UNIVERSITÄT KONSTANZ

Economic Complexity

Network Science of Socio-Economic Systems

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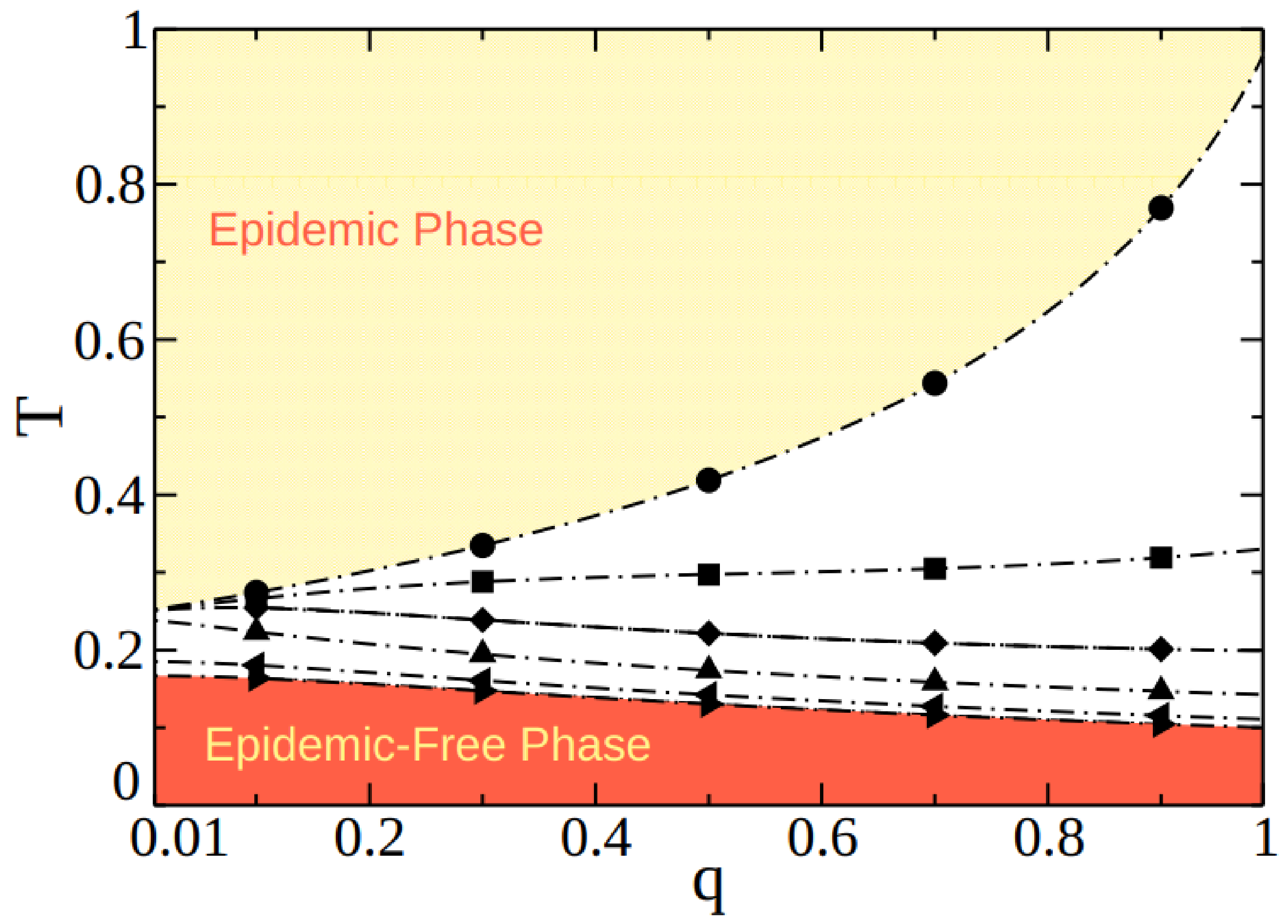


Recap

Multilayer Networks

Multilayer networks are a set of different networks, each belonging to a different layer.

Multiplex Networks

Multiplex networks are a subclass of multilayer networks, where the same set of nodes is found in every layer. We introduced the main properties of these networks.

Epidemics on multiplex networks

Epidemics spread on multiplex networks following different transport routes. The network with the lowest epidemic threshold dominates the dynamics.

Outline

1. Economic Complexity
2. Product Progression
3. Economic Complexity at Different Scales

Economic Complexity

Economy as a Complex System

The economy is a complex system where interactions between consumers, firms, and governments create

- Nonlinear behavior (e.g., financial crises).
- Emergent phenomena (inflation or economic growth)

Examples of this complexity include

- global trade networks
- financial systems with systemic risk
- the spread of technological innovations

Economic Complexity

Economic Complexity studies the structure and dynamics of economic systems using data-driven and network-based methods.

- **Founding Ideas**:
  - More data doesn't mean better understanding
  - Validation, tests and falsifiability
- **Main tools**:
  - Fitness and Complexity/Economic Complexity Index (nodes ranking)
  - Relatedness measures (nodes similarity)
- **Applications**
  - Identifying strategic industries or products for development.
  - Predicting future economic growth.

The Success of Economic Complexity

Often research done in accademia is not linked to the real world

- economic complexity is an exception
- many of the techniques developed in this field found application in the real world

Economic Complexity tools are used by many organizations and companies, including

- the World Bank
- the European Commission
- the International Labour Organization

Country-Product **Bipartite Network**

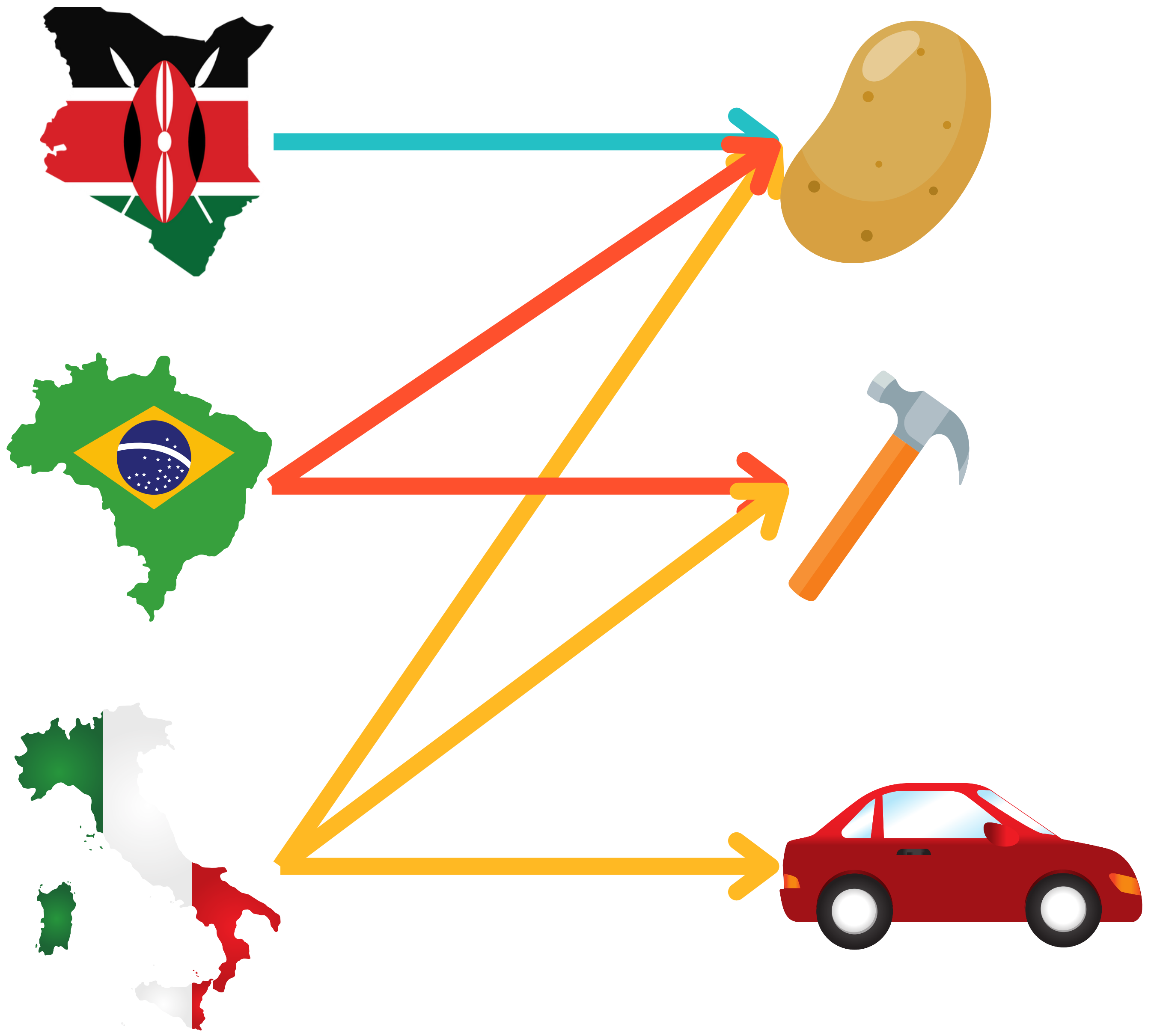
The products exported by a country summarize all its capabilities

- we go from hundreds of data to a single one
- we maximize signal to noise

We use UN Comtrade data to build the country-product bipartite network.

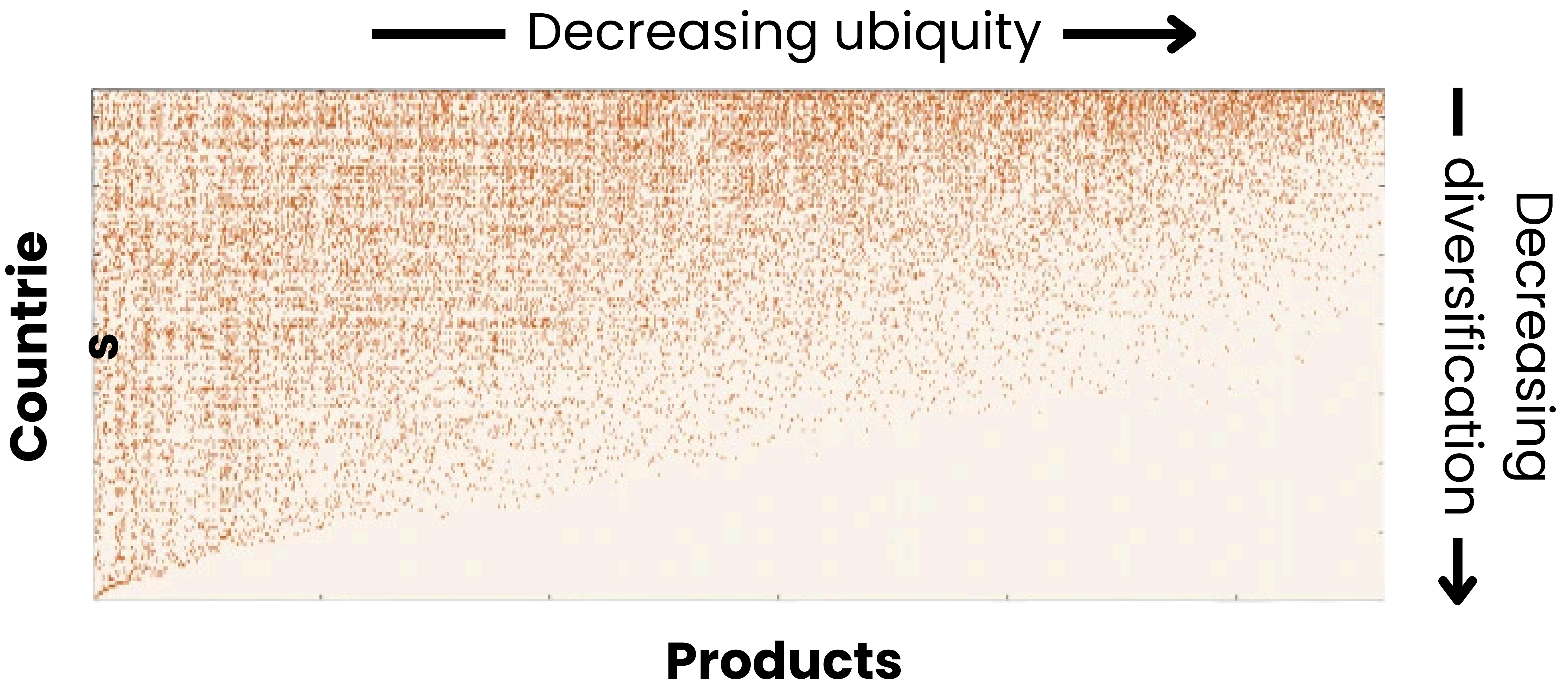
$$M_{cp} = \begin{cases} 1 \text{ if country } c \text{ export product } p \\ 0 \text{ otherwise} \end{cases}$$

Around 170 countries and 5000 products, more than 20 years.

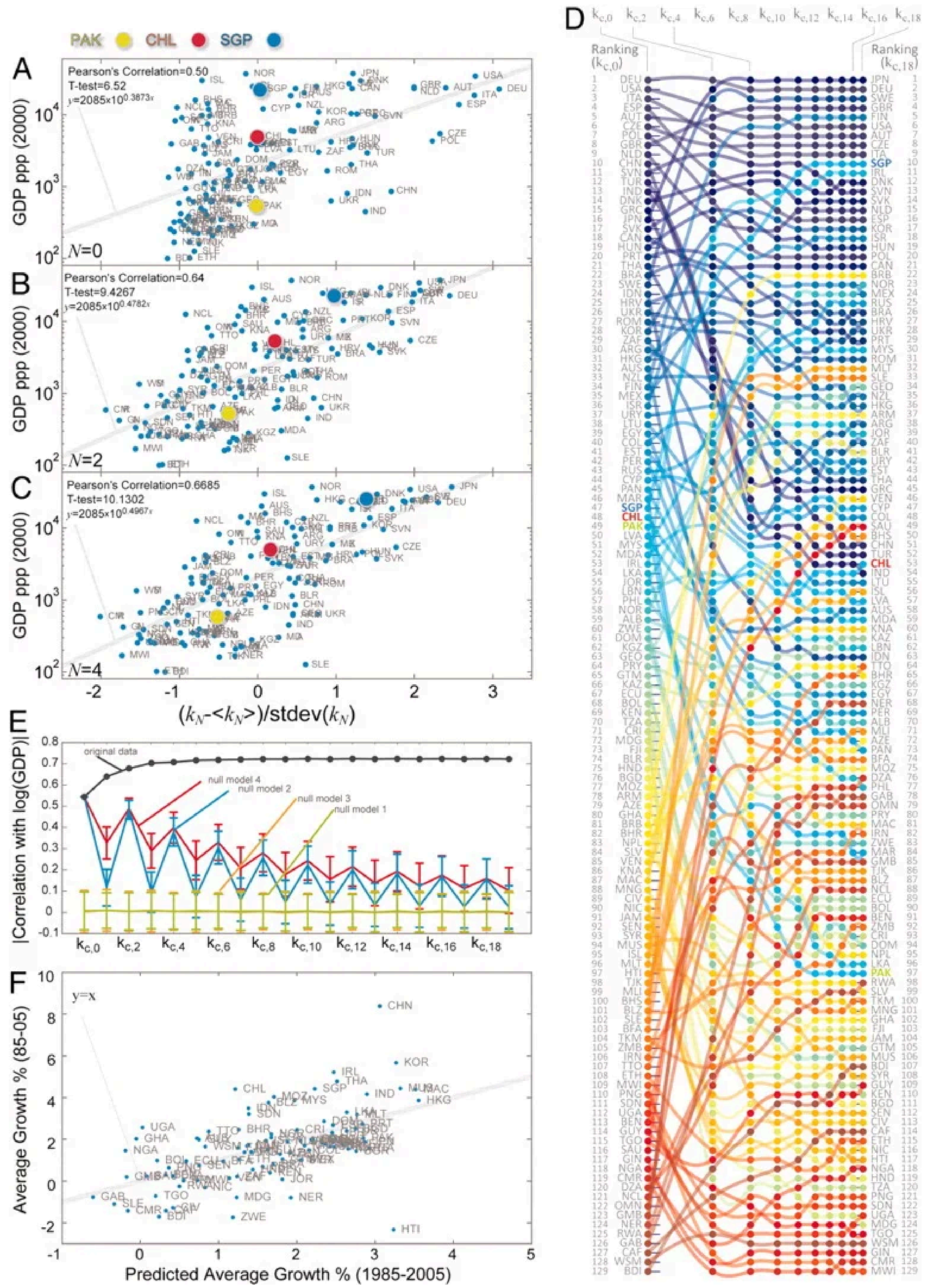


Nestedness

The country-product matrix shows a nested structure: diversification rather than specialization is the key factor!



Tacchella, A., Cristelli, M., Caldarelli, G., Gabrielli, A., & Pietronero, L. (2012). A new metrics for countries' fitness and products' complexity. Scientific reports, 2(1), 723.



The Economic Complexity Index

The Economic Complexity Index measures a country's productive capabilities based on the diversity and sophistication of the products it exports

$$k_{c,N} = \frac{1}{k_{c,0}} \sum_{p} M_{cp} k_{p,N-1}, \qquad k_{c,0} = \sum_{p} M_{cp},$$

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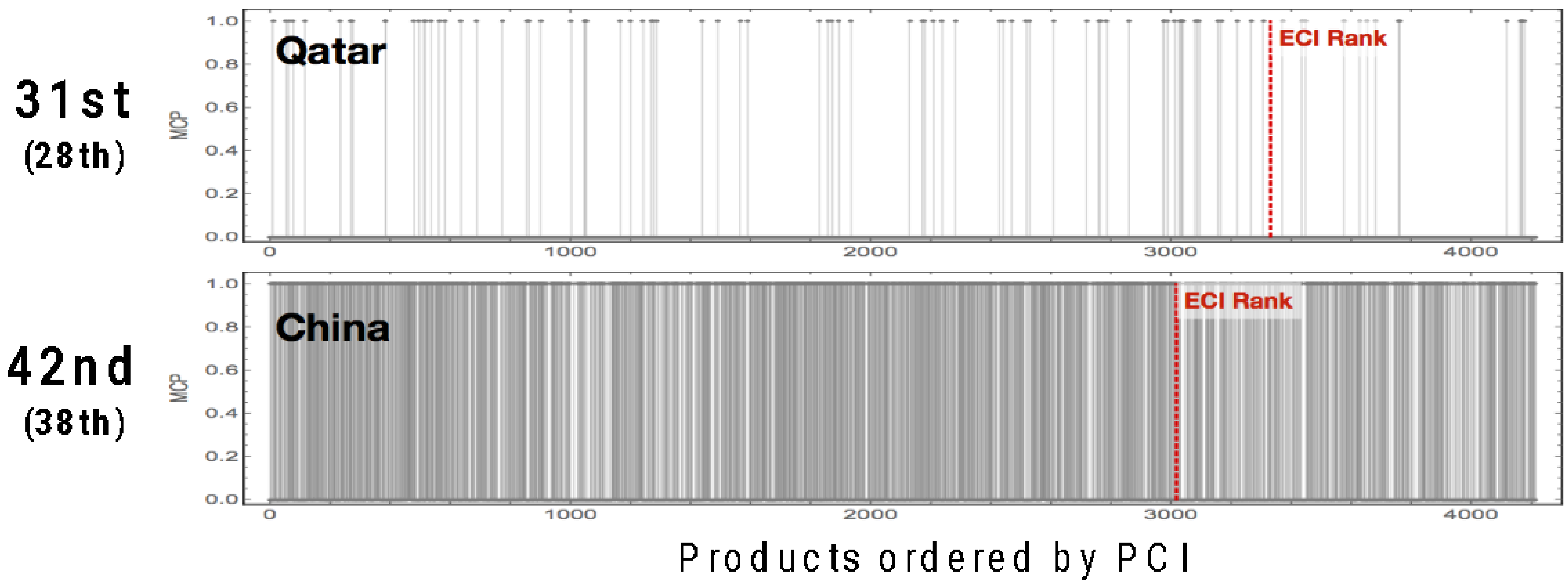
Hidalgo, C. A., & Hausmann, R. (2009). *The building blocks of economic complexity.* Proceedings of the national academy of sciences, 106(26), 10570-10575.

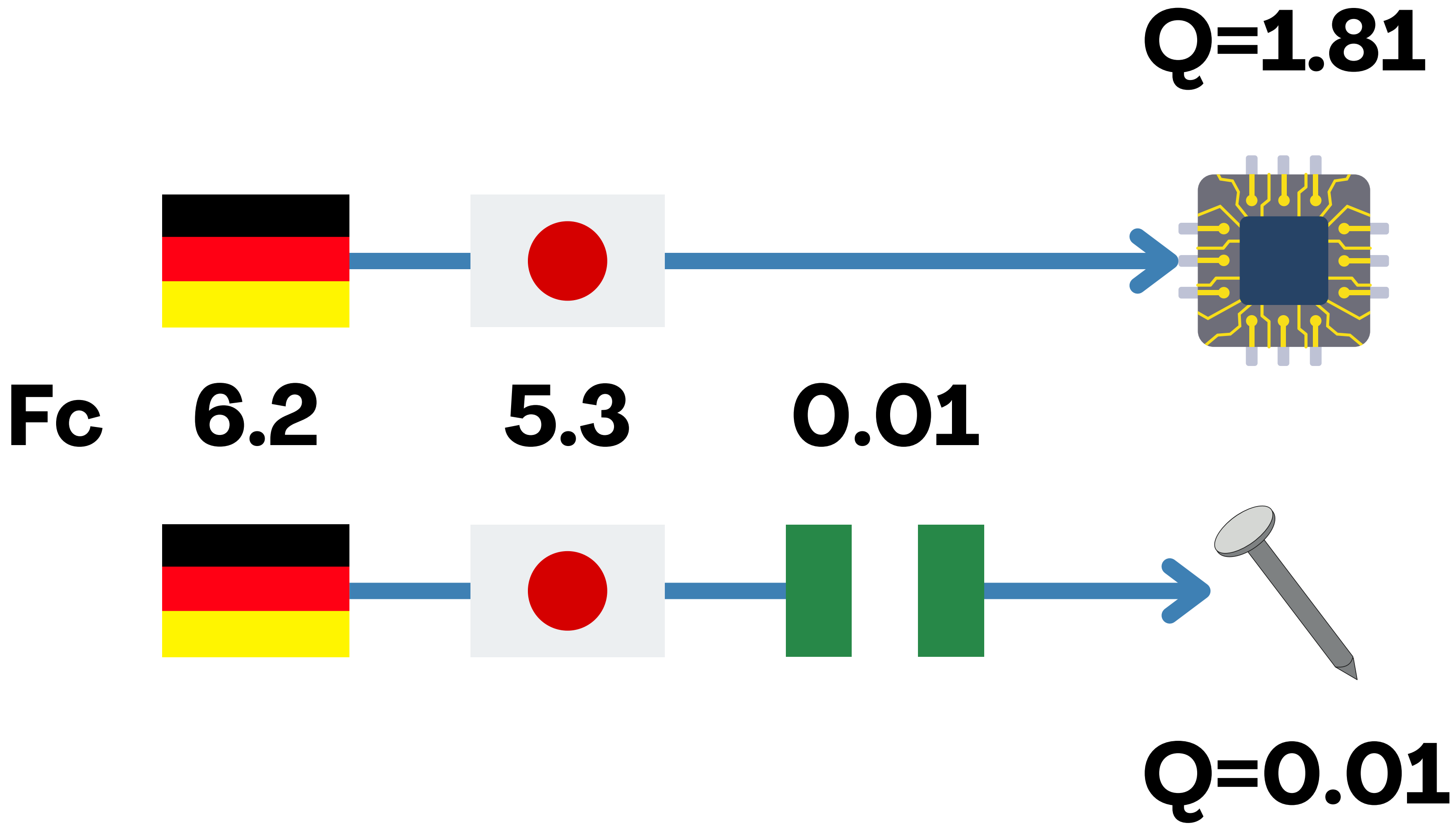
Limits of ECI

The Economic Complexity Index has several problems
- convergence issues
- it completely disregards diversification
- it's just a liner algorithm

ECI World (2015) (Reliability problems)



Economic Fitness and Complexity



Cristelli, M., Gabrielli, A., Tacchella, A., Caldarelli, G., & Pietronero, L. (2013). *Measuring the intangibles: A metrics for the economic complexity of countries and products.* PloS one, 8(8), e70726.

The goal is to quantify countries' capabilities and products' complexity

- a non linear algorithm is crucial
- Economic Fitness and Complexity (EFC) algorithm better captures the system's features

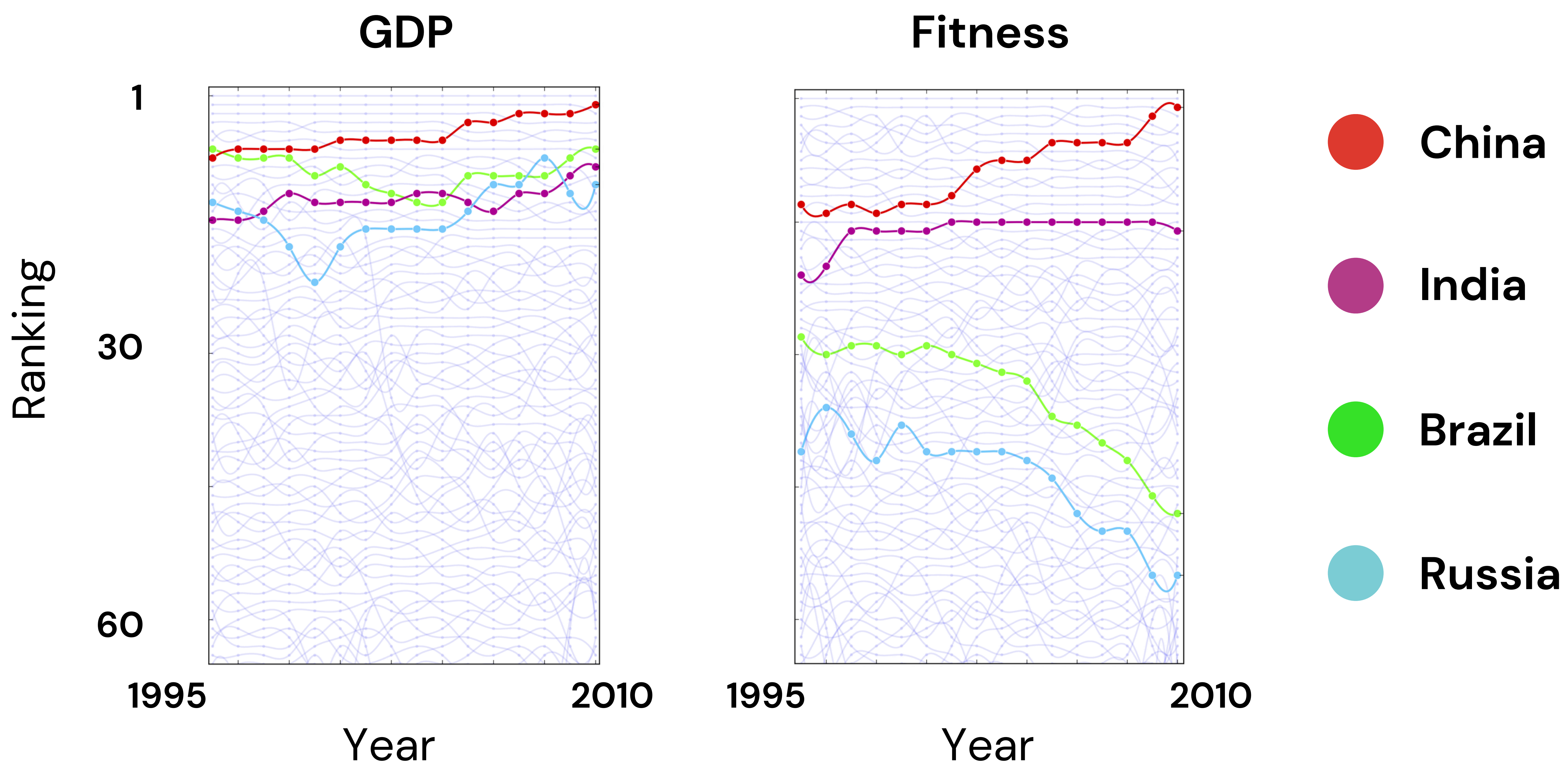
$$F_c^{(n)} = \sum_p M_{cp} Q_p^{(n-1)}$$

$$Q_p^{(n)} = \frac{1}{\sum_c M_{cp} \frac{1}{F_c^{(n-1)}}}$$

The idea is that the countries giving more information are those only exporting few, low complexity products

Example: BRIC Countries

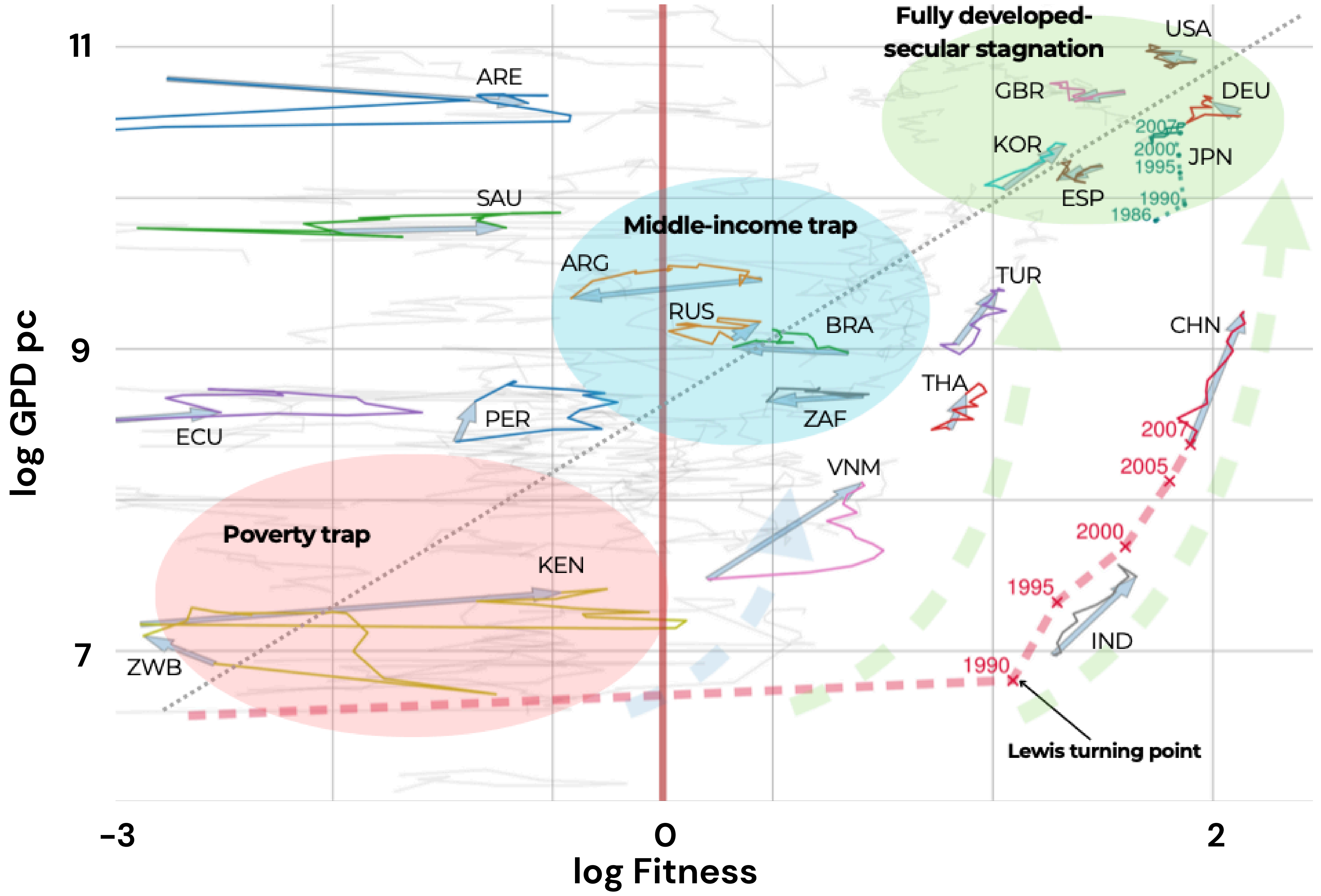
The Economic Fitness opens a new dimension. Countries that look similar when inspecting their GPD may have a completely different Fitness dynamics.



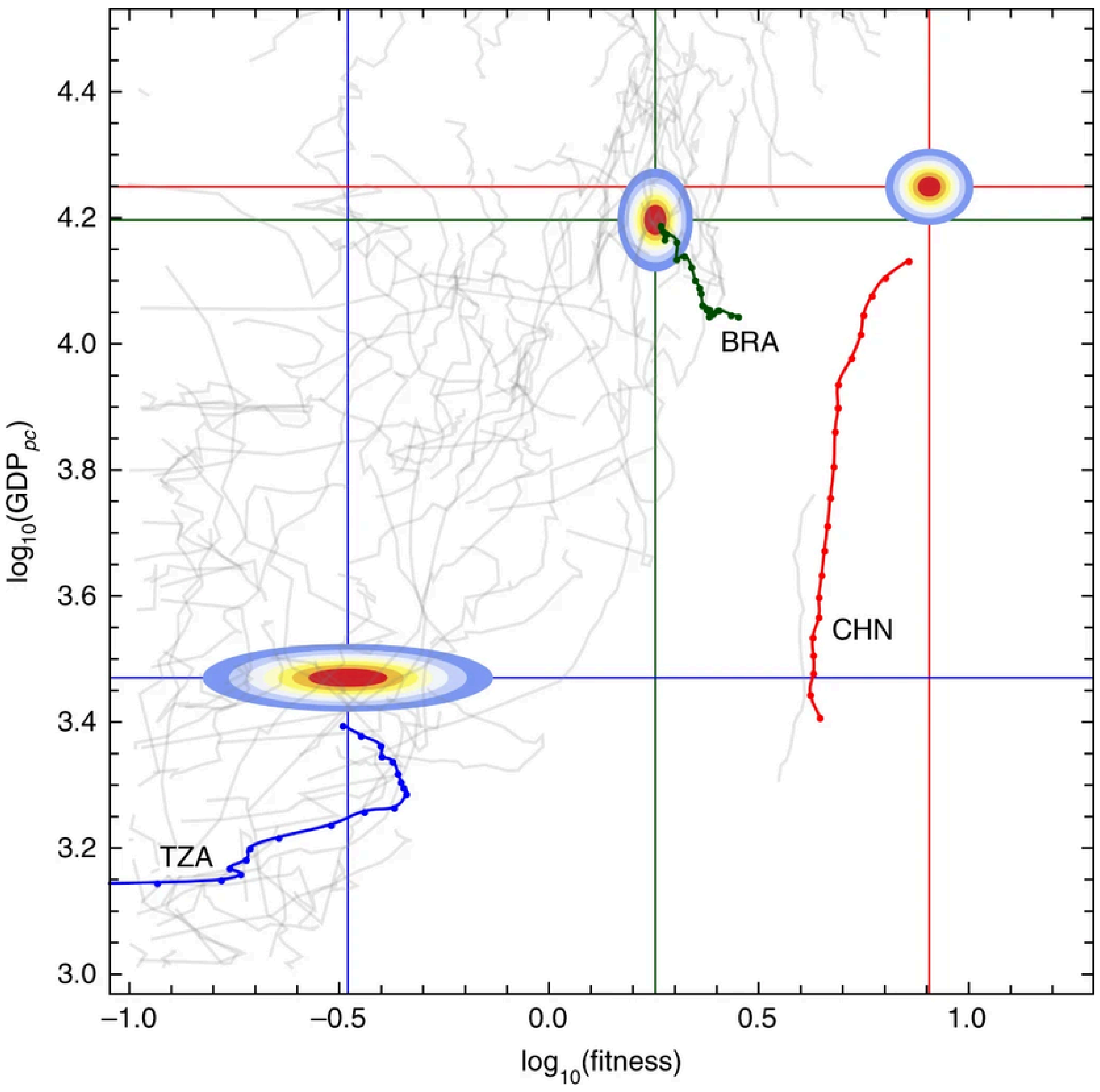
Fitness-GDP Plane

We can take advantage of the new dimension looking at the fitness gdp plane

- there are four quadrants
- china and india moved from the bottom right corner
- the top left corner contains oil producers
- countries tend to align along a diagonal



Forecasting Growth



Tacchella, A., Mazzilli, D., & Pietronero, L. (2018). *A dynamical systems approach to gross domestic product forecasting*. Nature Physics, 14(8), 861-865.

We can do GDP back forecasts to test the Fitness

- predictions with the methods of analogs
  - we look at what close countries did in the past
  - closeness is defined on the fitness-gdp plane

This procedure returns state of the art performances, better than IMF

- the technique has been adopted by the World Bank
- fitness is one of the parameter they use for measuring the development of countries

Product Progression

Forecasting Industrial Development

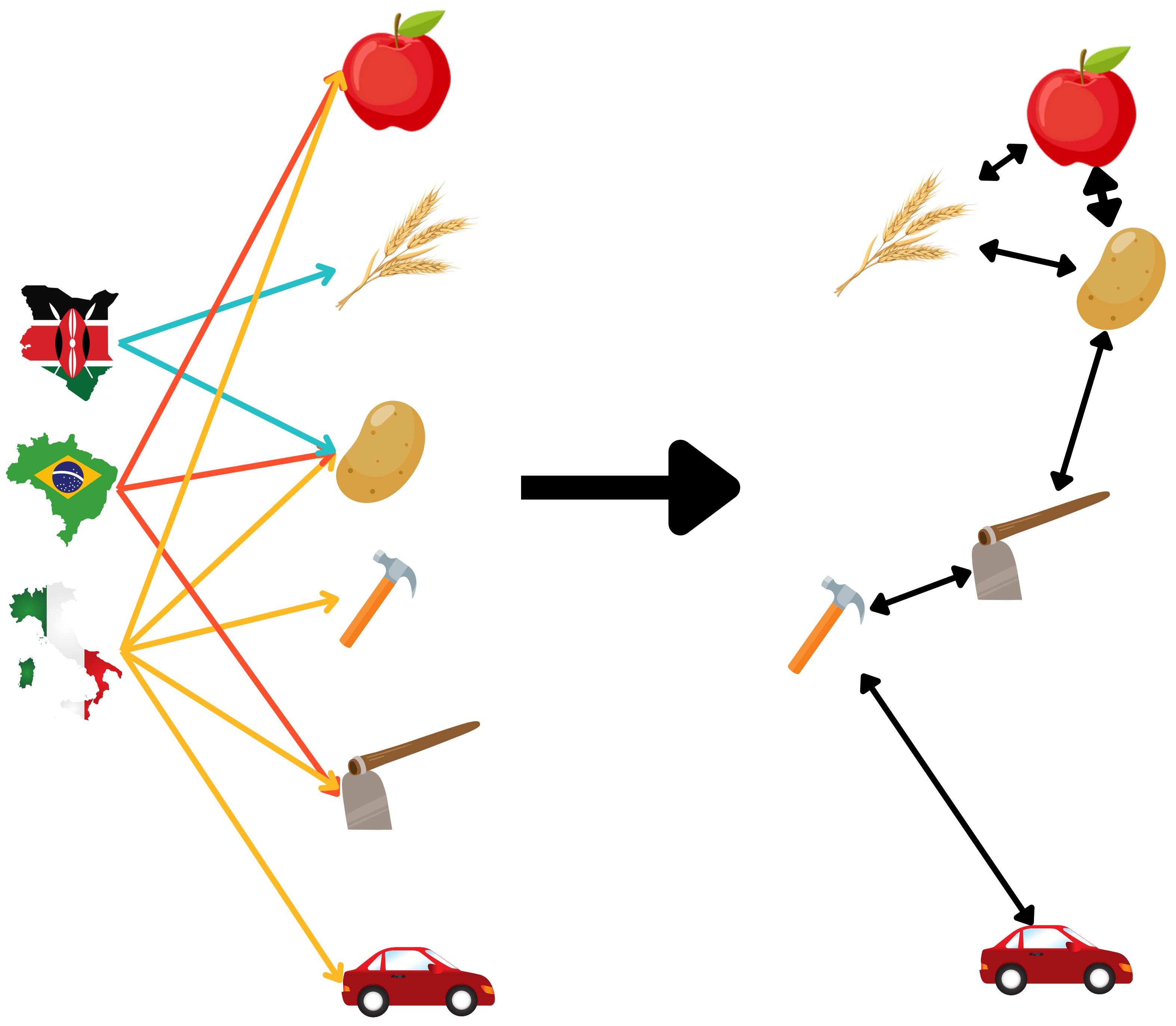
Predicting how countries develop their industrial capabilities is a crucial challenge in understanding economic growth and crafting effective policies

- The process involves understanding how nations transition from exporting basic goods to producing more complex, high-value products
- This progression is driven by the accumulation of capabilities—skills, technologies, and infrastructure

Understanding and forecasting industrial development is essential for policymakers and businesses

- It reveals potential opportunities for diversification
- identifies critical gaps in capabilities
- guides strategies to accelerate economic growth

With these insights, countries can design targeted interventions to climb the ladder of economic complexity



Relatedness

We want to quantify the similarity between products

- we can then use this simularity to forecast product progression

The basic idea is to use co-occurences

- if two products often co-occur they are similar
- we have to consider spurious effects
- many approaches (product space, taxonomy network ...)

$$C_{pq} = \sum_c M_{cp} M_{cq}$$

The **Product** Space

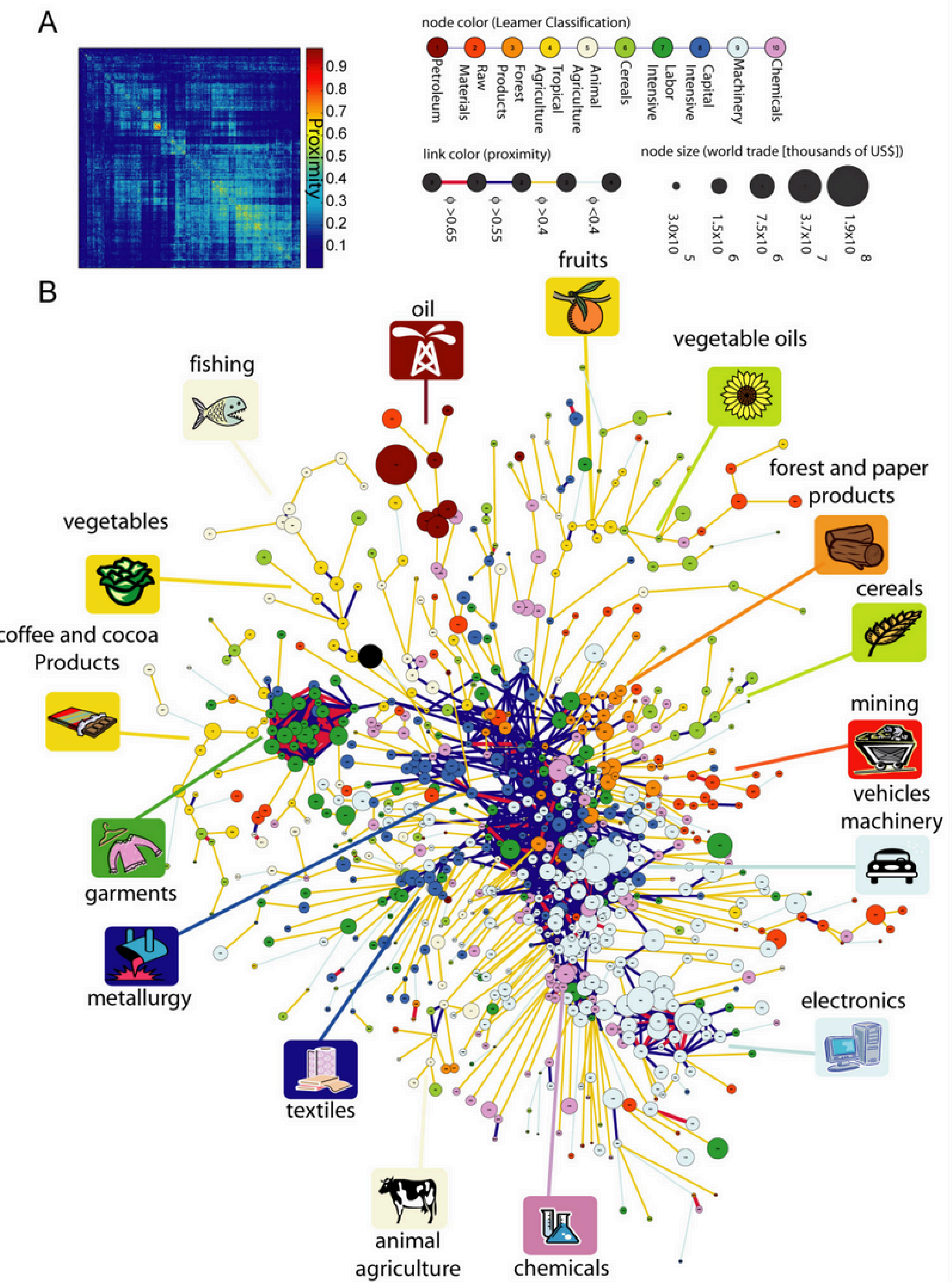
Let Mcp be the country-product bipartite matrix

- the product space connects products that require similar capabilities
- mathematically it is defined using co-occurrences

$$\phi_{p,q} = \frac{\min(P(p|q), P(q|p))}{\max(P(p|q), P(q|p))},$$

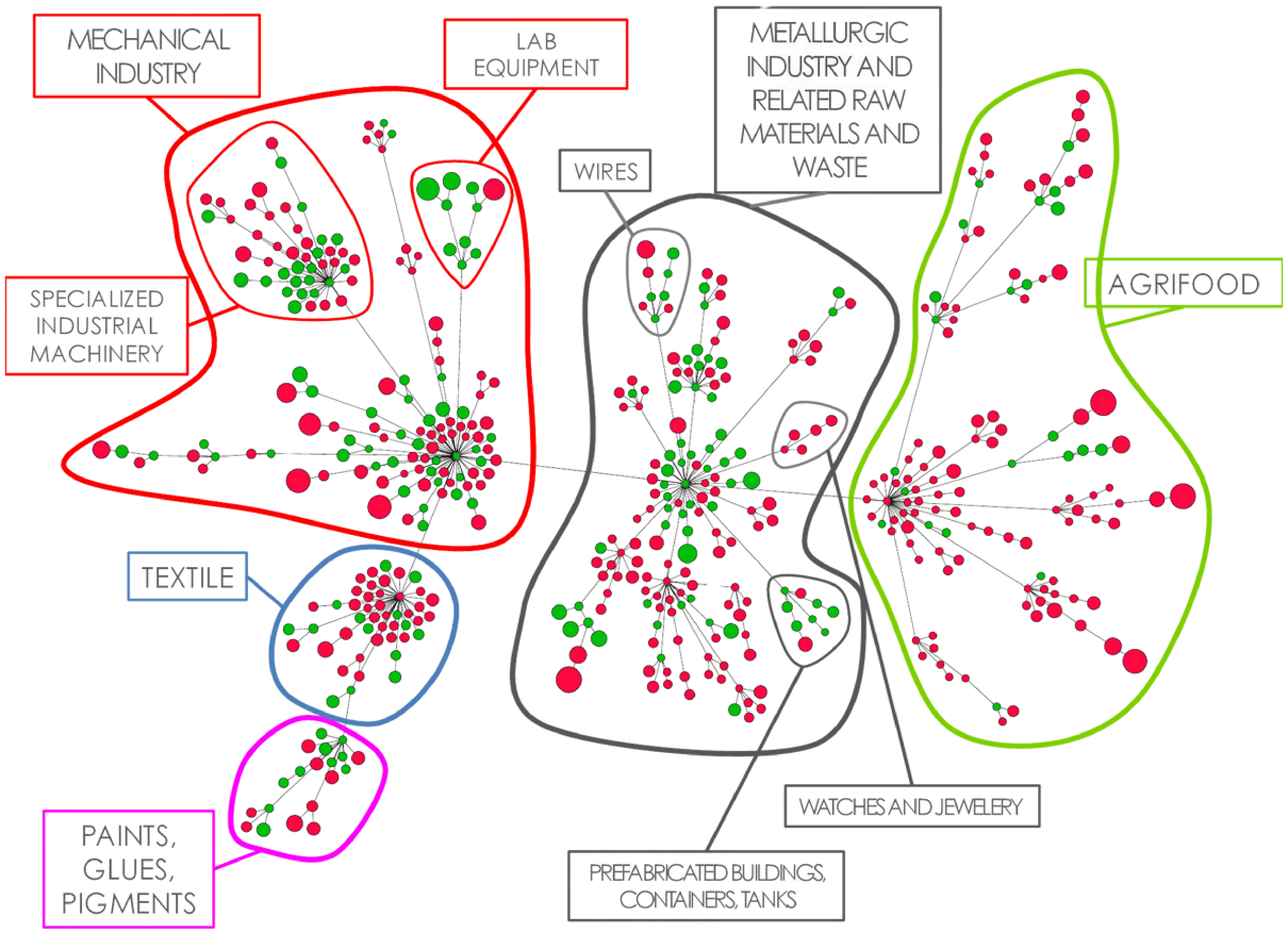
$$P(p|q) = \frac{\sum_c M_{cp} M_{cq}}{\sum_c M_{cq}}.$$

- the product space is symmetric and measures mutual relations



Hidalgo, César A., et al. "*The product space conditions the development of nations.*" Science 317.5837 (2007): 482-487.

Taxonomy Network



The Taxonomy Network is a hierarchical representation of products

- It captures causality between products
- simpler products are prerequisites for more complex ones
- cooccurrences are corrected taking into account ubiquity and diversification

$$d_c = \sum_p M_{cp} \qquad u_p = \sum_c M_{cp}.$$

$$B_{pp'} = \frac{1}{\max\left(u_p, u_{p'}\right)} \sum_c \frac{M_{cp} M_{cp'}}{d_c}$$

- only the strongest link is retained, forming a directed network

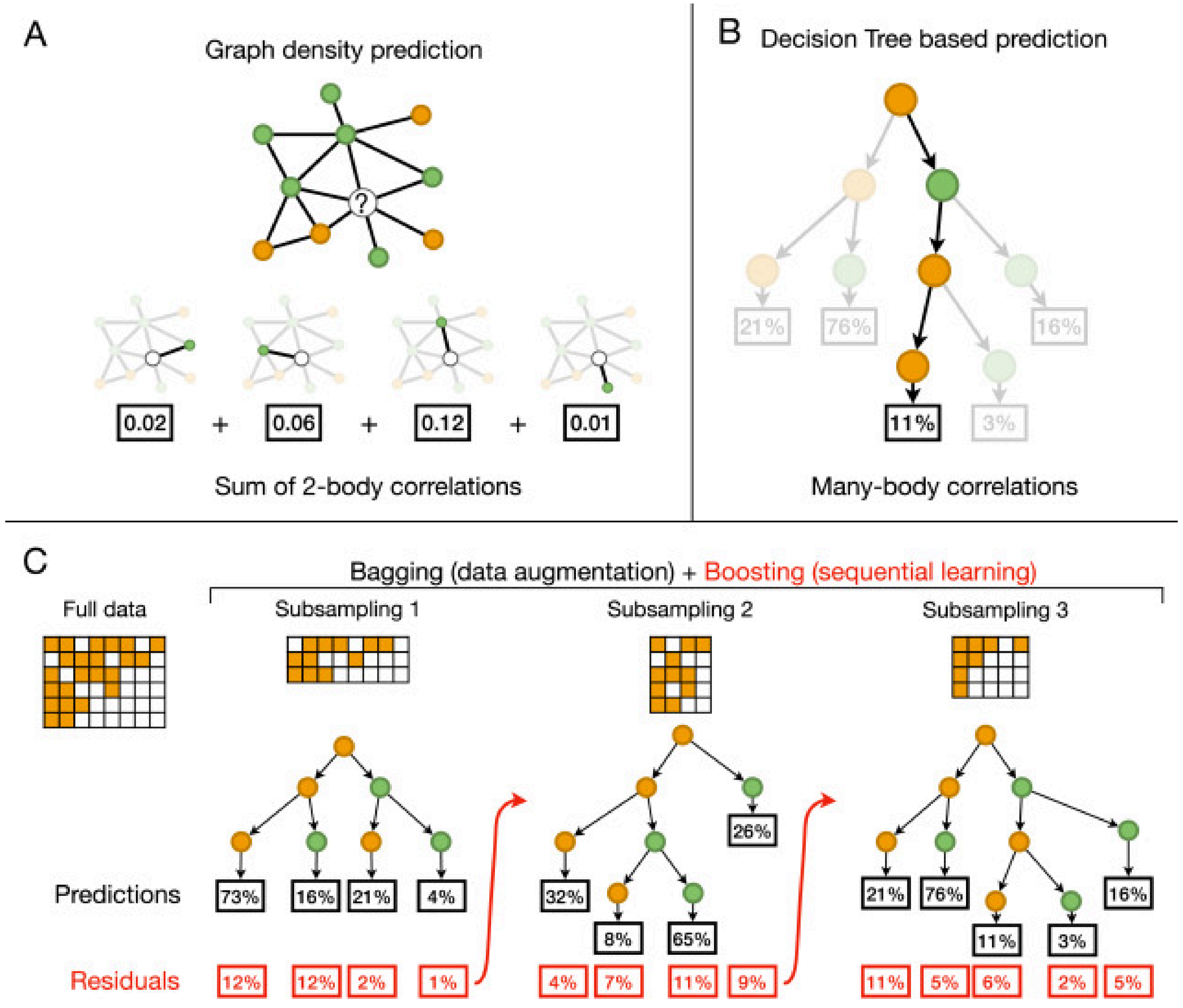
Zaccaria, Andrea, et al. "*How the taxonomy of products drives the economic development of countries.*" PloS one 9.12 (2014): e113770.

Networks vs **Machine Learning**

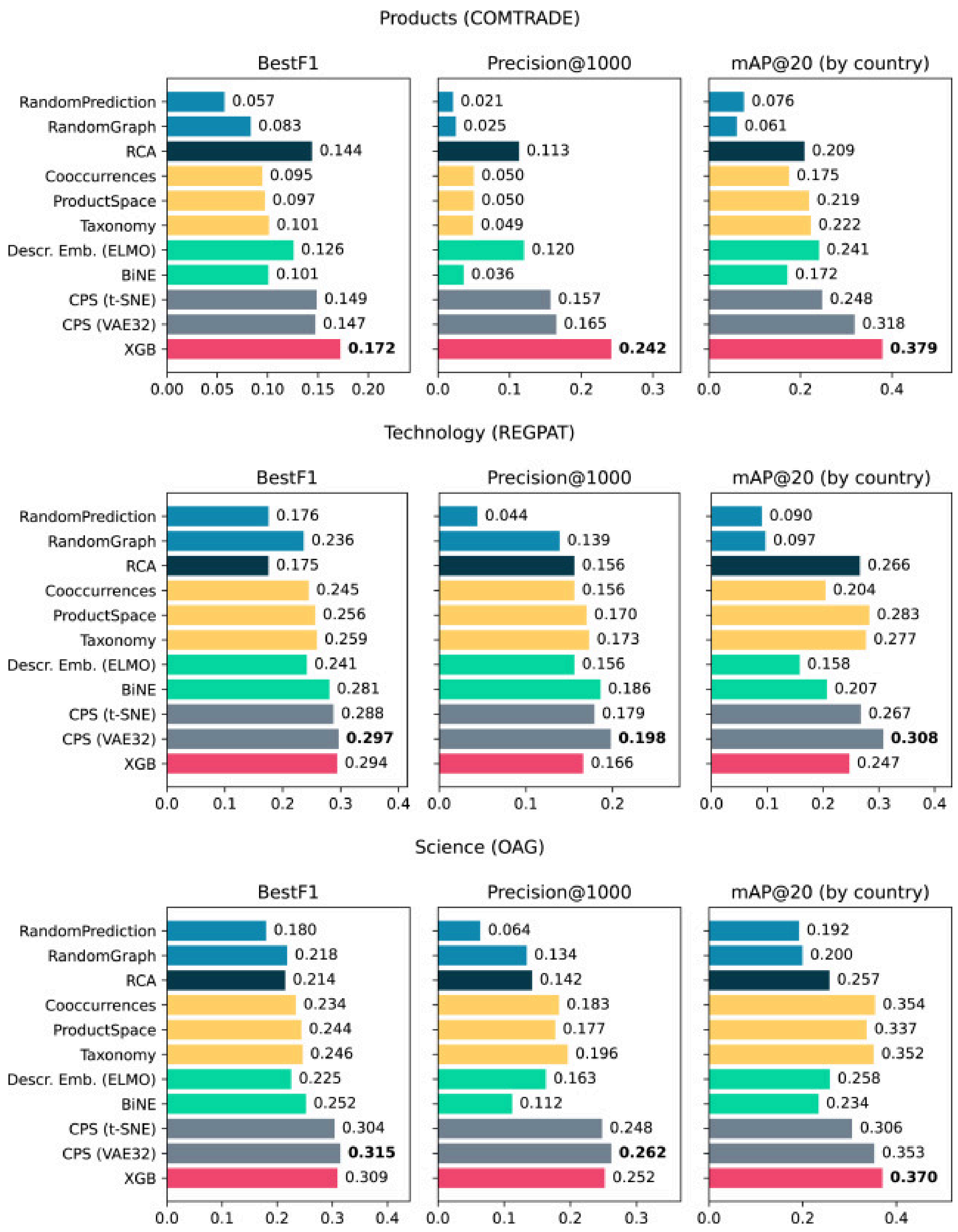
Network-Based approaches Relies on two-body correlations, examining pairwise relationships between products

- there are more complex higher order interactions
- complex patterns of presence/absence across multiple products

These can be captured using decision trees and machine learning



Tacchella, Andrea, et al. "*Relatedness in the era of machine learning.*" Chaos, Solitons & Fractals 176 (2023): 114071.



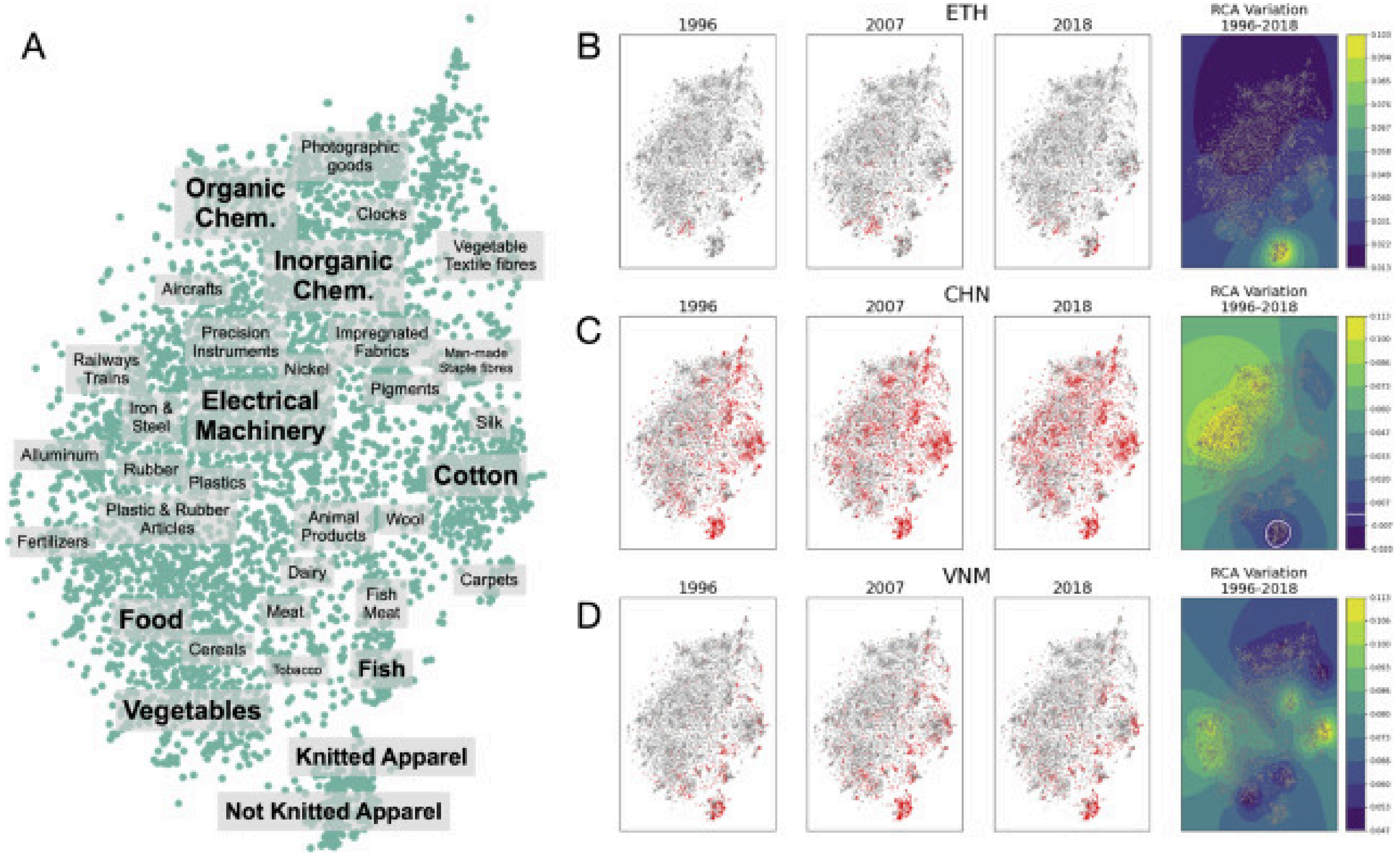
Performances

Different approaches can be evaluated using link prediction tasks on datasets like COMTRADE, REGPAT, and OAG.

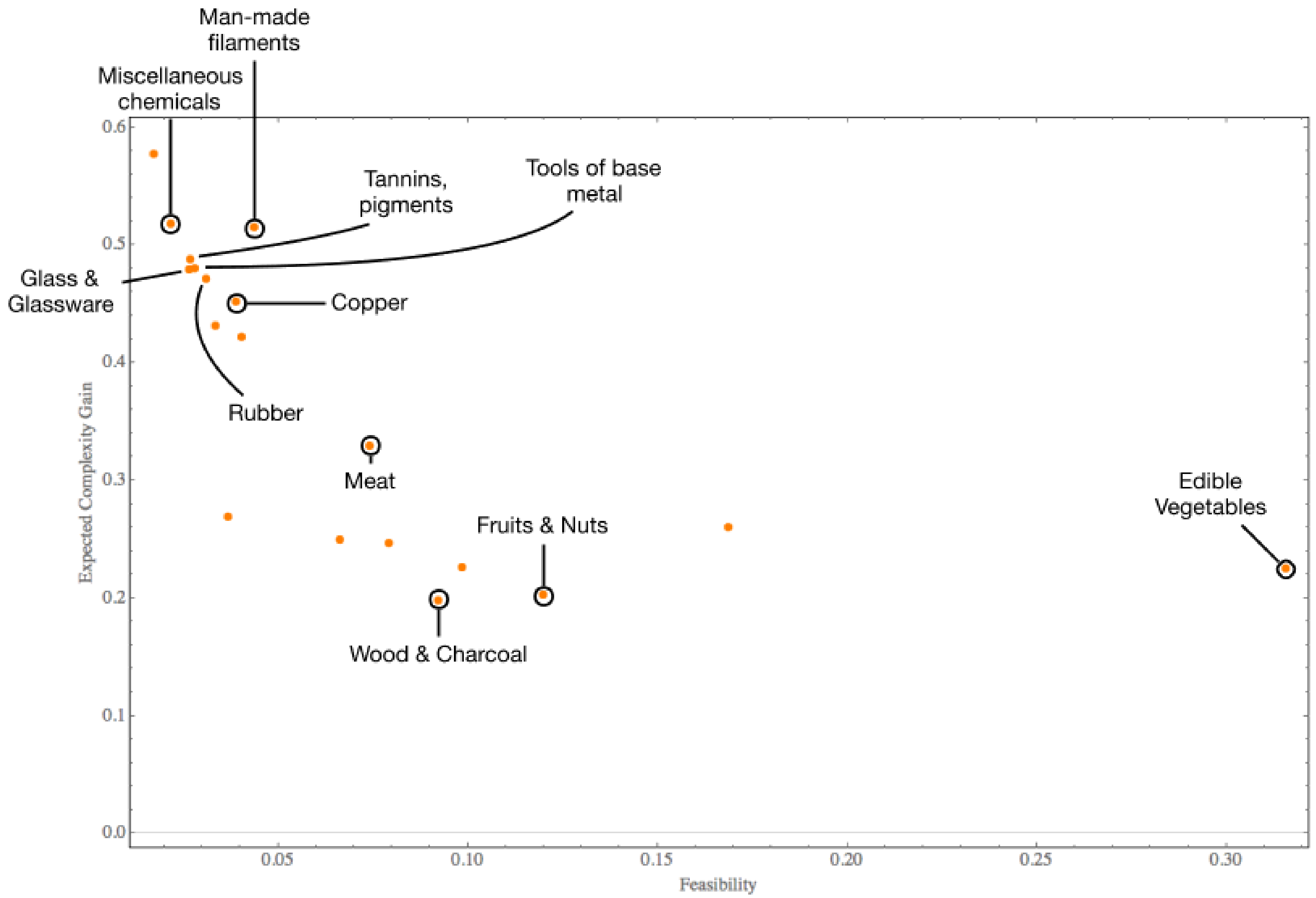
1. Network-Based Approaches:
   - Moderate performance often close to baseline
   - Fails to capture higher-order relationships
2. Decision Tree-Based Approaches:
   - Outperforms network-based methods significantly
   - Excels in forecasting new activities

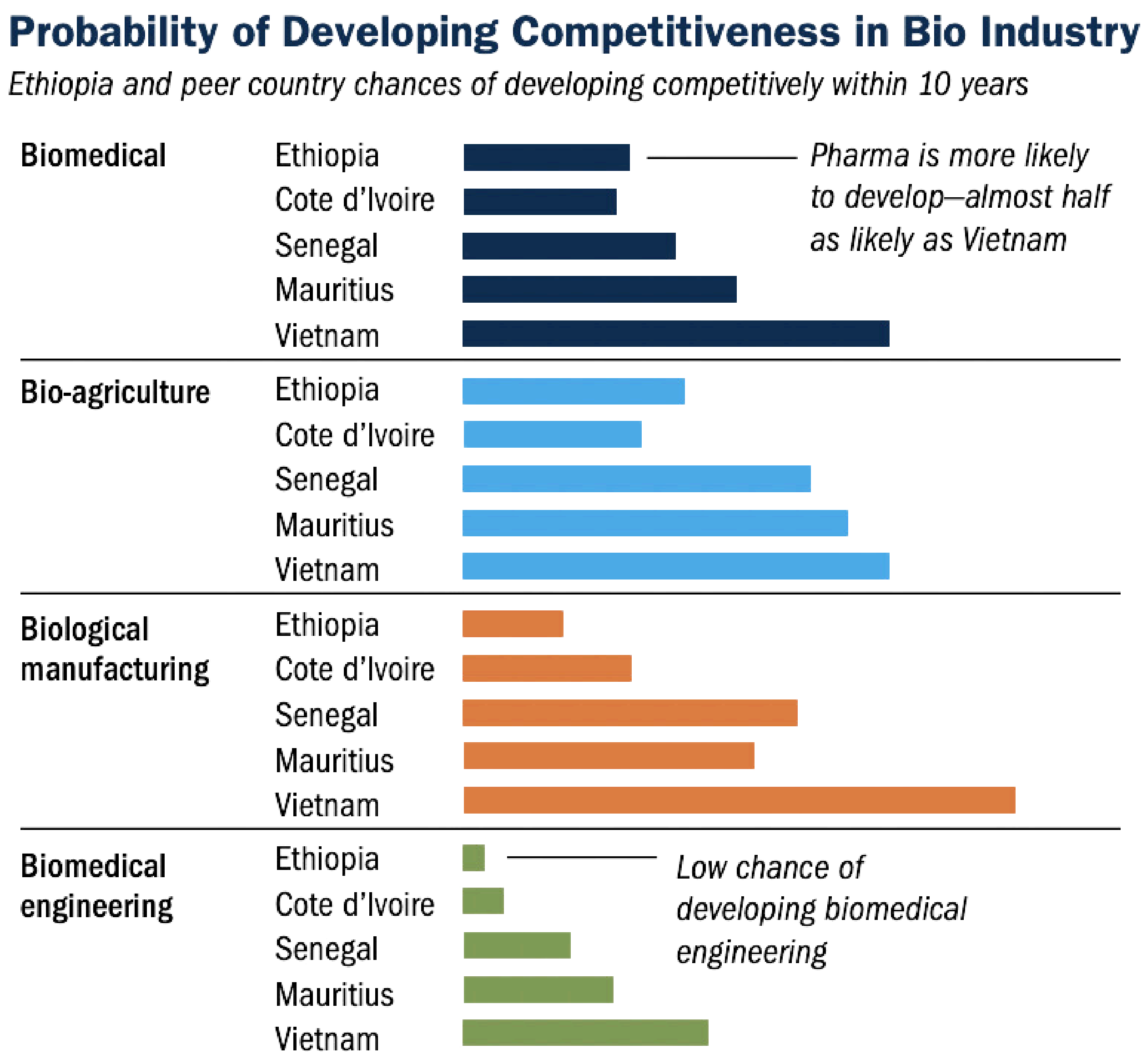
Continuous Projection Space

- Continuous Projection Space (CPS) is an embedding technique combining interpretability of networks with predictive power



Guiding **Development**



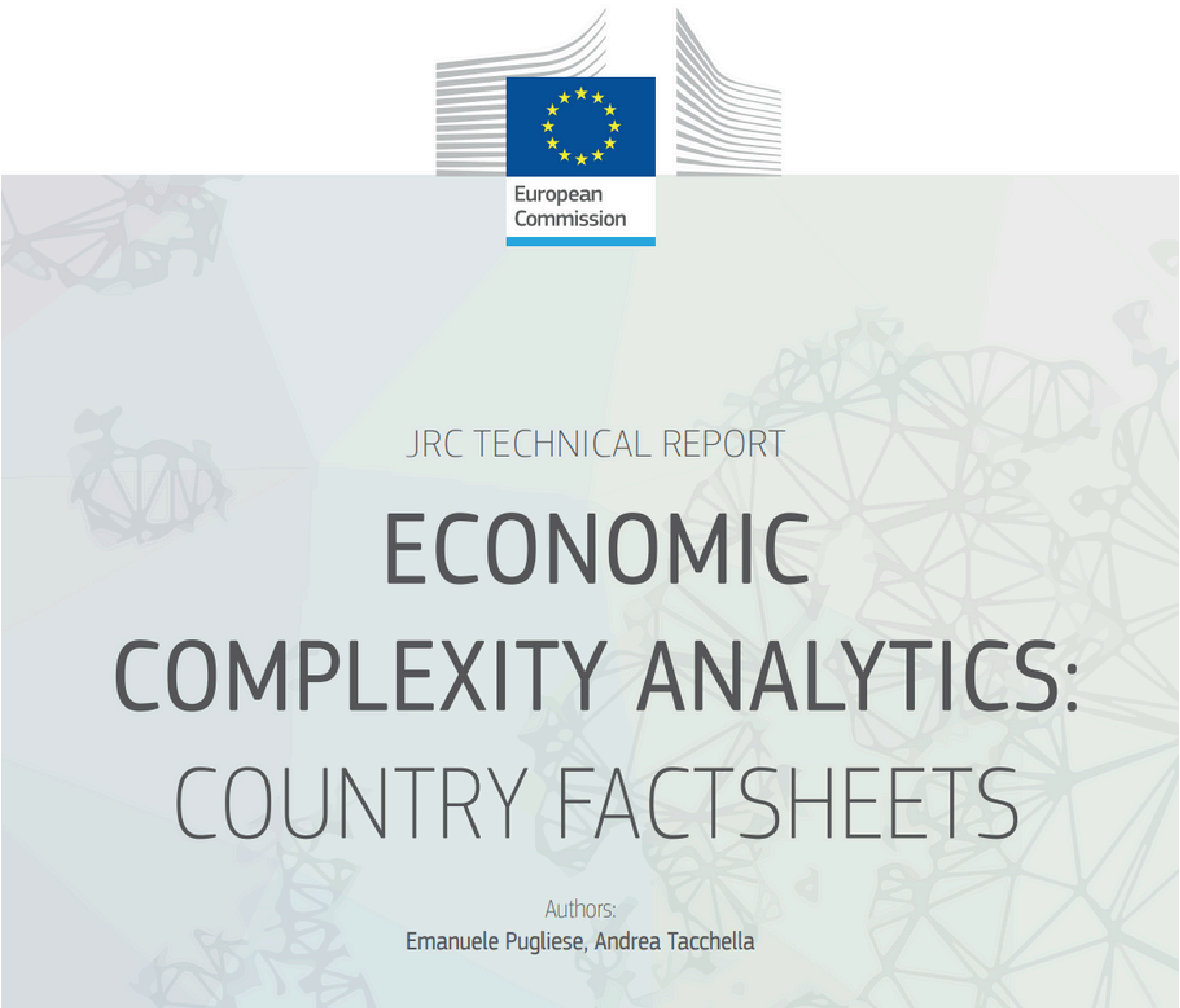


IFC International Finance Corporation WORLD BANK GROUP
Creating Markets, Creating Opportunities

Justin Lin, Masud Cader, and Luciano Pietronero. What African Industrial Development Can Learn from East Asian Successes IFC – WB, EM Compass Note 88, (2020)

EU Economic Complexity

"In these factsheets we provide an overview of quantitative facts for the 27 EU member countries resulting from the Economic Complexity analysis. The analyses range from forecasts of countries' economic performances, over a breakdown into industrial sectors, to an analysis of innovation capabilities down to the regional level with a product by product resolution."



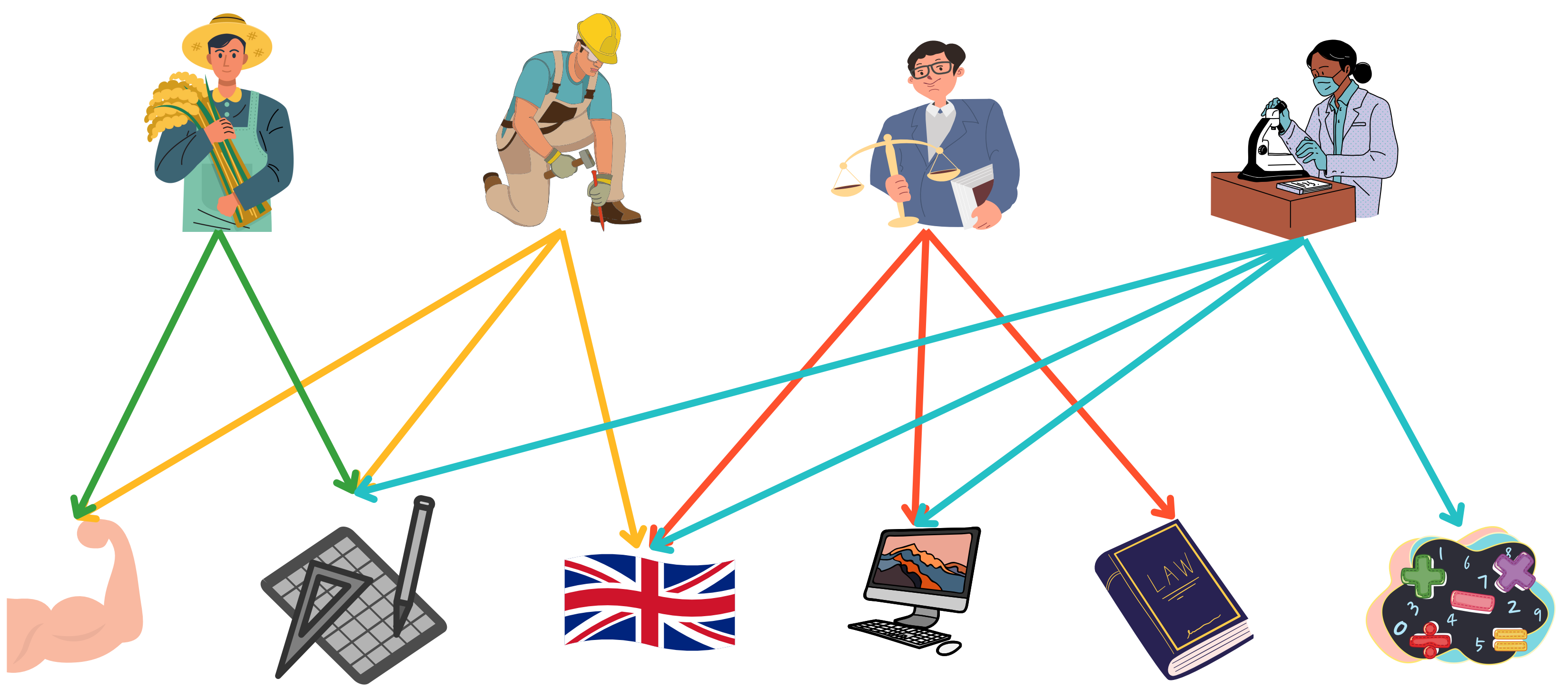
Economic Complexity at Different Scales

The Multiple Scales of Economy

Economic systems operate across a spectrum of scales, from the macro level of countries and industries to the micro level of individuals and their skills

- **Macro Level:** Countries and Products
  - At this scale, countries are seen as collective entities producing and trading goods.
- **Meso Level:** Regions, Provinces, and Cities
  - Economic activity is often concentrated in specific areas within countries, creating hubs of innovation and specialization.
  - Regions and cities act as engines of economic growth, influenced by their geographical, cultural, and industrial contexts.
- **Micro Level:** Firms and Individuals
  - Firms: The building blocks of industries, firms drive economic activity through innovation, competition, and specialization.
  - Individuals: Skills, education, and mobility of people form the foundation of productivity and innovation.

Occupation-Skill Bipartite Network



At the lowest level capabilities are directly linked to individuals

- we can look at the occupation-skill bipartite network
- skills are

We use ONET data to build the Job-Skill bipartite network:

- US data
- around 450 occupational categories
- around 70 different skills

Aufiero, Sabrina, et al. "*Mapping job fitness and skill coherence into wages: an economic complexity analysis.*" Scientific Reports 14.1 (2024): 11752.

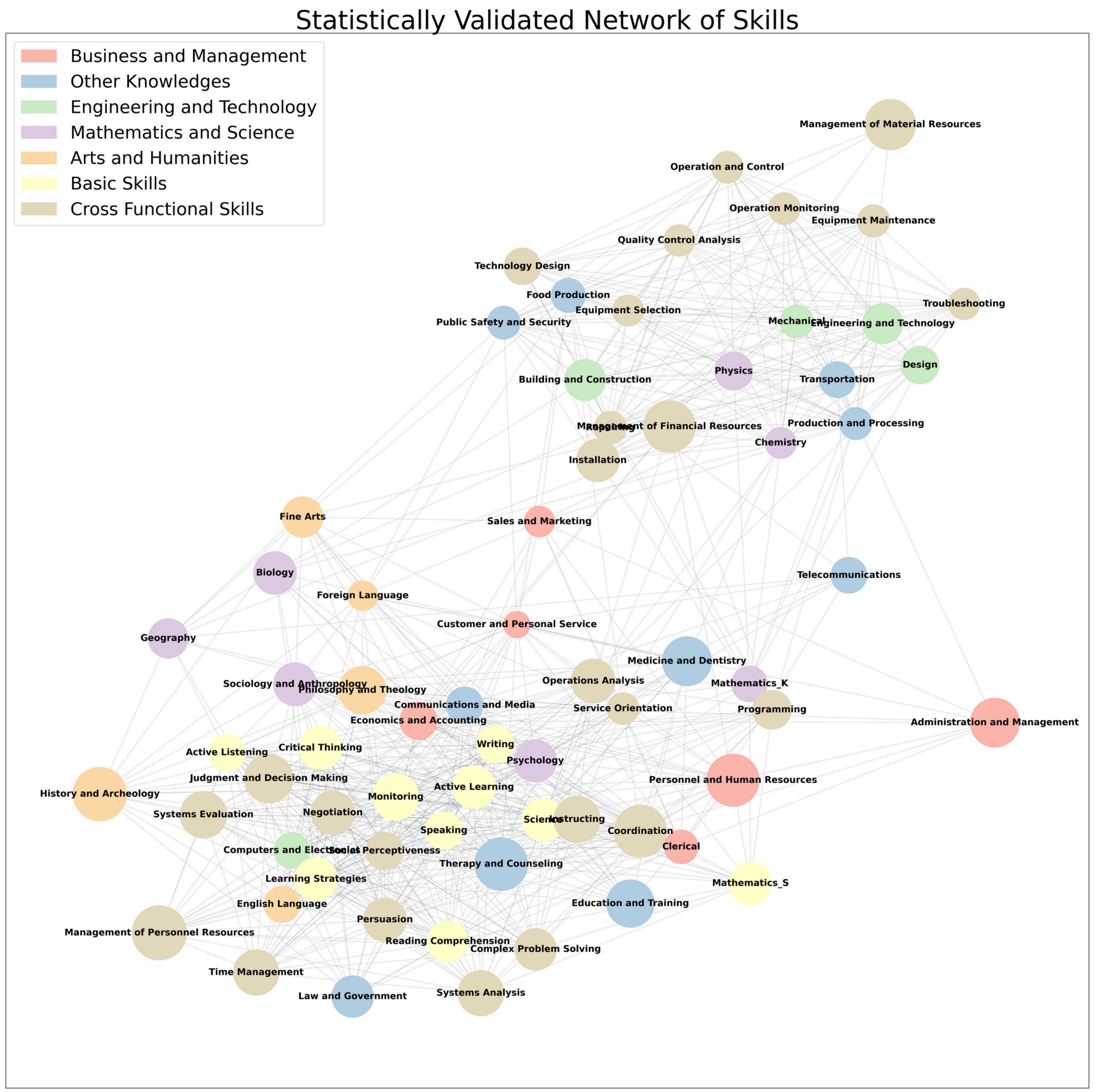
Skill Network

We can project the bipartite network to get the network of skills

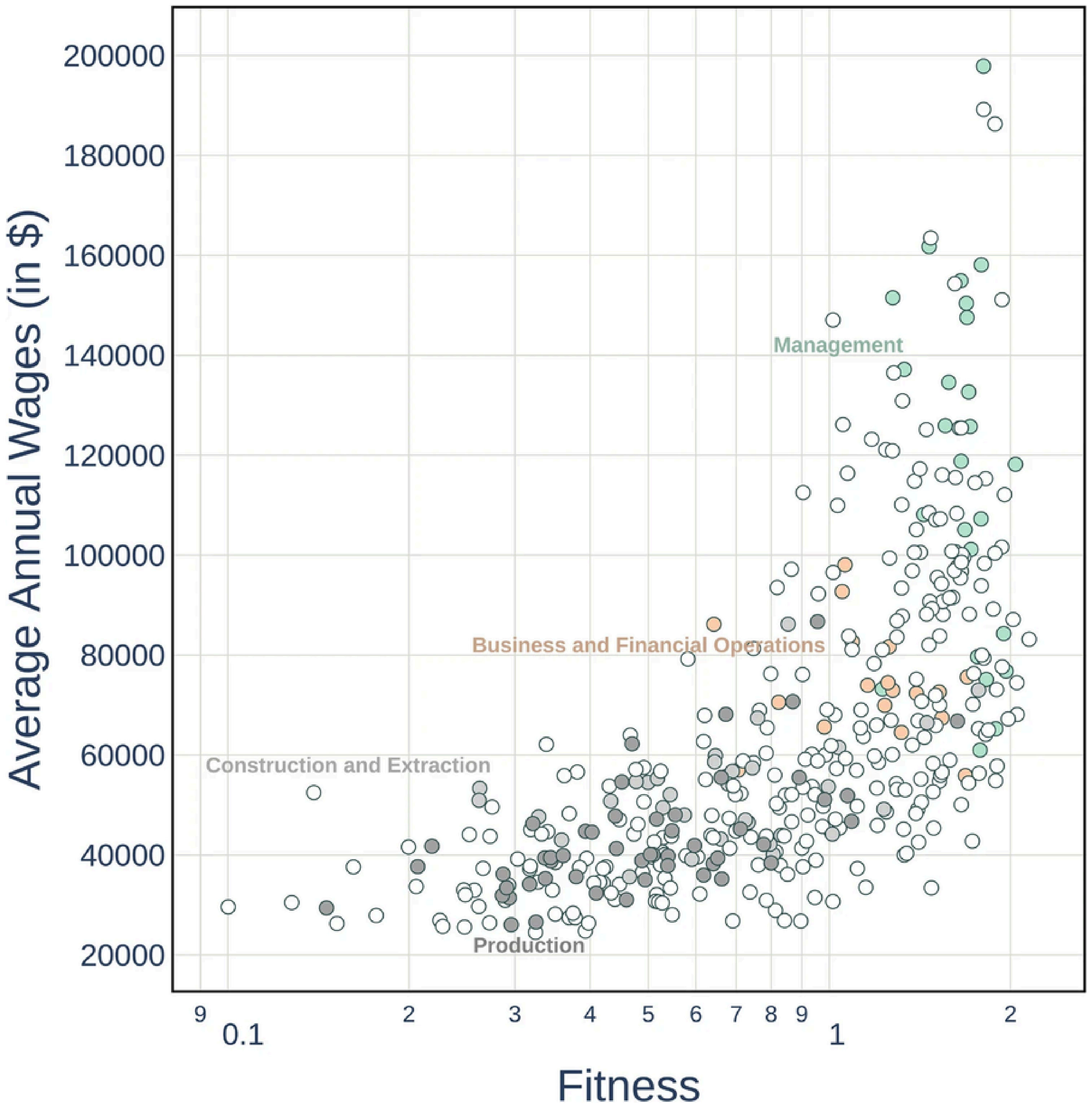
- we use the same approach of the taxonomy network
- we also apply the bipartite configuration model to filter out spurious links

We detect two distinct communities

- The first community is associated with industrial production processes
- The second community contains more abstract skills



Fitness of Occupations



We can measure the skill content of occupation using the fitness and complexity algorithm

- this assigns a fitness to each occupation
- high fitness occupation require many complex skills

We observe a correlation between fitness and wages

- however occupations with similar fitness may have a huge pay difference

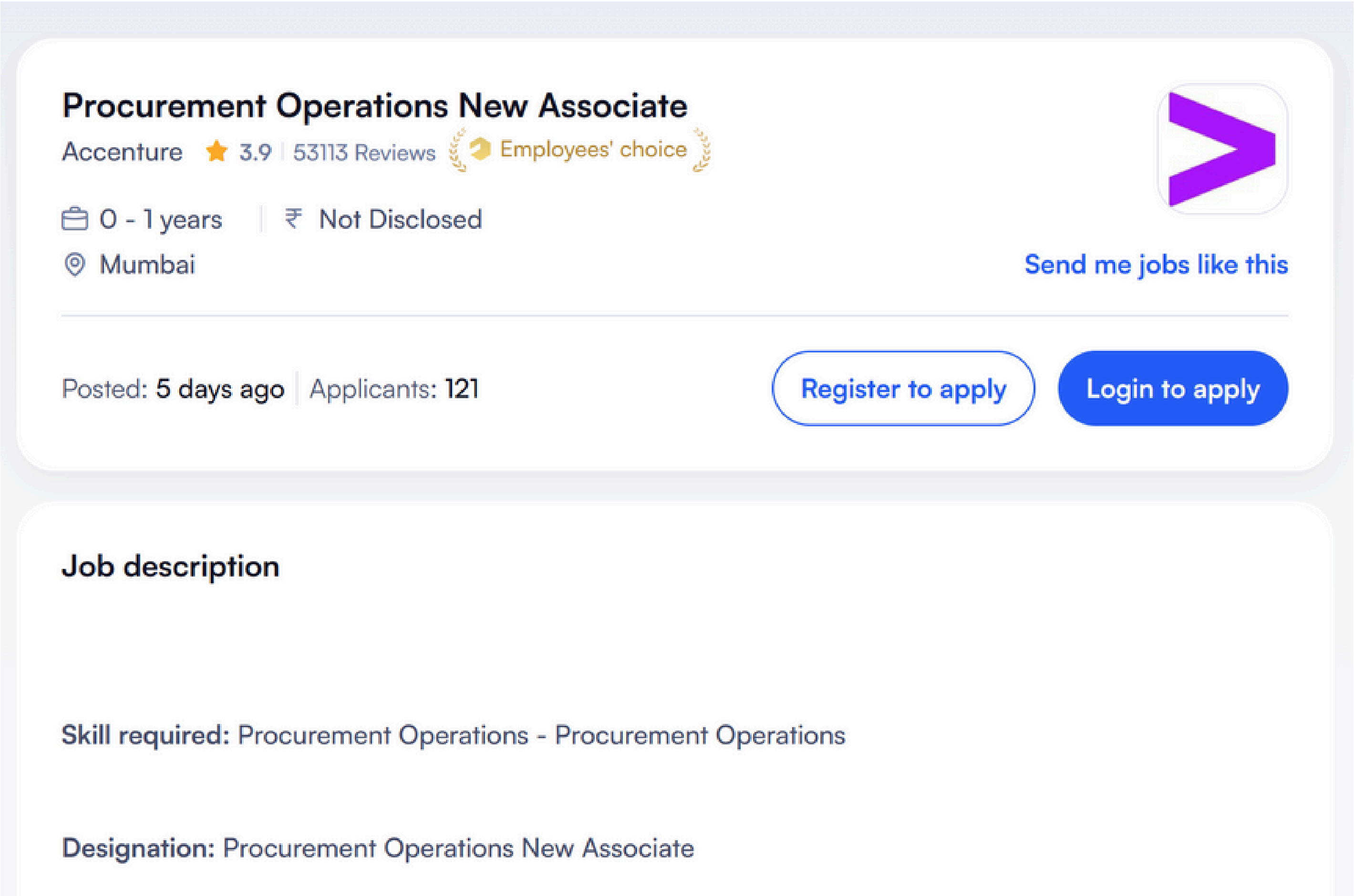
Online Job Platforms

ONET only provides data for the US, thus giving a limited picture of skills and occupations

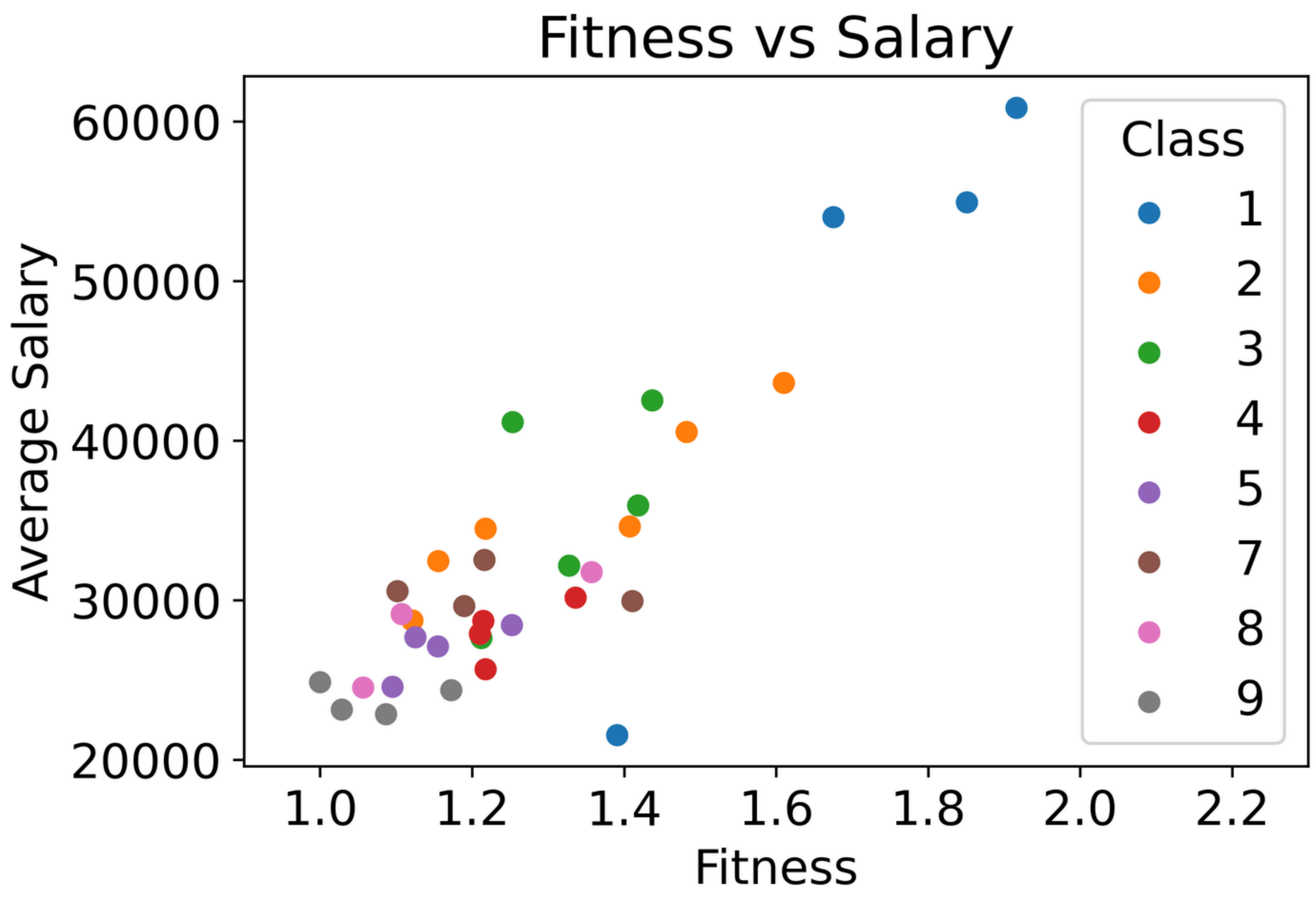
- we can use online job platform data
- there are millions of online job ads
  - we need to determine to which occupation they refer
  - we need to associate skill requirements
  - machine learning is crucial

We have access to

- India (~10M)
- Russia (~100M)
- Brazil (~1M)
- Uruguay (~100k)
- South Africa (~10M)



Fitness of Occupations



From online job posts we extract

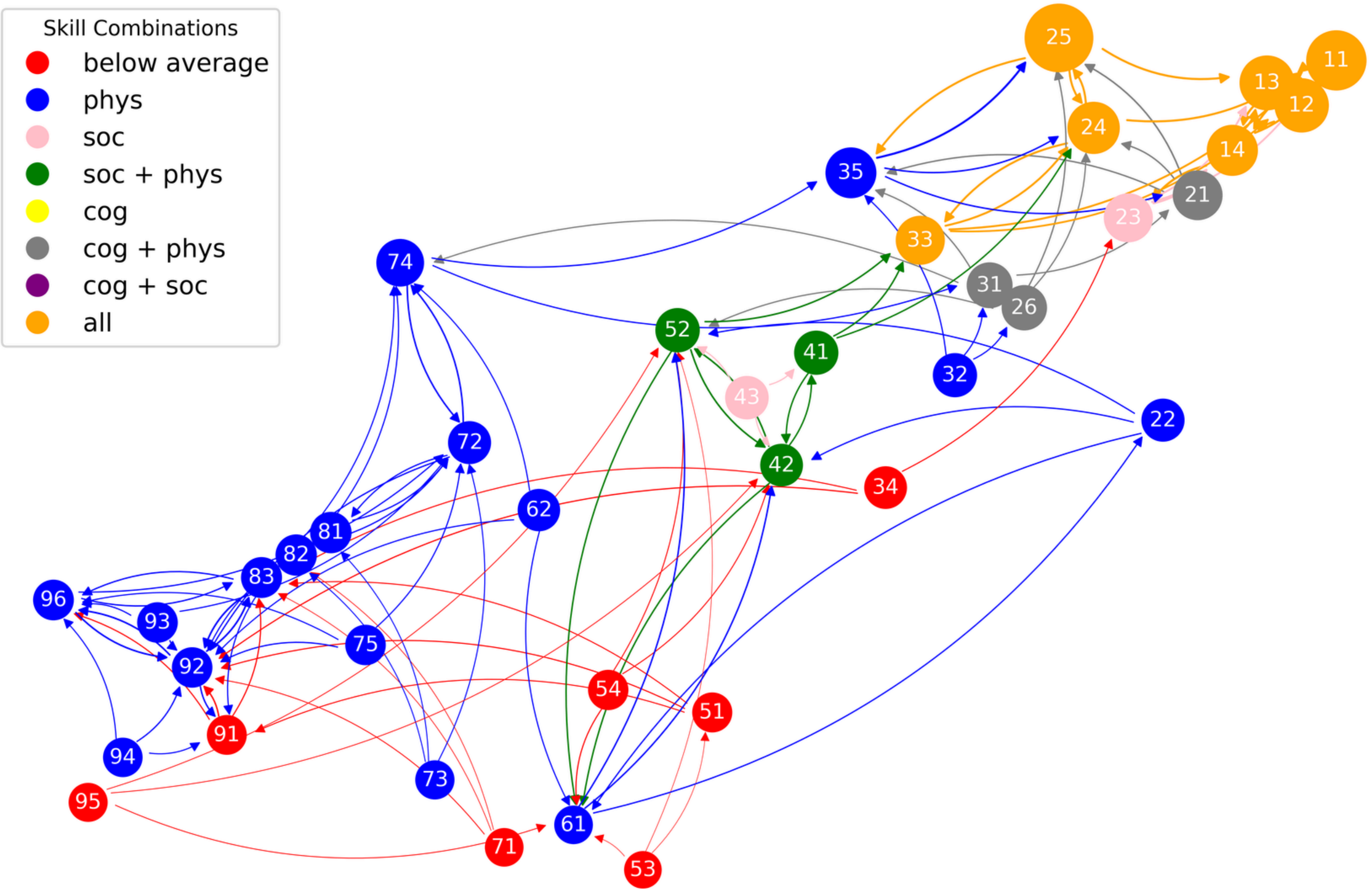
- 43 sub-major ISCO occupation groups
- 15 skills

