Economic Complexity

Collective knowledge as distributed expertise

Symposium: data Science in Fundamental Physics

and its bridge to industry & society

Santiago de Compostela, June 7, 2024

Complexity Science Hub

@FrankNeffke

Science of Cities / Transforming Economies

Complexity Science Hub: Research topics

→ Foundations of Complex Systems

Societies Under Stress

→ Collective Minds
→ Human Migration
→ Social Complexity & Collapse

Societies in Transition

→ Urban Sustainability
→ Transforming Economies
→ Algorithmic Fairness

Metabolism of Societies

→ Financial Technologies
→ Supply Chain Science
→ Healthcare & Medicine
→ Health Across Species

→ Data Analytics

As of 2024:

- ***75 resident scientists***
  - *22 senior scientists*
  - *15 postdocs*
  - *28 doctoral students*
  - *10 data engineers*
- ***82 external faculty***
- ***47 associate faculty***
- ***2 spin-offs***

New: Digital Innovation School

- Graduate program in complexity science in cooperation with partner universities
- 5-7 new students each year
- Training leaders for business, administration and research with the skills to shape the digital transformation
- