
- **Ownership Networks**
  - directed graph where nodes represent firms or entities, and edges indicate ownership relationships
- **Board of Directors Networks**
  - firm-director bipartite network
  - edges indicate the membership in a firm's board of directors
- **Supply Chains**
  - Supply chain networks are directed graphs where nodes represent entities such as suppliers, manufacturers, distributors, and retailers, and edges indicate the flow of goods or services between them.

Short Recap

We already saw an example of firms-product bipartite network

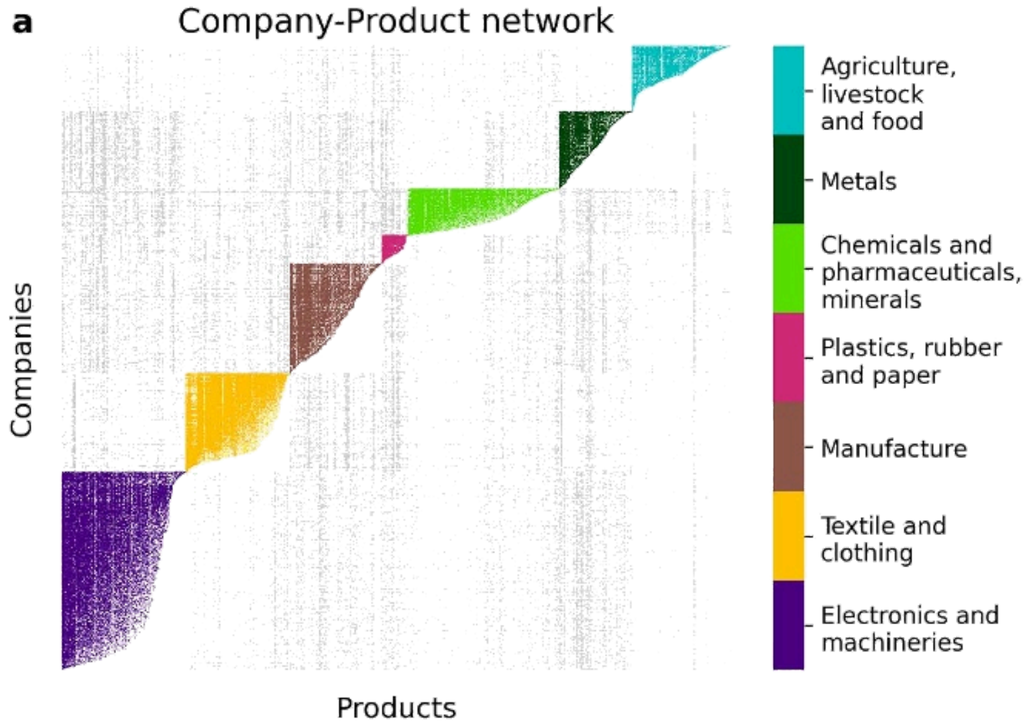
- these type of data are generally very hard to get
- national statistic offices have in theory access to the data

The Italian company-product network

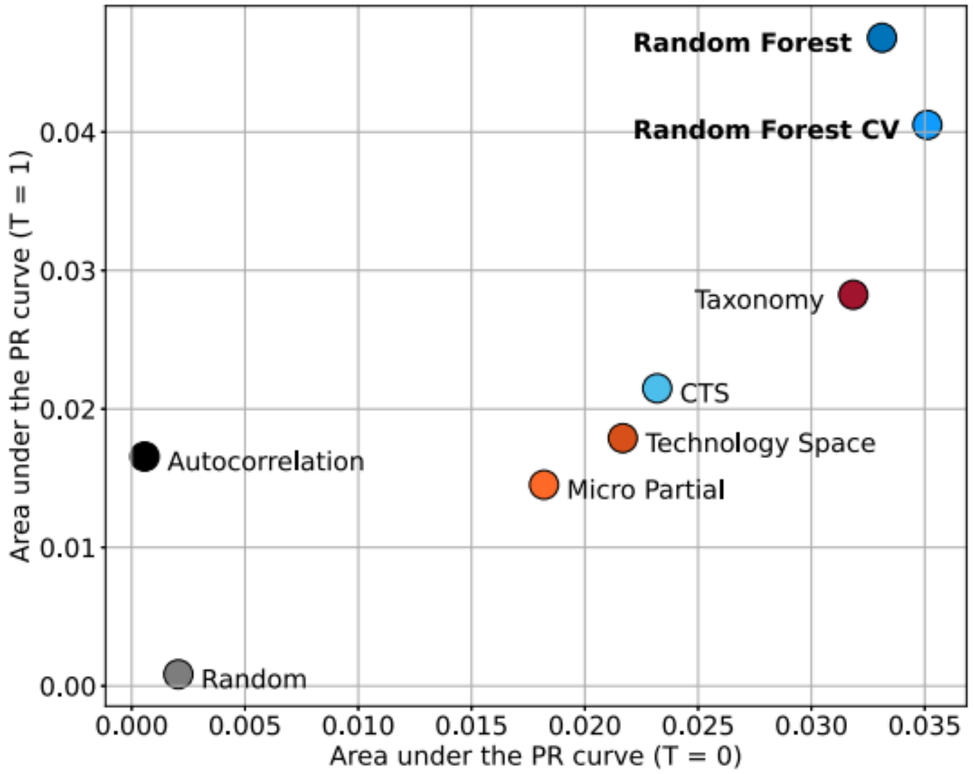
- shows a block structure
- each block is nested

This means that

- companies specialize in a specific sector
- they tend to diversify within their sector



Forecasting Technology Production



Patent databases allow to link technologies to firms, building a bipartite network

- data exists and can be accessed, but they are typically expensive

All the techniques we discussed in last lesson can by applied

- this allows to forecast which new technology a firm will patent
- also in this case machine learning works better than networks

Straccamore, Matteo, Luciano Pietronero, and Andrea Zaccaria. "Which will be your firm's next technology? Comparison between machine learning and network-based algorithms." Journal of Physics: Complexity 3.3 (2022): 035002.

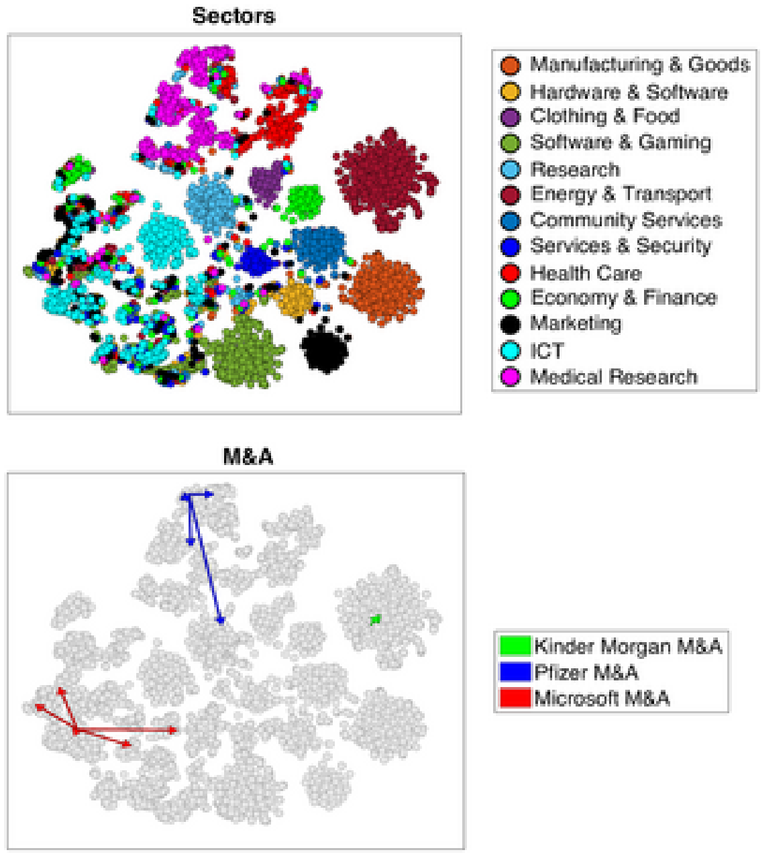
Merger and Acquisitions

Starting from patent data it is also possible to study merger and acquisitions

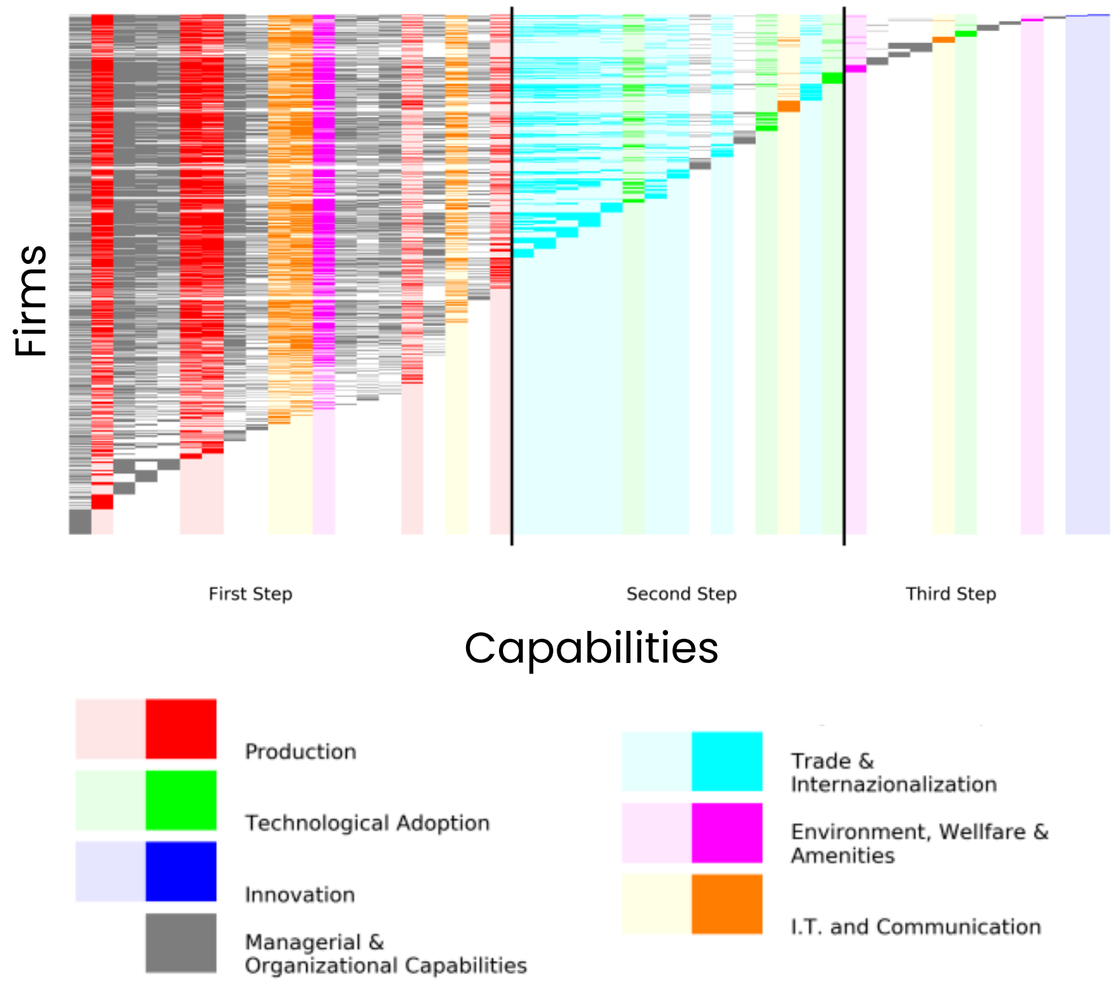
- these are processes by which companies acquire other firms
- often large companies buy small firms because of their technologies or patents

Using patent data we can forecast this process

- also in this case the cooccurences between two companies is a good metric
- statistical validation must be performed
- machine learning typically outperforms network based techniques



Arsini, Lorenzo, Matteo Straccamore, and Andrea Zaccaria. "*Prediction and visualization of Mergers and Acquisitions using Economic Complexity.*" Plos one 18.4 (2023): e0283217.



C. Alexander, N. Mathew, and E. Pugliese. *Positioning firms along the capabilities ladder*. Maastricht Economic and Social Research Institute on Innovation and Technology (UNU-MERIT), 2021.

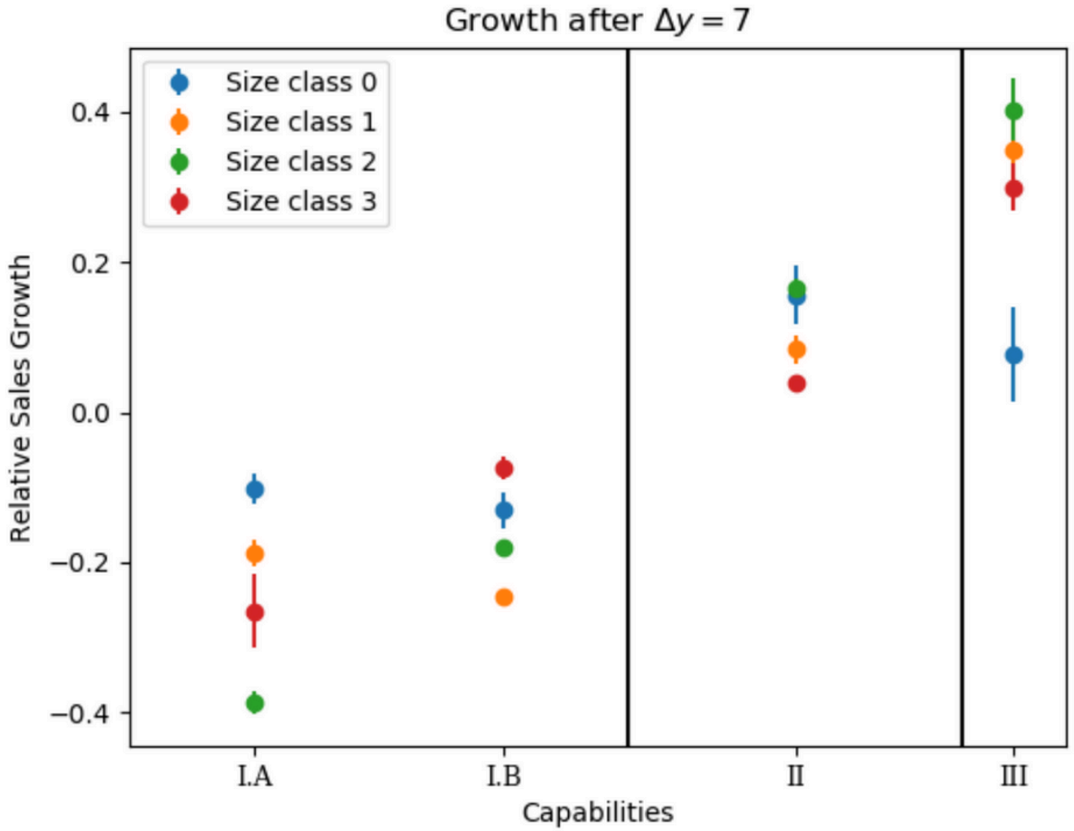
The Ladder of Capabilities

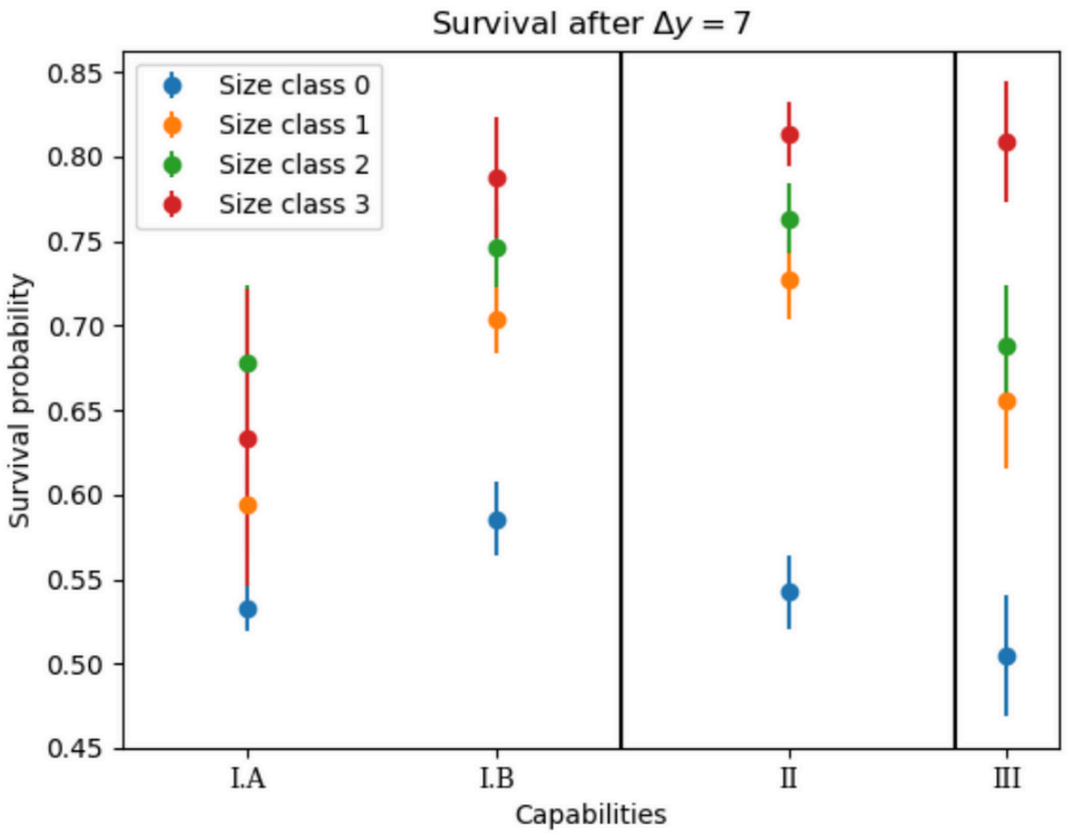
Both products and patents are the results of the capabilities within firms

- capabilities can be reconstructed looking at balance sheets of firms
- for instance PROWES Indian database (not free)
- authors build a bipartite network
  - ~16k firms and 47 activities
- example activities are
  - Export of goods
  - Advertising expenses
- the bipartite matrix is nested

Capabilities and Growth

Being placed further right in the capabilities ladder, i.e. having more sophisticated activities, results in higher growth and survival





Ownership and Directors Networks

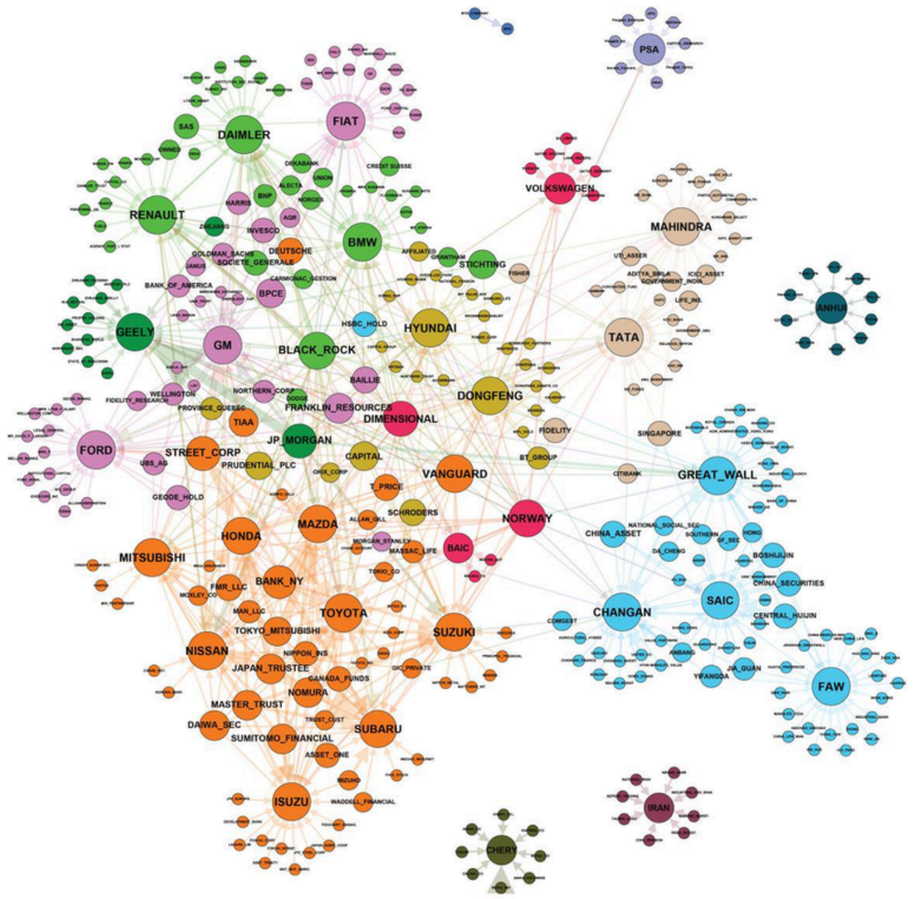
Ownership Networks

Firms are interconnected through complex ownership structures

- Large corporations own stakes in multiple smaller firms
- These relationships can span across industries and countries,

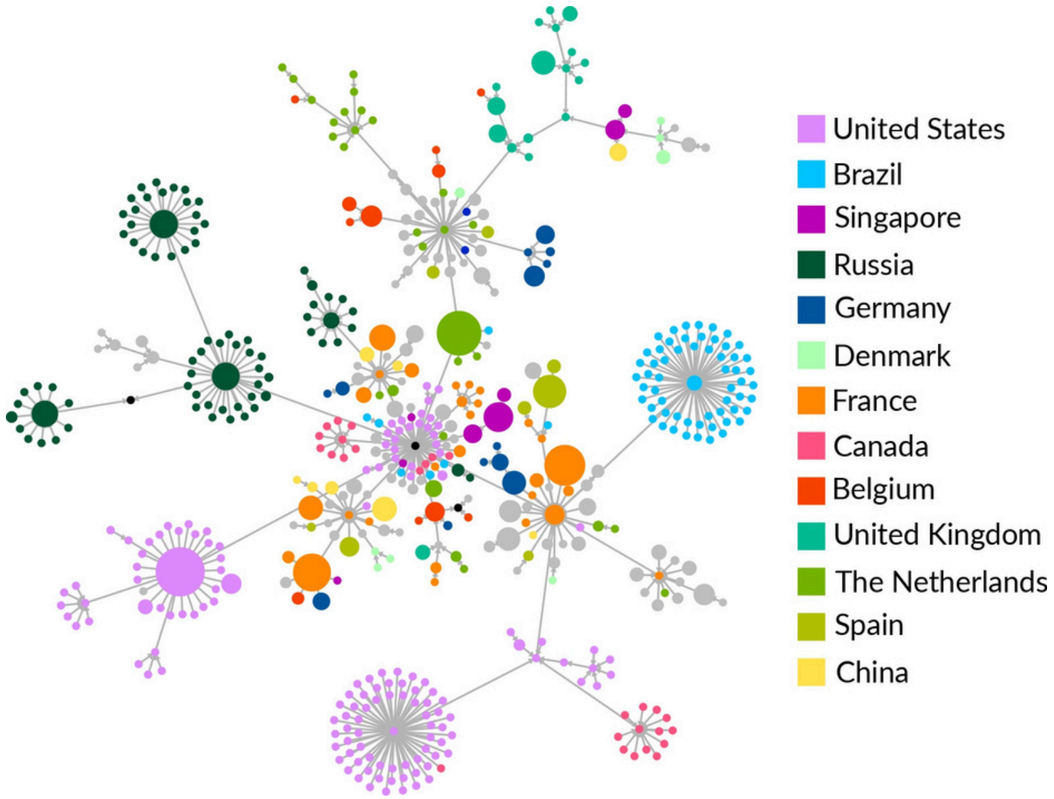
Ownership networks model these relationships as directed graphs

- nodes represent firms
- edges indicate ownership stakes, often weighted by control



Neto, Mario Sacomano, et al. "Corporate ownership network in the automobile industry: Owners, shareholders and passive investment funds." Research in Globalization 2 (2020): 100016.

Shifting Profits



Large corporations create complex networks of subsidiaries across multiple countries

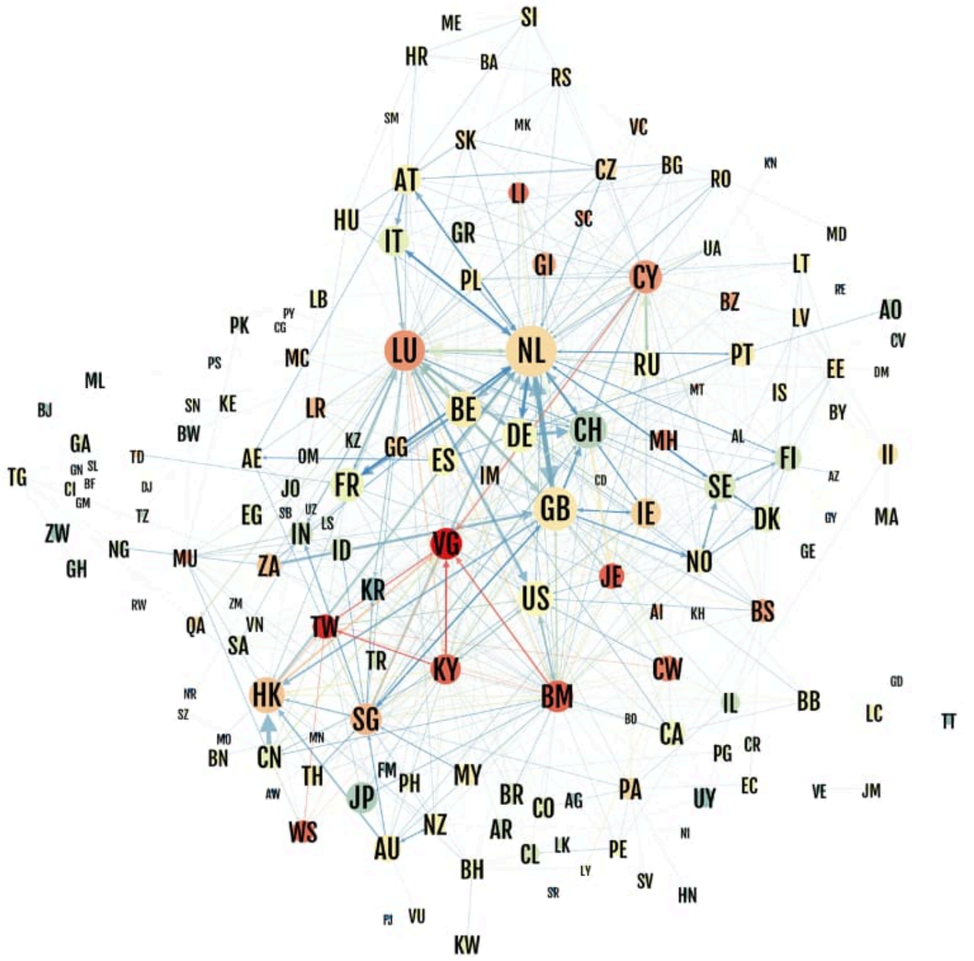
- This is often designed to shift profits and avoid tax obligations
- There are many techniques
  - Transfer Pricing
  - Intellectual Property Migration
  - Shell Companies
- This is bad but legal

The figure show the corporate structure of a single large company

Ownership Flows
Between Countries

Starting from the firm ownership network we can reconstruct the flow of values between countries

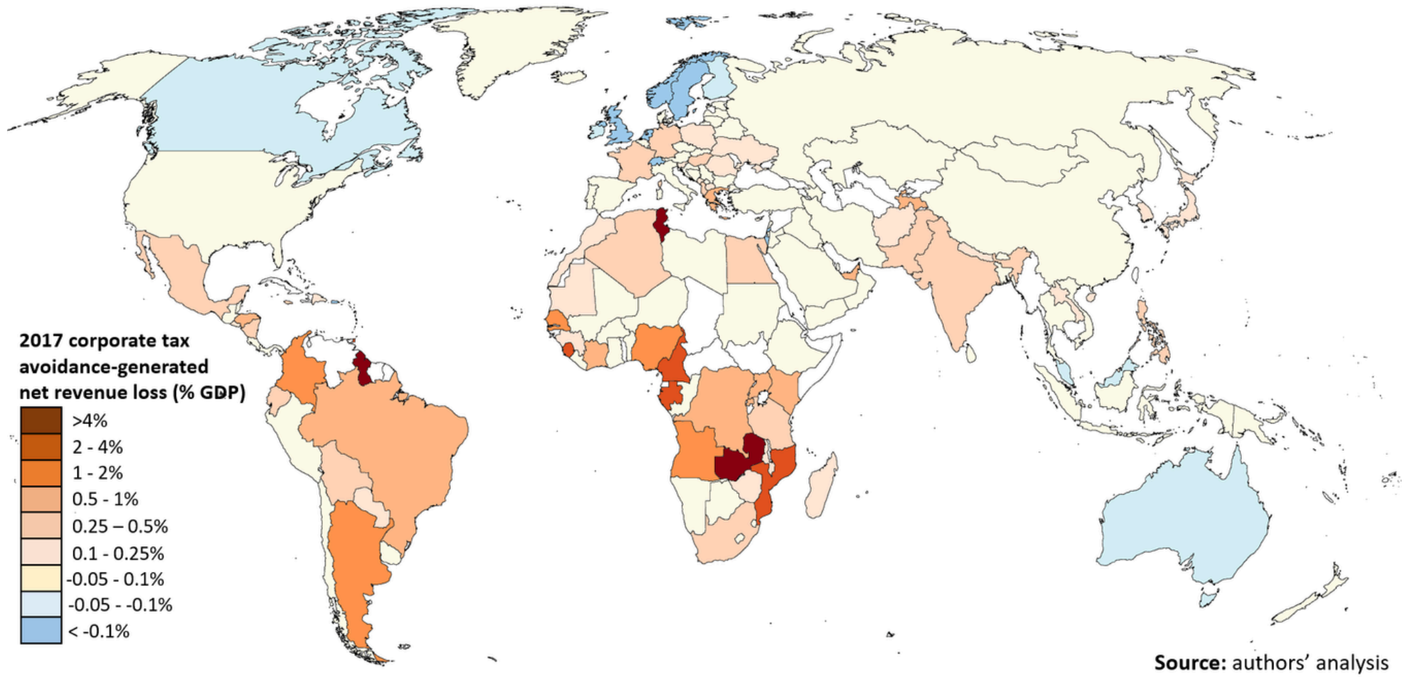
- we can define Ofshore Financial Centers (OFC) as countries that attract and retain foreign capital
  - there are Sink and Conduit OFC
- node color shows a measure of Sink OFC (red is bad)
- node size shows a measure of Conduit OFC
- in Europe we observe Luxembourg and the Netherlands, in Asia Hong Kong



Garcia-Bernardo, Javier, et al. "*Uncovering offshore financial centers: Conduits and sinks in the global corporate ownership network*." Scientific reports 7.1 (2017): 6246.

The Indirect Costs of Tax Avoidance

Profit shifting does not affect all countries equally. The higher margins results in better dividends for the stock owner, therefore the avoided taxes are redistributed among the investors. Rich countries thus get (some) money back

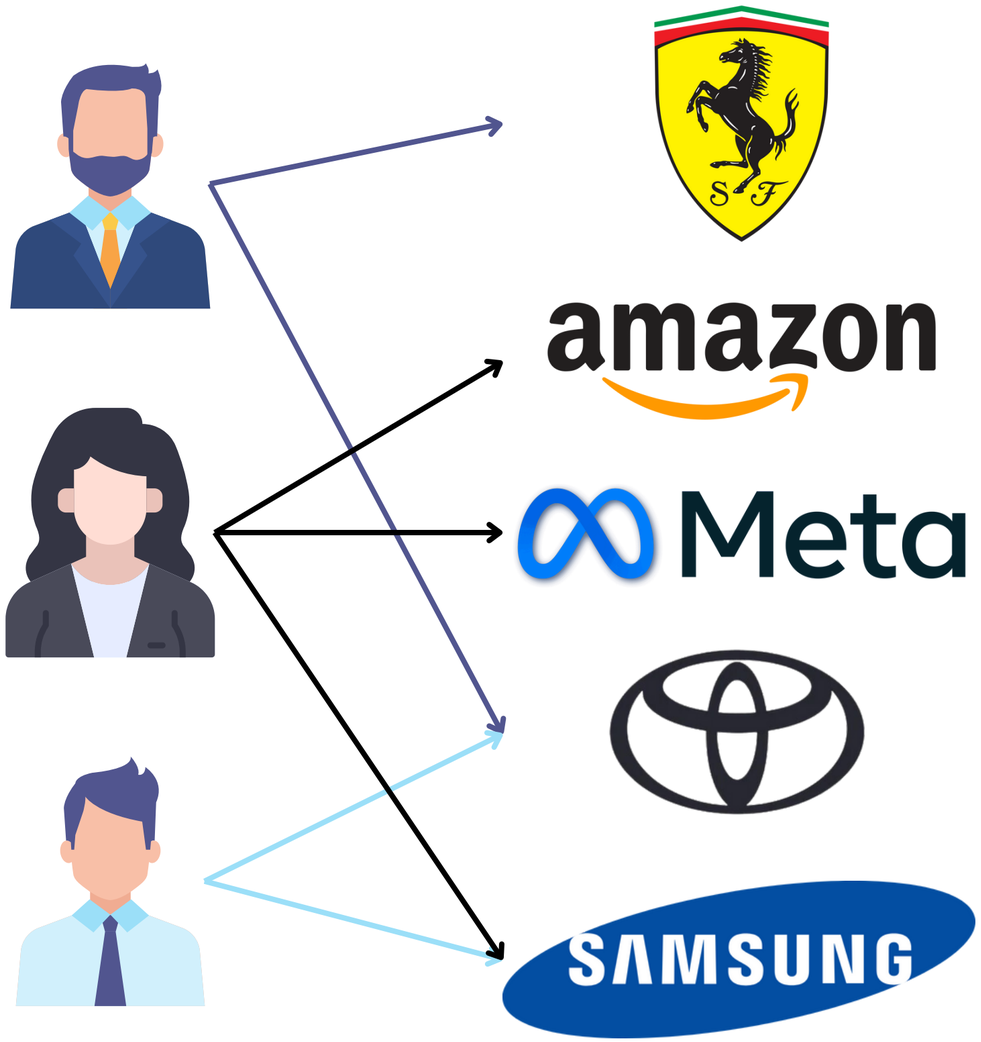


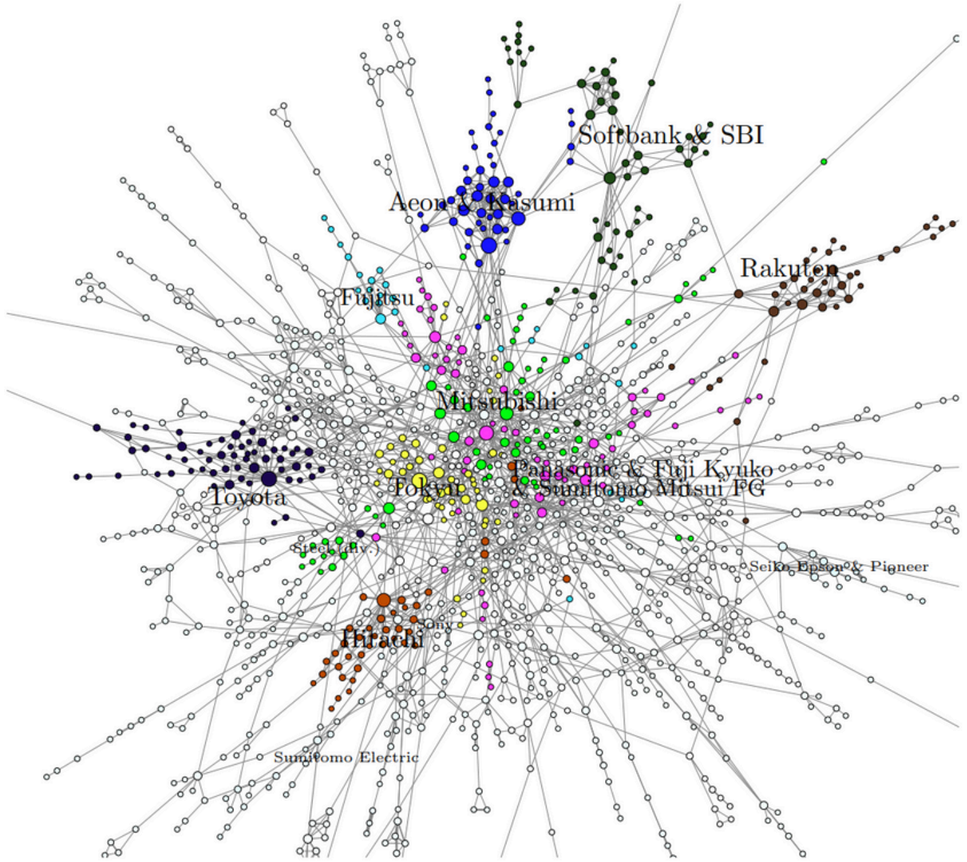
Garcia-Bernardo, Javier, et al. *The indirect costs of corporate tax avoidance exacerbate cross-country inequality.* No. 2022/33. WIDER Working Paper, 2022.

Board of Directors
Bipartite Network

Firms are also interconnected through shared board members, forming a bipartite network

- Individuals serving on multiple boards create links between firms
- This leads to shared governance, influence, and strategic alignment
- We have two types of nodes:
  - Firms, Directors
- A link exists if a director serves on the board of a firm





Raddant, Matthias, and Hiroshi Takahashi. *The Japanese corporate board network.* No. 2130. Kiel Working Paper, 2019.

Projected Networks

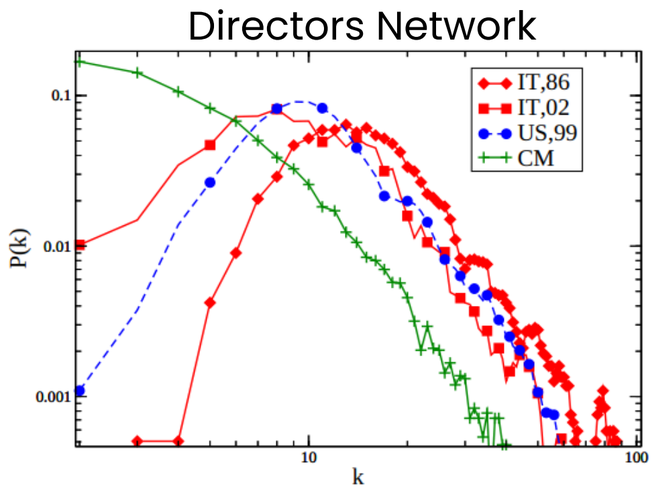
By projecting the board of directors bipartite network we can construct firm-firm and director-director networks

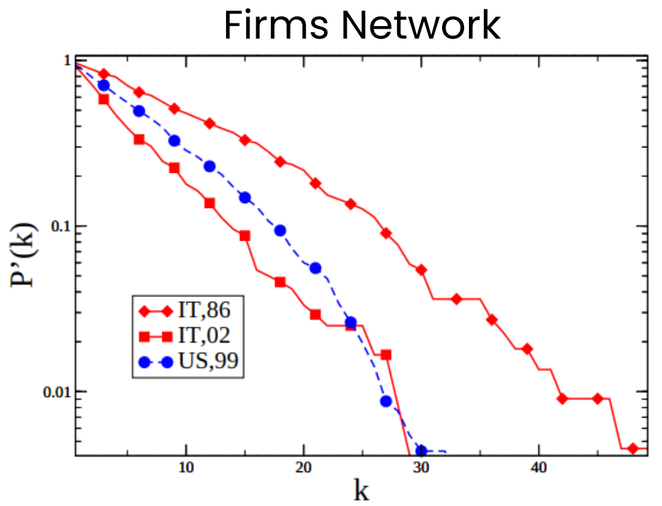
- as always the starting point are cooccurences and different filtering techniques can be applied
- the figure show a firm-firm network obtained using data from Japan
- we can observe some communities related to big companies
- this network is related to the ownership network of firms

Degree Distributions

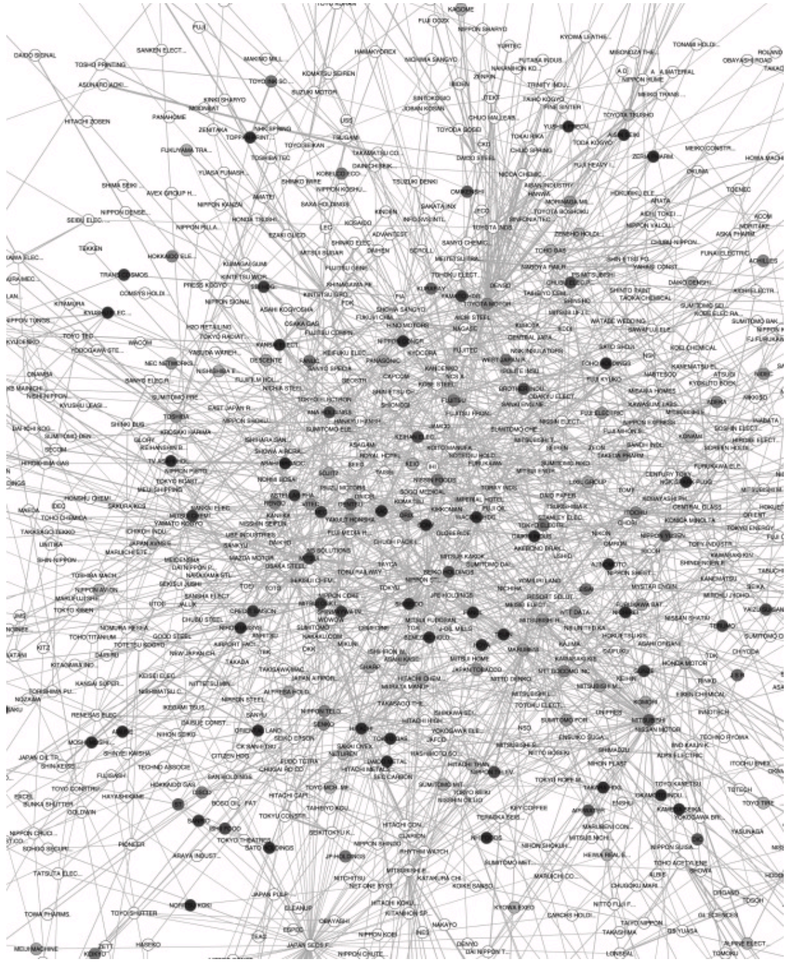
The firm and director networks show different statistical properties

- different datasets considered
- projection based on simple cooccurences
- the director projected networks show power law degree distributions
- there are individuals connected to thousands of other board members
- the firm networks instead are characterized by an exponential like degree distribution





Battiston, Stefano, and Michele Catanzaro. "*Statistical properties of corporate board and director networks.*" The European Physical Journal B 38 (2004): 345-352.



Raddant, Matthias, and Hiroshi Takahashi. "Interdependencies of female board member appointments." International Review of Financial Analysis 81 (2022): 102080.

Female Board Members

Women remain underrepresented in corporate boards worldwide

- 20-30% in many developed countries

Japan lags significantly, with only 2% during the period 2004-2013

- representation grew from 1.04% in 2004 to 1.94% in 2013, mainly auditing roles
- firms linked to those with female board members are more likely to appoint women, showing a contagion effect


Supply Chains

What is a Supply Chain?

A supply chain is the entire system of organizations, people, activities, information, and resources involved in producing and delivering a product or service from suppliers to consumers

- It represents another way to view the relationships among firms, focusing on the flow of goods and services rather than ownership.
- Key Stages of a Supply Chain include
  a. **Raw Material Suppliers** – Provide essential materials and components.
  b. **Manufacturers** – Transform raw materials into finished products.
  c. **Distributors & Wholesalers** – Handle storage and transportation.
  d. **Retailers** – Sell products to end consumers.
- For instance if we consider a smartphone
  - Lithium from Chile (batteries), silicon from China (chips)
  - Companies (TSMC, Samsung) produce microchips, screens, cameras…
  - Foxconn (China) assembles parts into finished smartphones.
  - Products are shipped globally and sold (Apple, Amazon etc)

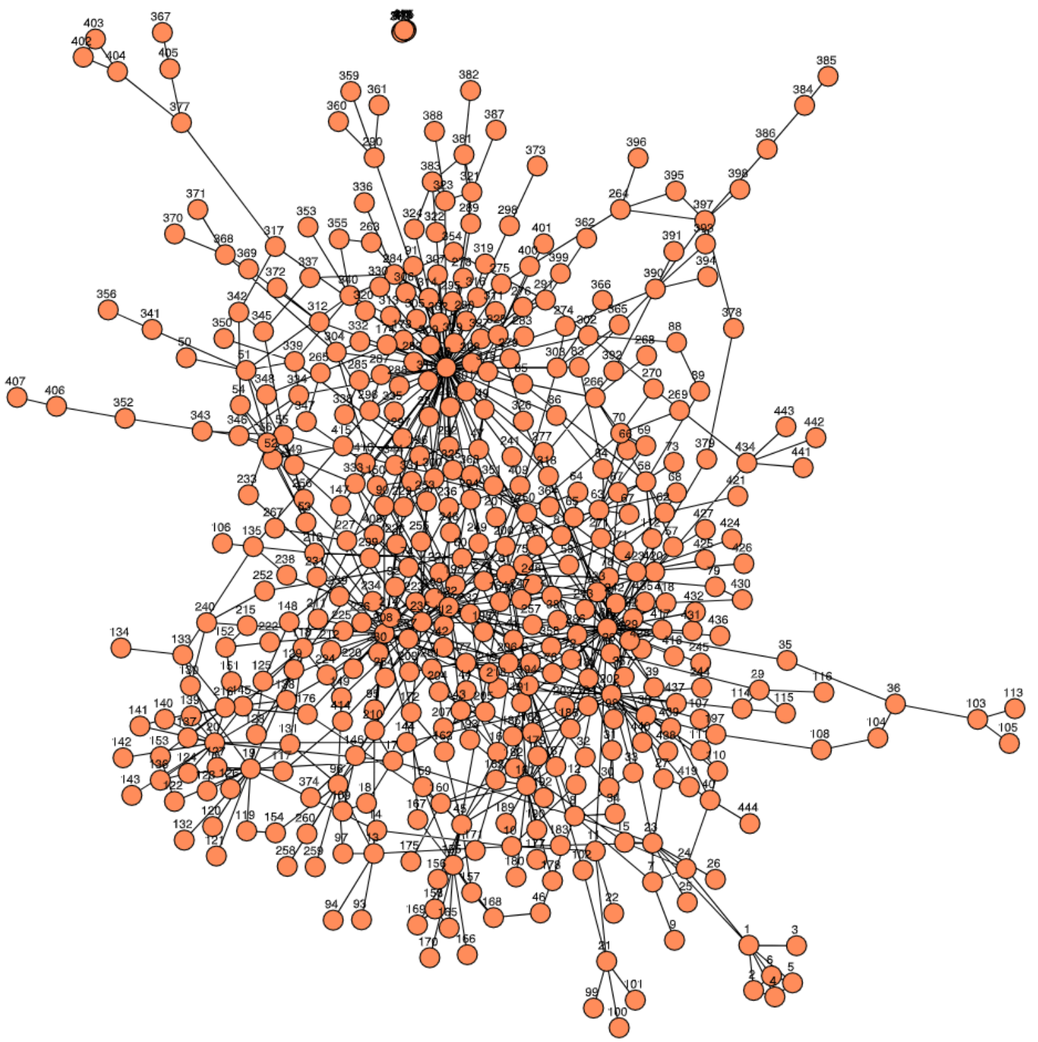
Supply Chains are Complex

Supply chains are often seen as linear sequences, where goods move step-by-step from suppliers to consumers.

- This "chain" perspective strongly simplifies interactions

In reality, supply chains form highly interconnected networks,

- firms interact with multiple suppliers, distributors, and partners
- Dependencies, redundancies, and global connections make supply chains extremely complex



Acemoglu, Daron, et al. "T*he network origins of aggregate fluctuations*." Econometrica 80.5 (2012): 1977-2016.

The Importance of Supply Chains

Understanding supply chains is crucial for ensuring economic stability, resilience, and strategic planning

- **Avoiding or Mitigating Shock Propagation**
  - Supply chain disruptions, such as natural disasters, pandemics, or financial crises, can cascade through the network, affecting entire industries.
- **Guiding Investment and Policy Decisions**
  - Policymakers and businesses need to understand supply chains to effectively guide strategic investments and policies
- **Defending Against Foreign Influence**
  - Supply chains can be targets of economic or geopolitical attacks, where foreign entities may acquire strategic companies or halt supplies to exert influence

Despite this there is still no common effort to reconstruct the European Supply Chain

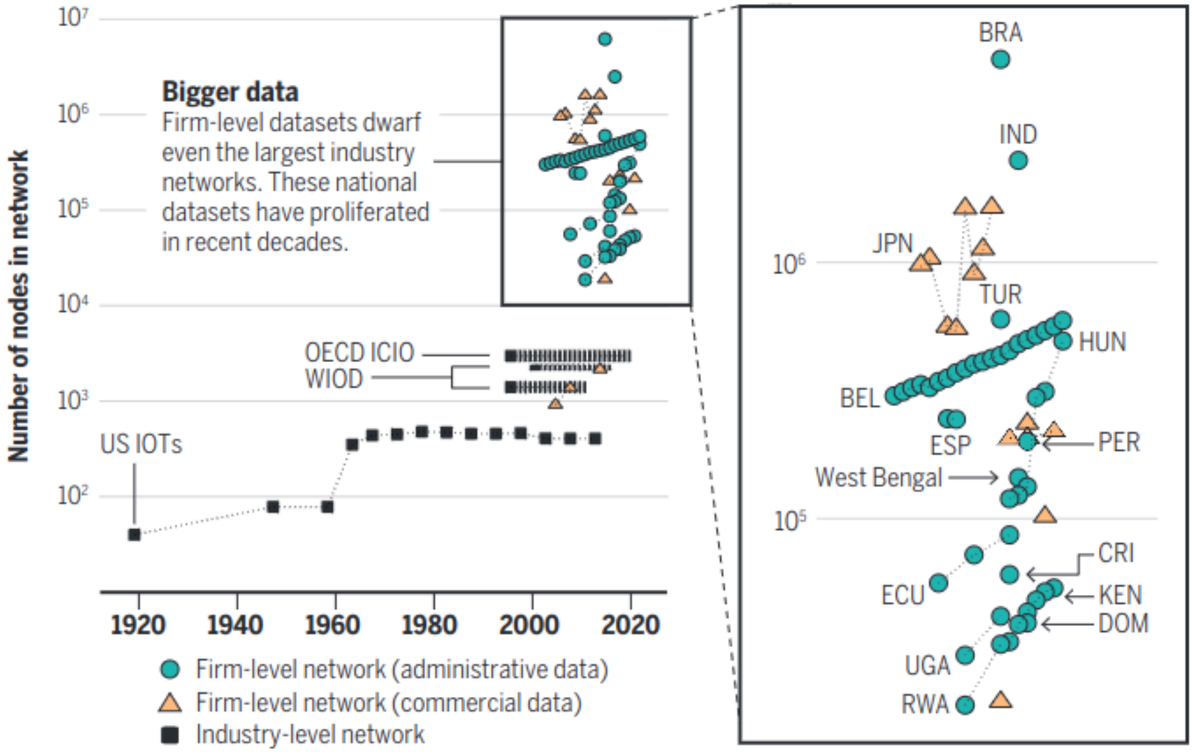
Existing Data

Existing supply chain data are still limited and cover single countries

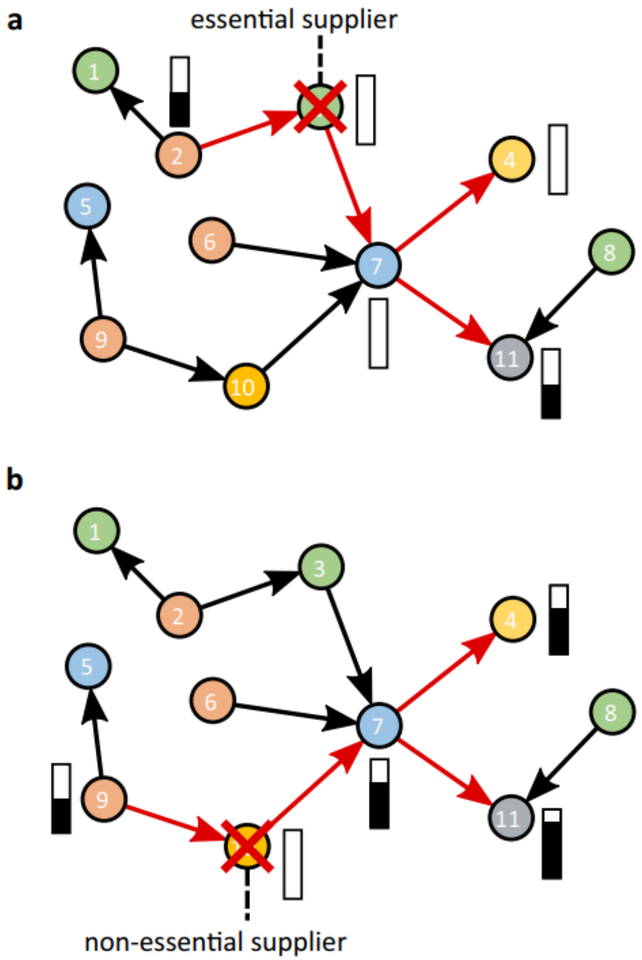
- data are hard to access
- replicating studies is difficult
- in theory every country should be able to reconstruct the supply chain from VAT data

However firm level data provide a much more detailed picture with respect to industry level ones

- firm levels are much larger
- the industry level is often not enough to describe the supply chain



Pichler, Anton, et al. "Building an alliance to map global supply networks." Science 382.6668 (2023): 270-272.



Diem, Christian, et al. "*Quantifying firm-level economic systemic risk from nation-wide supply networks.*" Scientific reports 12.1 (2022): 7719.

Supply Chain Shocks

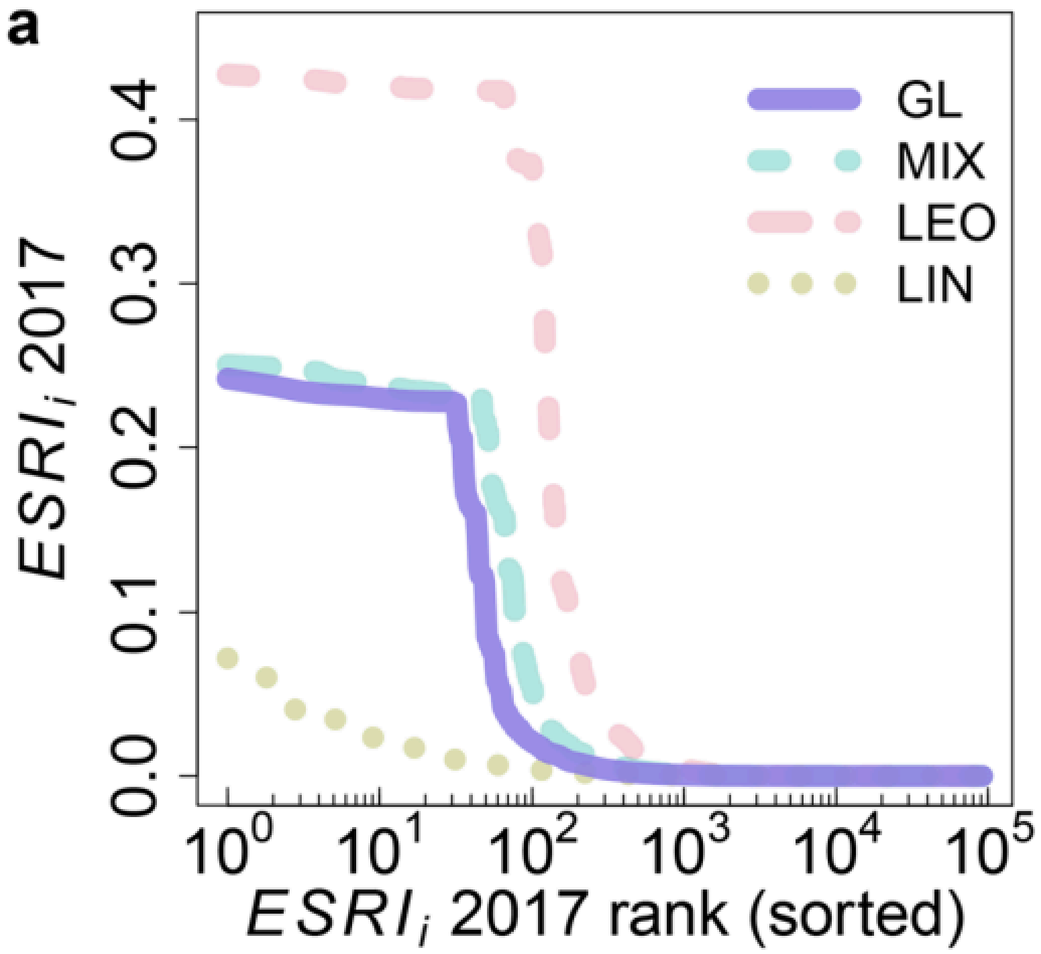
A supply chain shock occurs when a firm in the supply chain experiences a sudden disruption, such as bankruptcy, natural disasters, or geopolitical events

- Downstream Shocks:
  - When an essential supplier fails, dependent firms cannot continue production
- Upstream Shocks:
  - When firms reduce demand due to downstream disruptions, suppliers experience a drop in orders, leading to production cuts
- Shocks can propagate and affect the whole supply chain starting from a single firm

Economic Systemic Risk Index

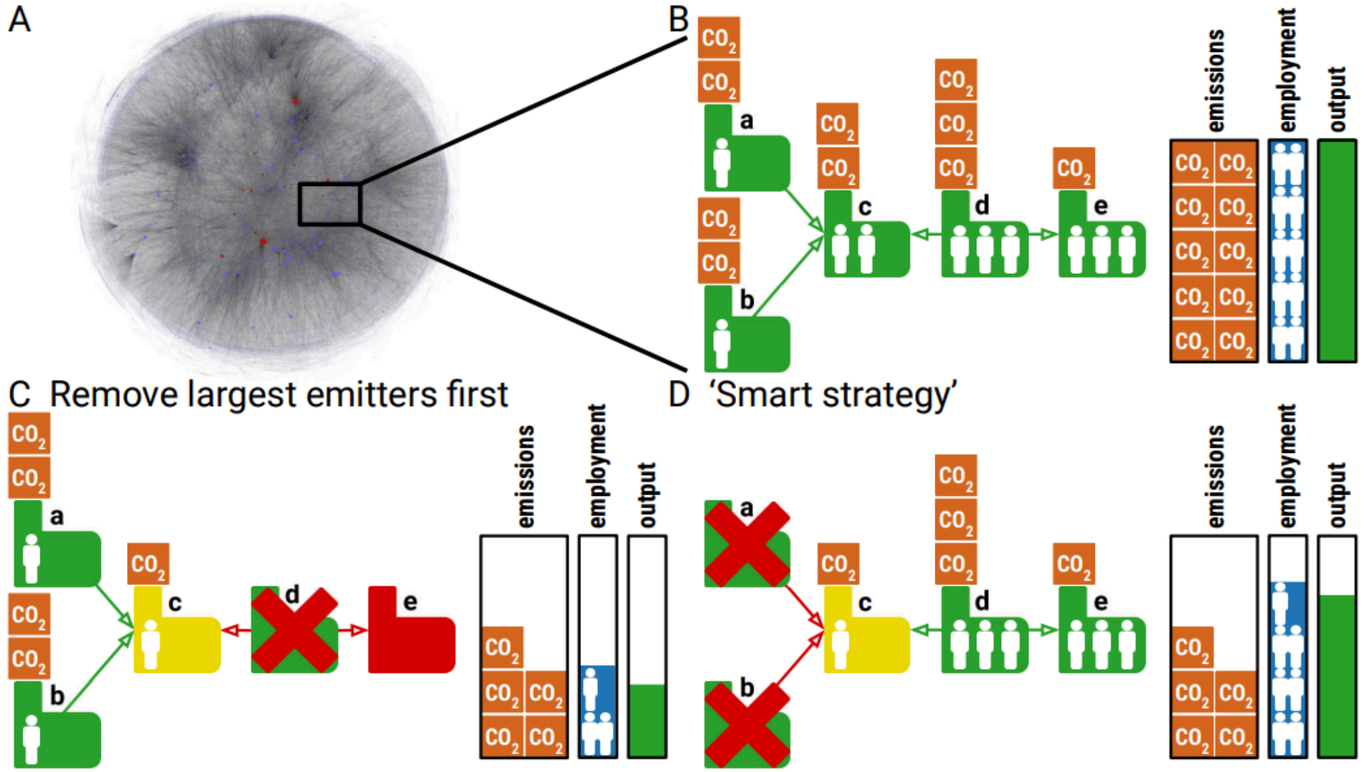
The Economic Systemic Risk Index (ESRI) quantifies the potential impact of a firm's failure on the overall economy

- simulates the propagation of disruptions through supply networks
- Each firm’s production capability is modeled using a production function, which describes how inputs are transformed into outputs.
- When a firm fails, its inability to supply and demand propagates
- Both Downstream Shocks and Upstream Shocks are considered



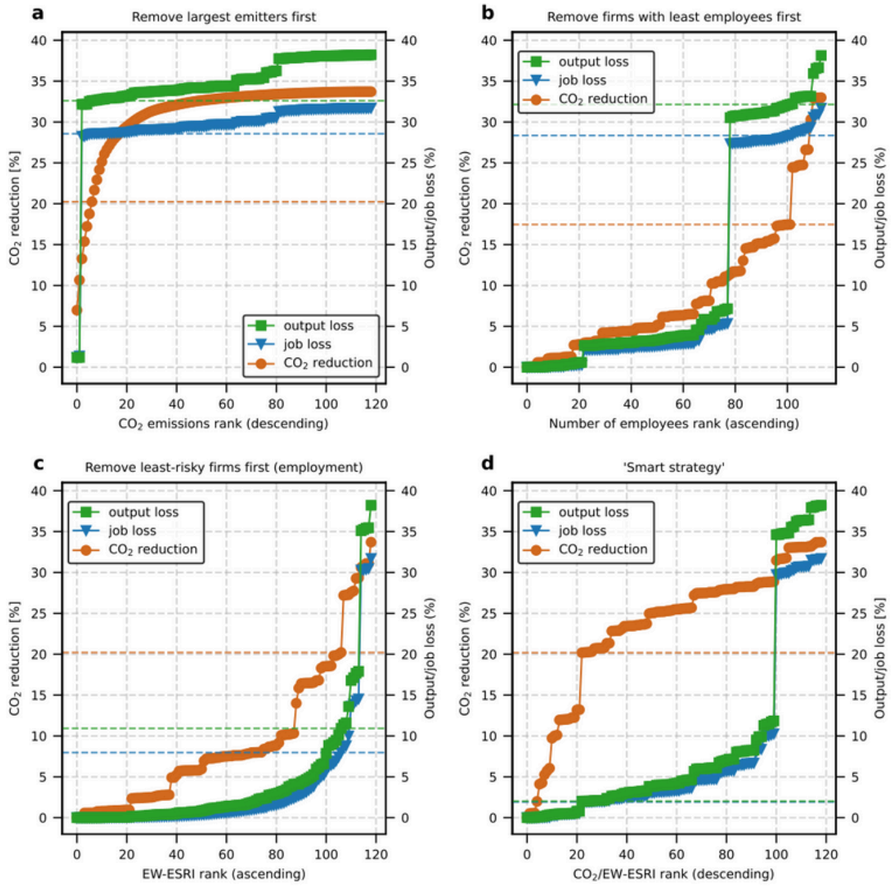
Guiding Decarbonization

A very relevant application of supply chain data is guiding policy in decarbonization, by identifying the firms with the lowest impact on the economy



Stangl, Johannes, et al. "*Firm-level supply chains to minimize unemployment and economic losses in rapid decarbonization scenarios.*" Nature Sustainability (2024): 1-9.

Minimizing Losses



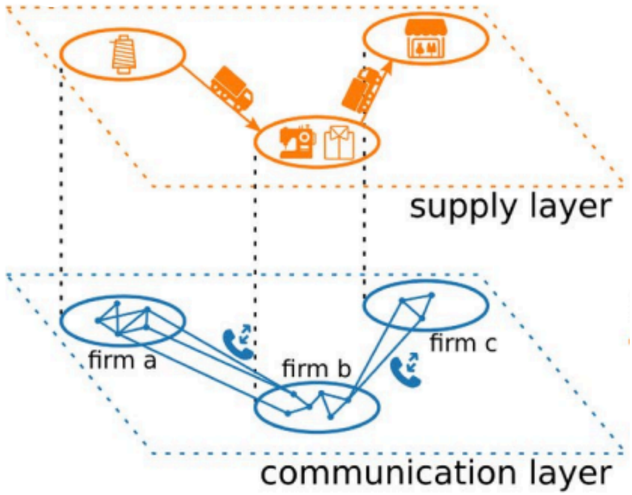
A poorly designed decarbonization policy may lead to significant job losses and economic disruptions

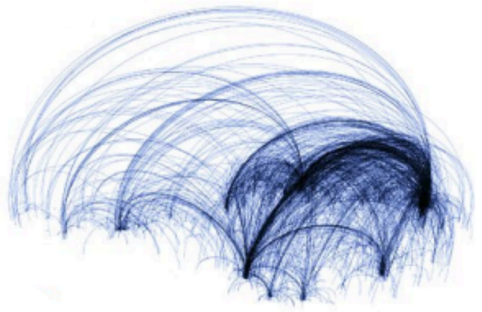
- Largest Emitters First:
  - Rapid emission cuts but high job and output losses.
- Least Employees First:
  - Many firms need closure to meet targets.
- Least Risky Firms First (EW-ESRI):
  - Slow economic impact, requires many closures.
- Smart Strategy (CO2/EW-ESRI):
  - Targets high emissions, low systemic risk firms.
  - Efficient reduction with minimal job/output loss.