We can then apply all the techniques we know to this bipartite network

- we can use EFC algorithm to compute the fitness of occupations
- we observe a strong correlation with salary in almost all datasets
- the figure shows the case of Uruguay

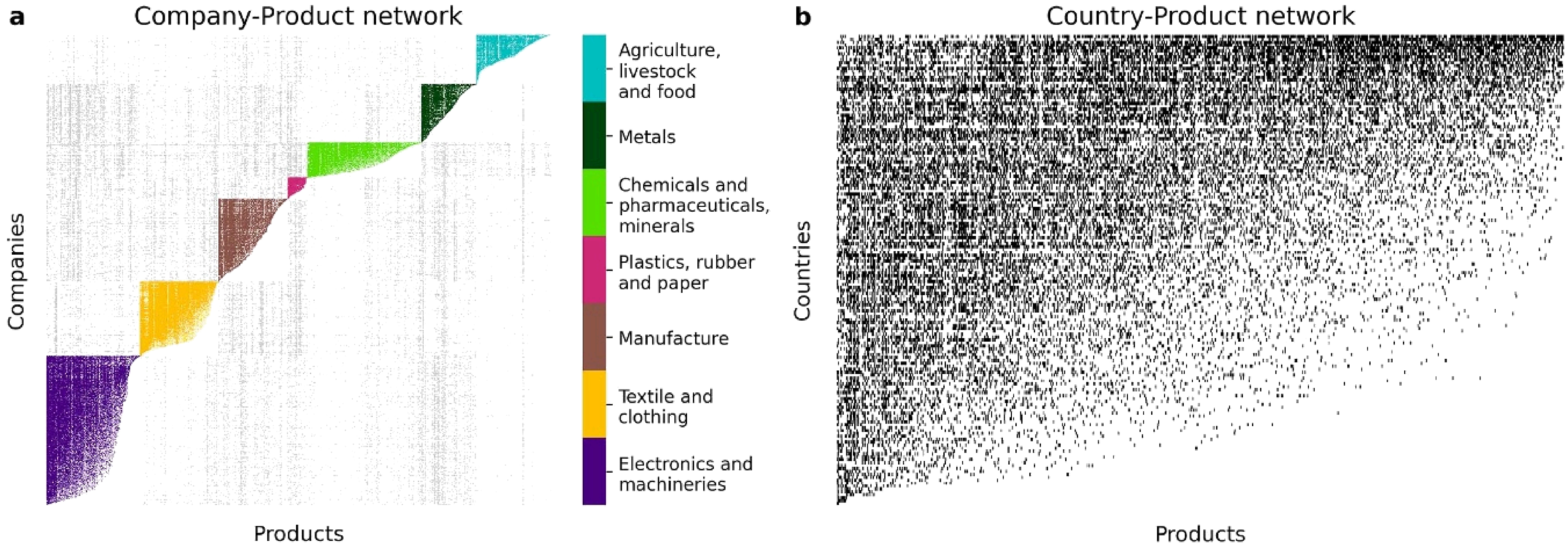
Occupation **Progression**

Using the taxonomy network approach we can reconstruct the occupation progression. This can help relocating people who lose their jobs



Economic Complexity of Firms

Individuals groups into firms, that are the building blocks of economy. Analyzing Italian firms we observe a block-nested structure, with a clear division into industrial sectors. Within each sector, the structure is similar to the country-product network



Laudati, D., Mariani, M. S., Pietronero, L., & Zaccaria, A. (2023). The different structure of economic ecosystems at the scales of companies and countries. Journal of Physics: Complexity, 4(2), 025011.

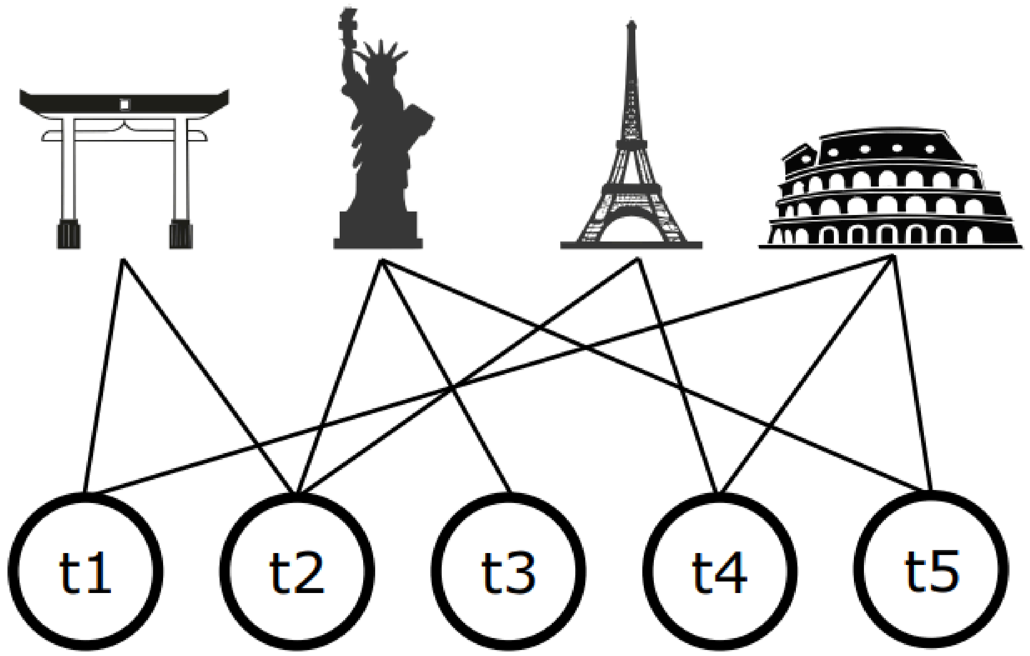
Urban Economic Complexity

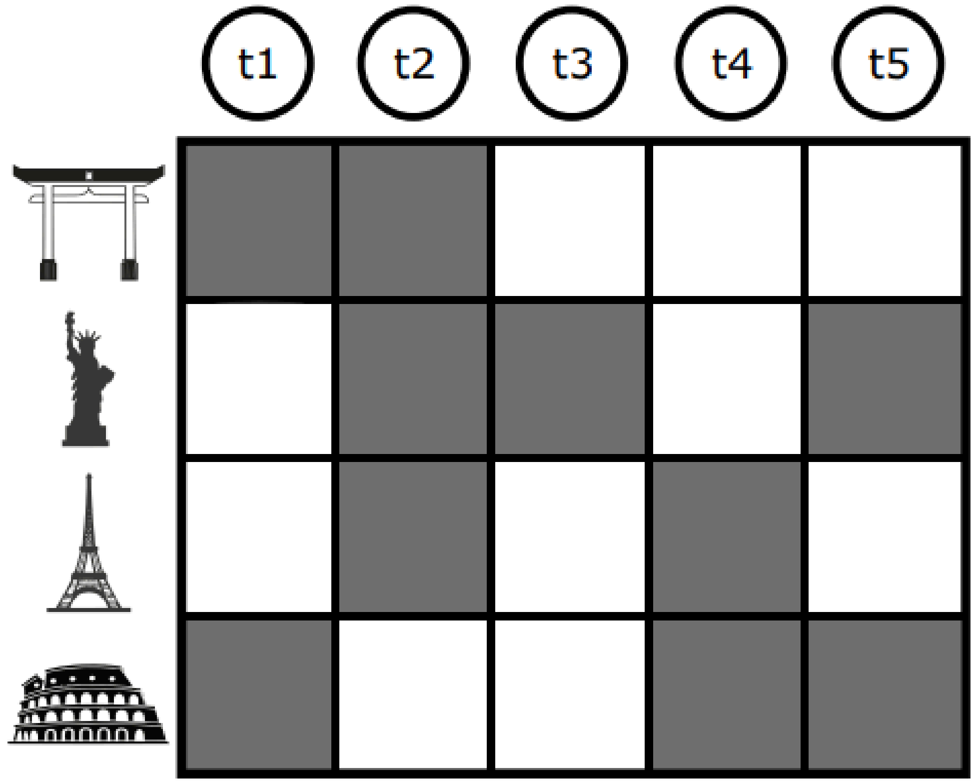
Innovation often occurs at small scales, i.e. at the scale of cities

- silicon valley
- European capitals (Paris, London)

Using patent data we can study cities and the innovation they produce

- we connect cities to the technology they patent
- we obtain a bipartite network of
  - cities
  - technological codes

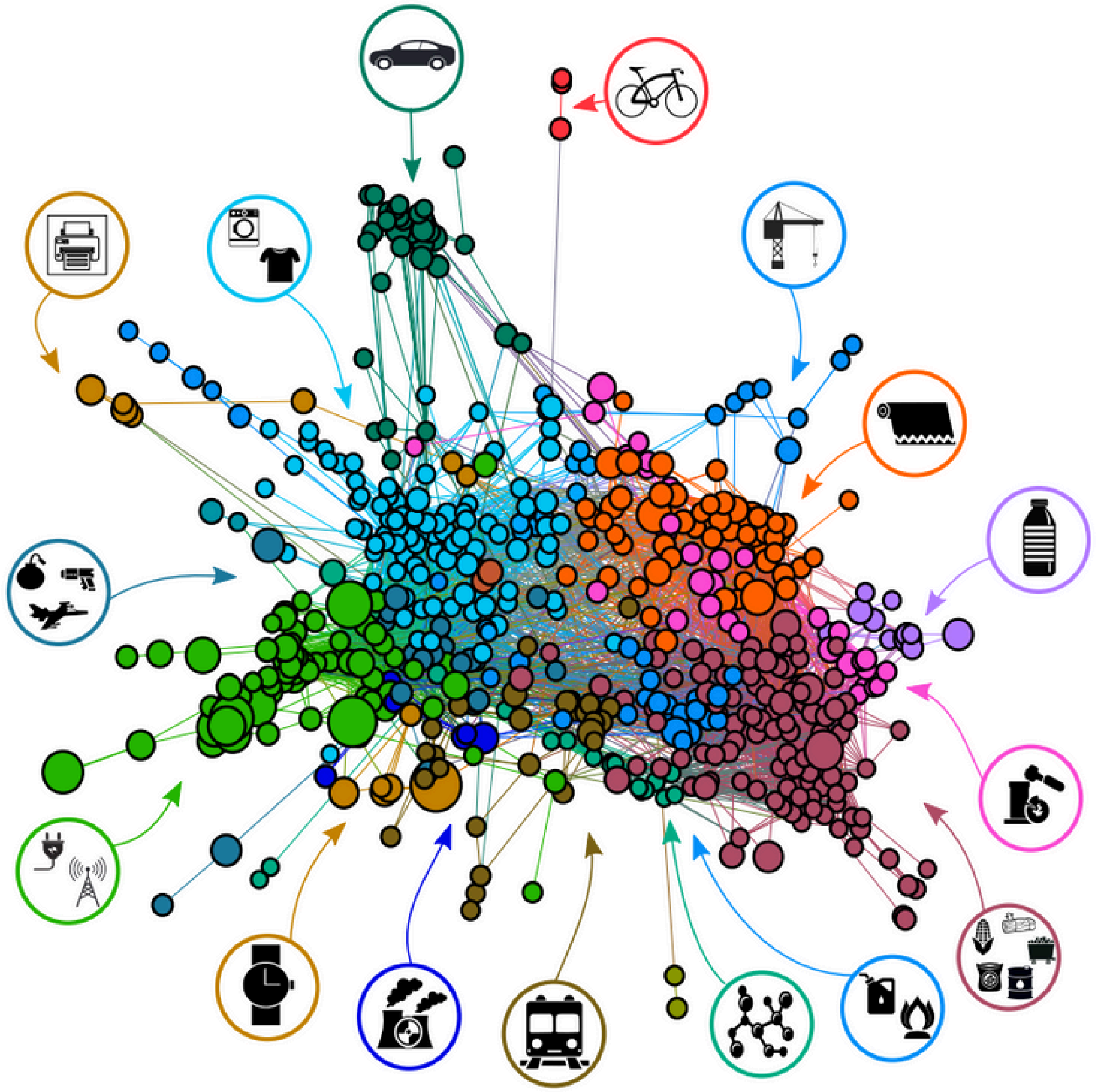


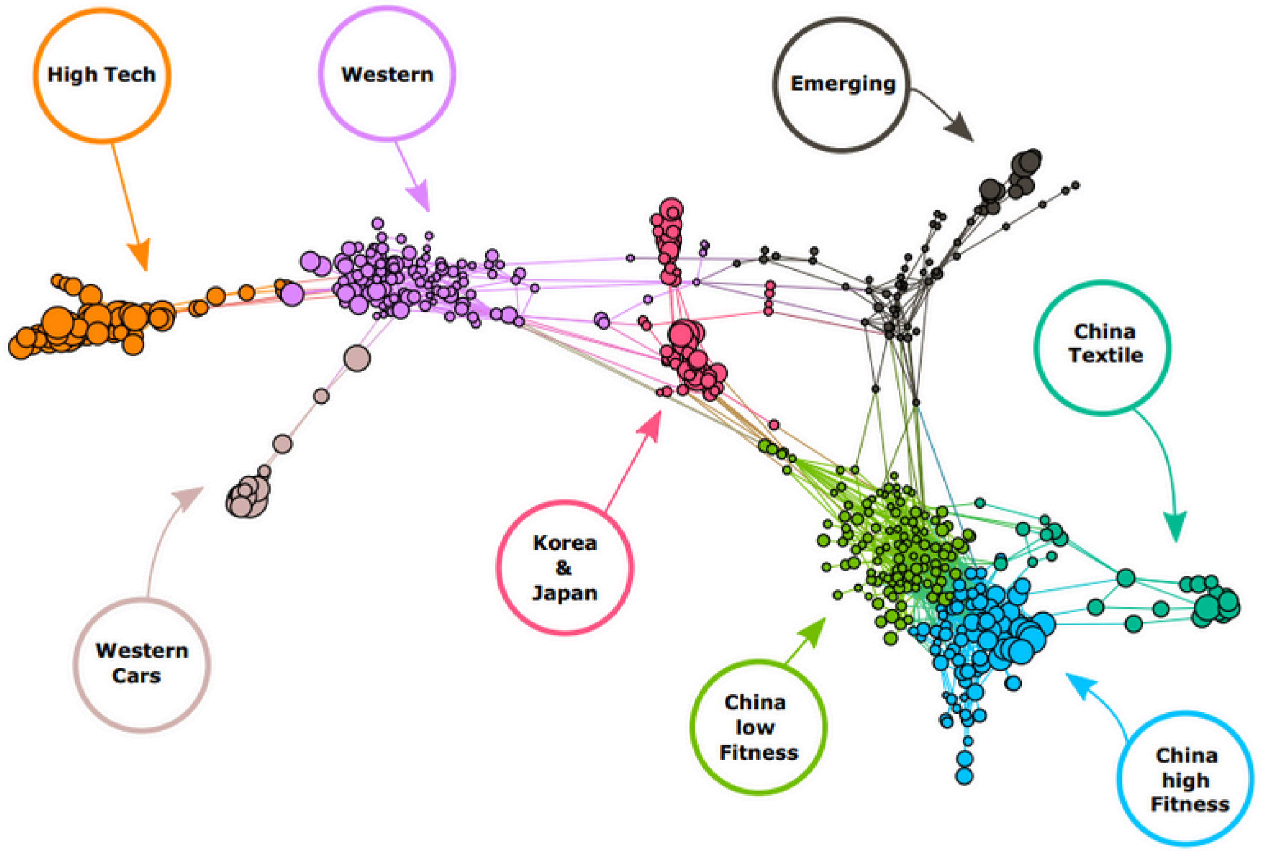


Straccamore, Matteo, et al. "*Urban economic fitness and complexity from patent data.*" Scientific Reports 13.1 (2023): 3655.

Relatedness Networks

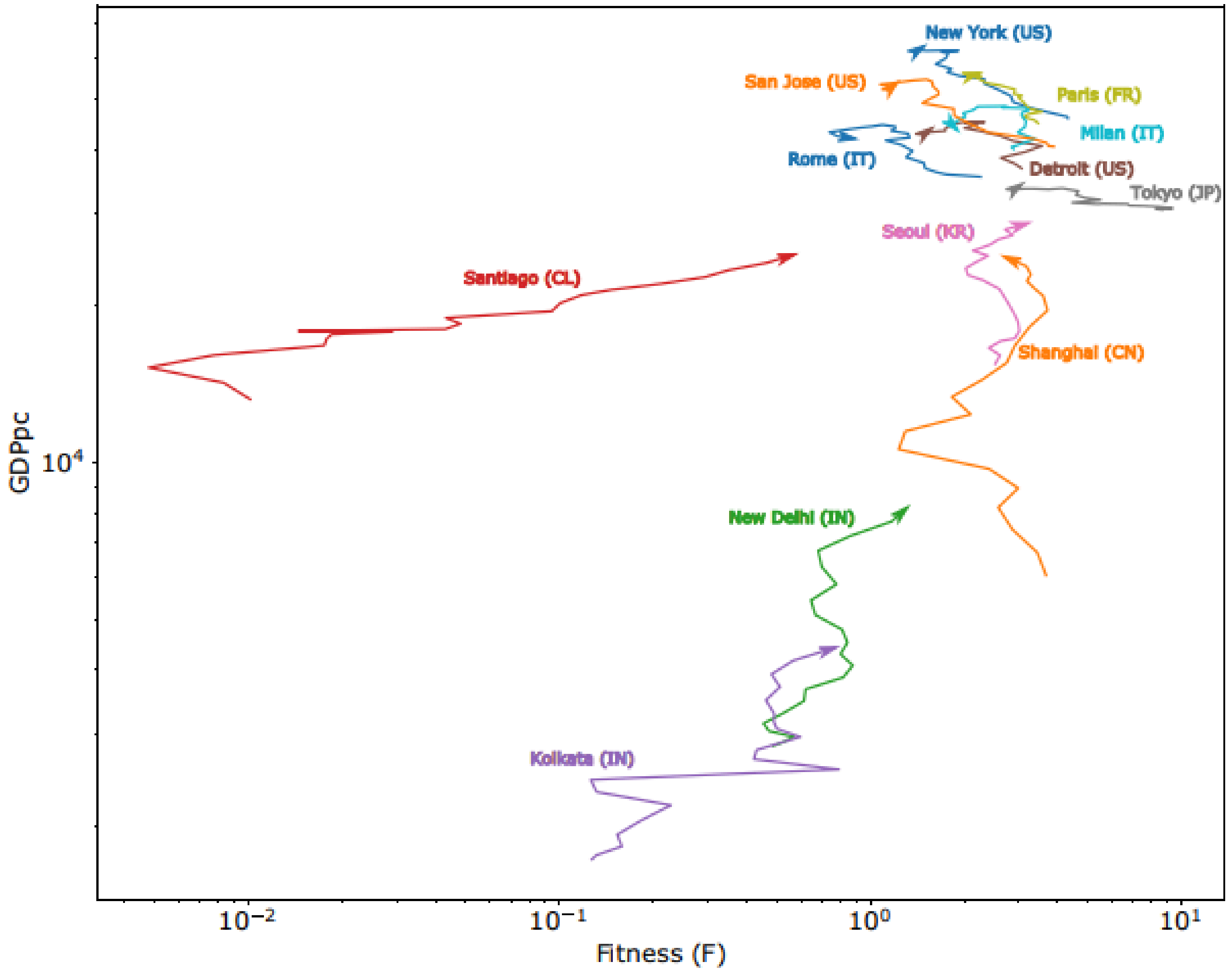
We can project the bipartite network to get both a network of technologies and of cities. Also in this case a validation based on the BiCM is important.

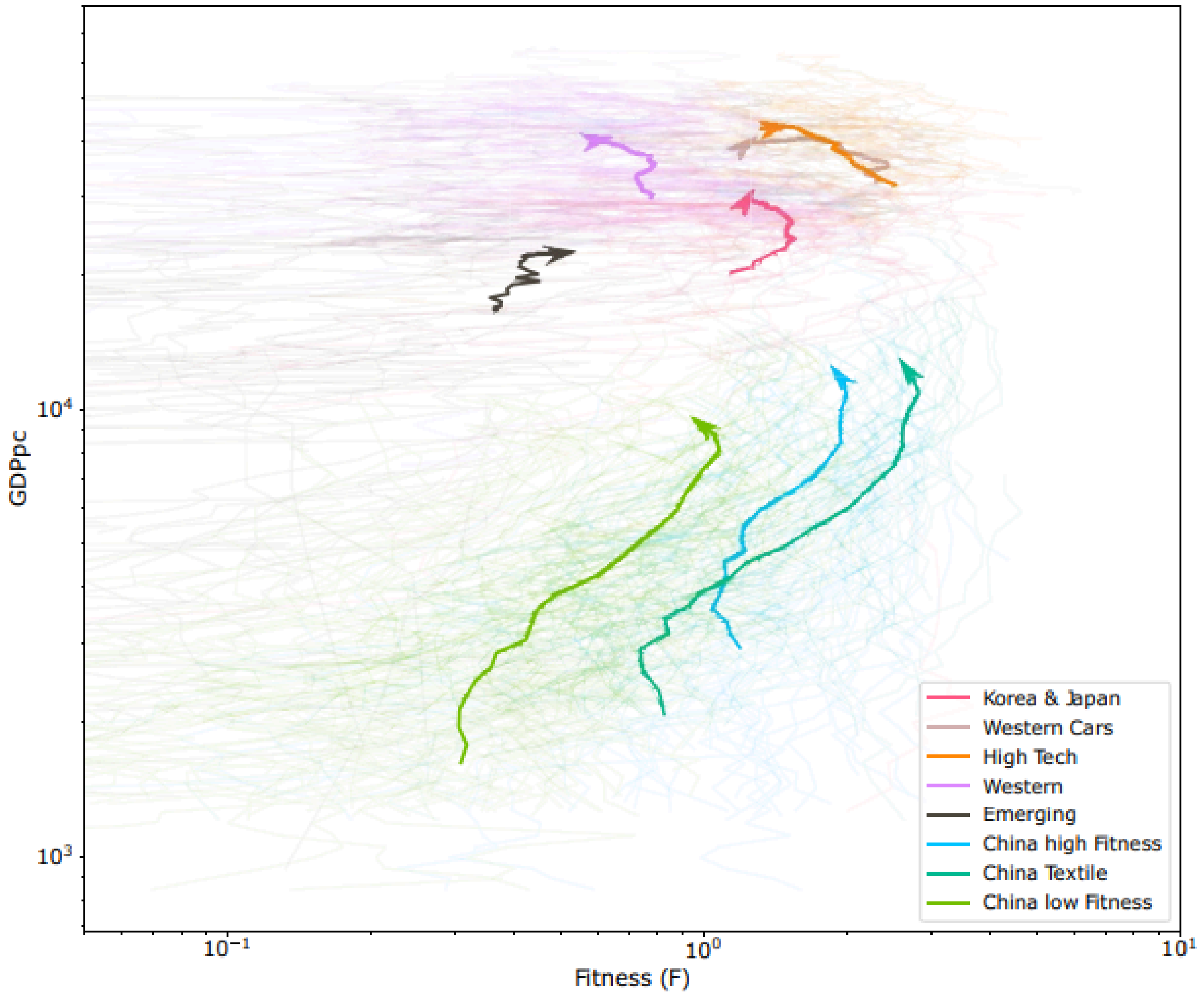




The Growth of Cities

The EFC algorithm allows to determine the technological fitness of cities, that can be related to their growth potential in terms of GDP. This is clear, for instance, in Chinese and Indian cities





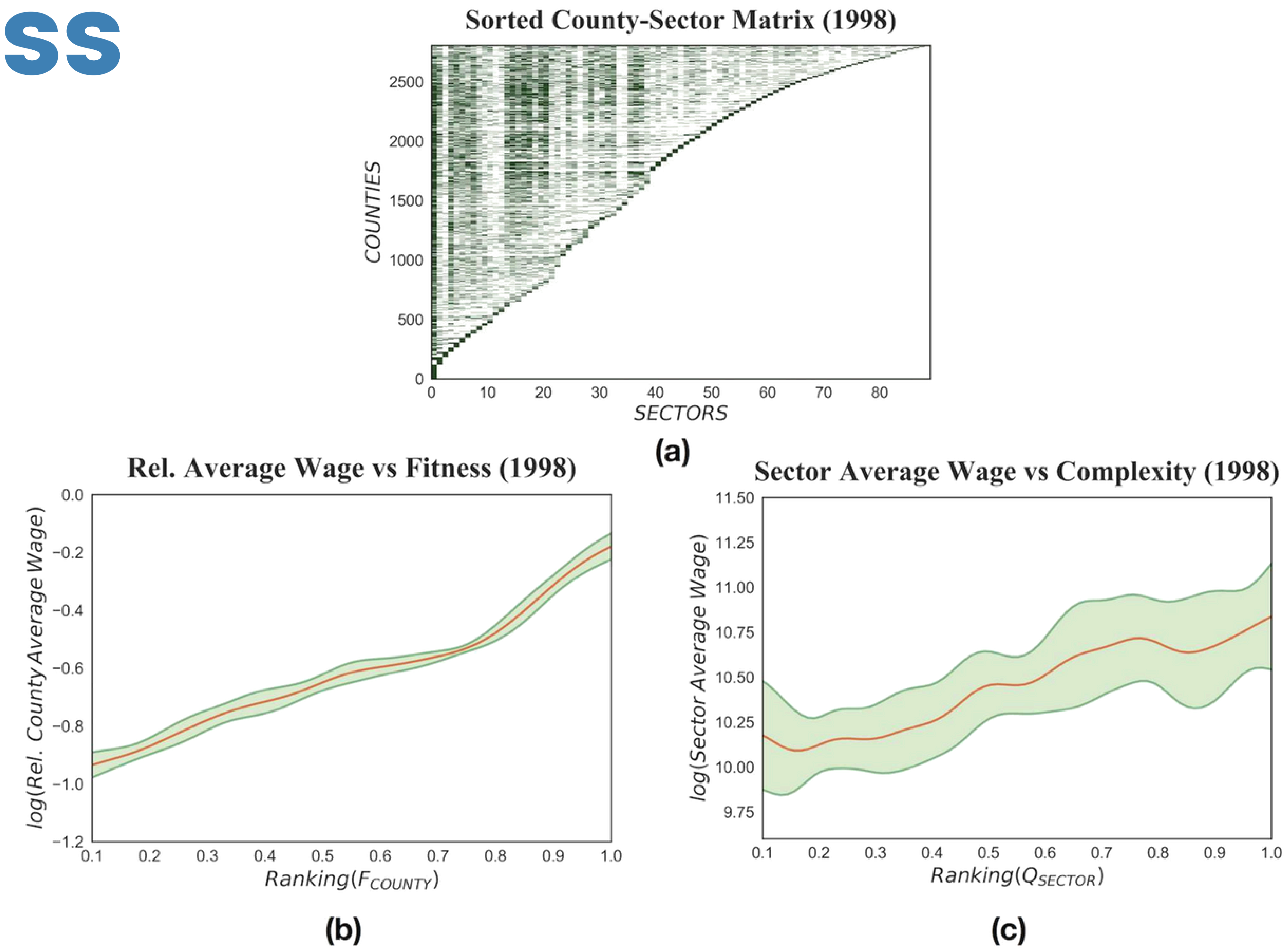
US Counties
Industrial Fitness

We can analyze industrial fitness looking at the bipartite network of counties and industrial sectors

- this is analogous to countries and products
- however the analysis is performed at a much smaller scale

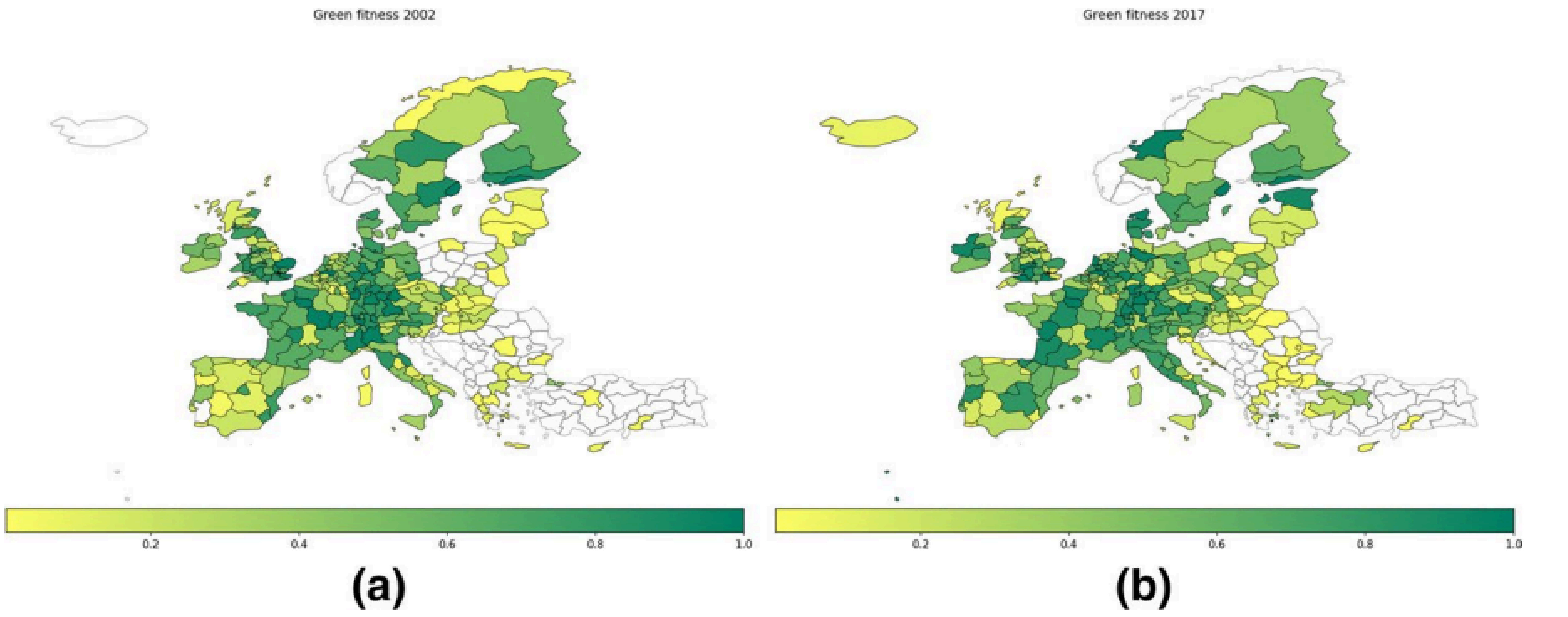
We obtain very similar results

- nested structure
- correlation between wages and fitness/complexity



Regional Technological Fitness

Instead of looking at the industrial sectors, we can link regions to the technology they produce using patent data. This gives the Technological Fitness



Barbieri, Nicolò, et al. "Regional technological capabilities and green opportunities in Europe." The Journal of Technology Transfer 48.2 (2023): 749-778.

Conclusions

Economic Complexity

Economic Complexity studies the structure and dynamics of economic systems using data-driven and network-based methods. The Economic Fitness and Complexity algorithm allows to characterize countries and products.

Product Progression

Economic Complexity techniques allow to forecast the industrial progression of countries. Machine learning based approaches tend to perform better. These tools can guide the development of countries

Economic Complexity at Different Scales

Economy is a hierarchical system with many different scales. We observe a similar nested structure at almost all scales and the techniques developed for the country-product network can be used to study several systems.

Quiz

- Oil is a simple or complex product according to ECI?
- What about for the EFC algorithm?
- What is the role of non-linearities in the EFC algorithm?
- Why using networks to predict product progression if machine learning works better?
- Why is Economic Complexity approach different from standard Economy?
- What other type of systems could be studies using Economic Complexity techniques?