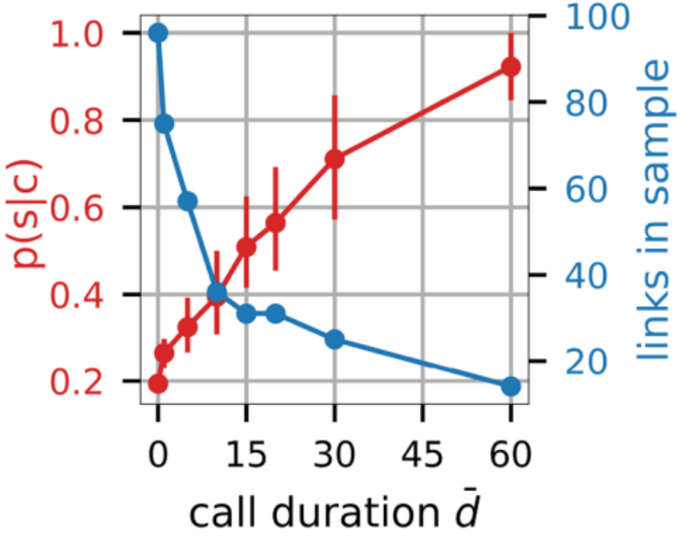
Reconstructing Supply Chains

Traditional methods for mapping supply chains rely on VAT records, surveys, or payment system data, which are often unavailable

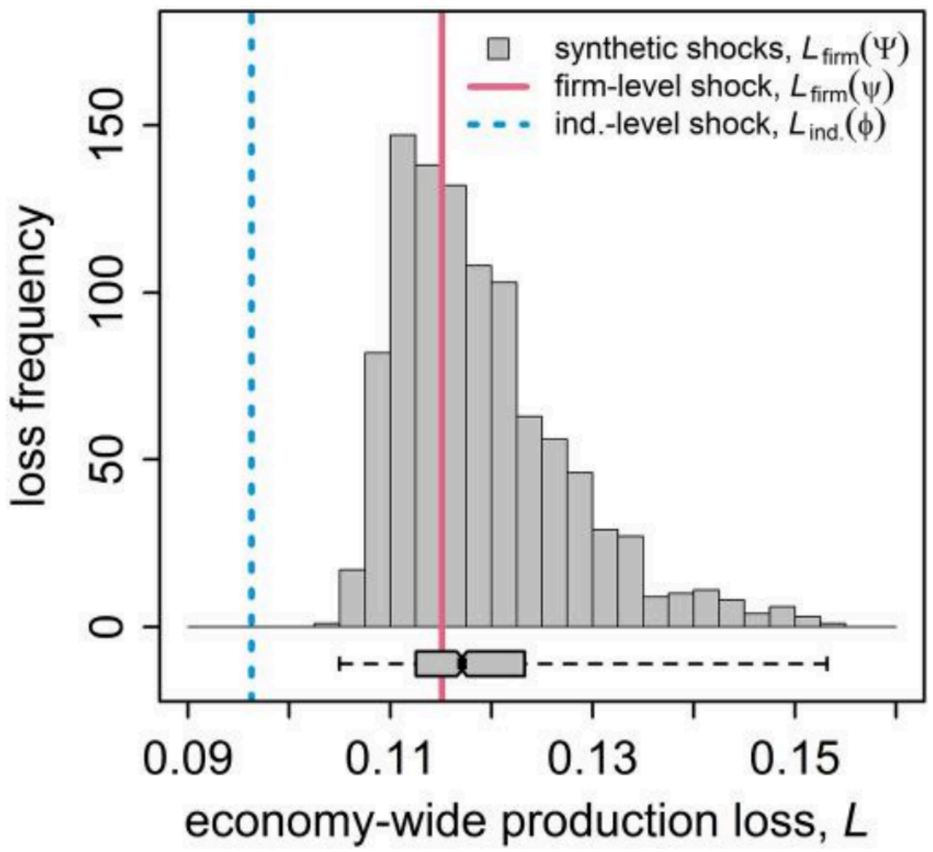
- Firms frequently communicate with their suppliers via phone calls
- calls are a proxy for business relationships.
- Studies show a high correlation between communication links and supply links
- This approach enables continuous tracking of supply chain changes







Reisch, Tobias, et al. "*Monitoring supply networks from mobile phone data for estimating the systemic risk of an economy.*" Scientific reports 12.1 (2022): 13347.



Diem, Christian, et al. "*Estimating the loss of economic predictability from aggregating firm-level production networks.*" PNAS nexus 3.3 (2024): pgae064.

The Risk of Using Aggregated Data

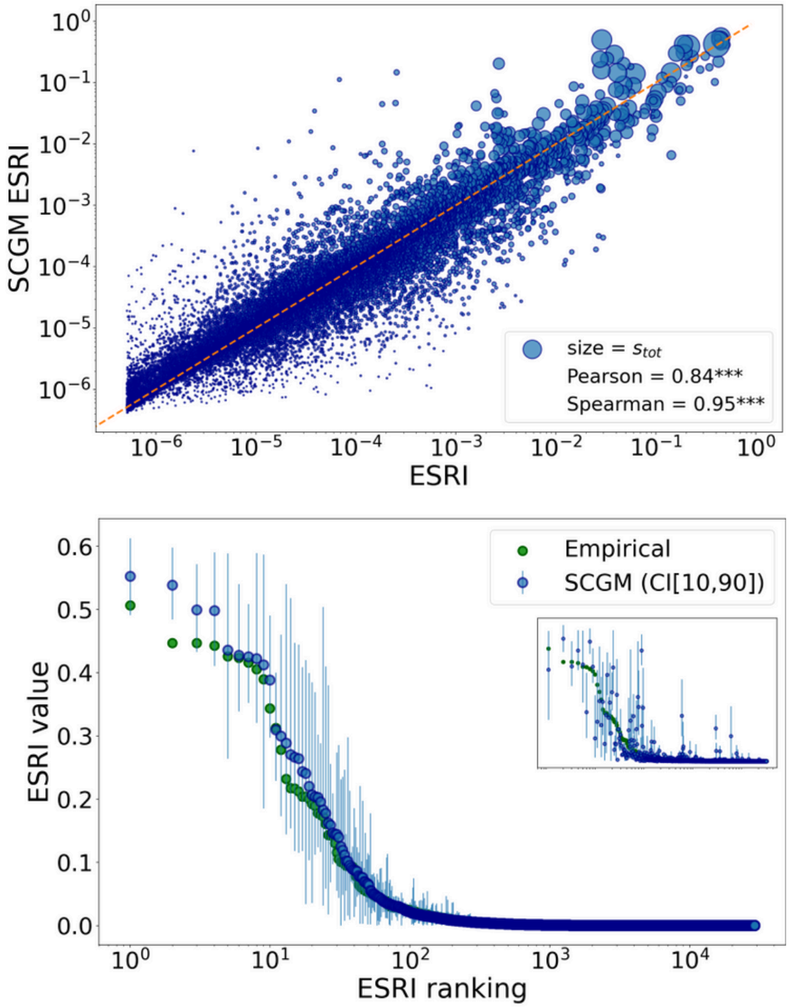
Economic systems are often analyzed using industry-level input-output tables

- This aggregation simplifies the analysis and ignores the fine-grained structure of supply chains
- However firms within the same industry are highly heterogeneous
- Aggregation leads to significant underestimation of production losses when assessing the impact of shocks.
- Firm-level networks reveal that losses can be up to 37% higher compared to industry-level models

Maximum Entropy Approaches

Maximum entropy methods provide a way to reconstruct firm-level networks

- Uses available aggregated data such as input-output tables and firm-level sectoral outputs
- Generates the most statistically unbiased network that satisfies known constraints (e.g., sector-wise sales and purchases)
- The best approach is the Stripe-Corrected Gravity Model (SCGM) that Preserves sector-specific input-output relationships



Fessina, Massimiliano, et al. *"Inferring firm-level supply chain networks with realistic systemic risk from industry sector-level data."* arXiv preprint arXiv:2408.02467 (2024).

Conclusions

Firms Output Networks

Firms can be studied looking at their outputs, such as products, patents or activities. A nested or block-nested structure is observed and the forecasting techniques we introduced for countries can be used.

Ownership and Directors Networks

Ownership Networks links firm in a directed graph following ownership relations. These links are often used to avoid taxation. This network is often related to the director network, obtain from the board of directors-firm bipartite network.

Supply Chains

Supply chain links all firms in an economy following exchange of products or services. These networks allow to predict the effect of shocks such as economic crisis and to guide policies.

Quiz

- What is the difference between tax evasion and tax avoidance?
- How many tax havens are there in Europe?
- What is the limit of country-level supply chains datasets?
- What are some recent event that caused a shock in the supply chain?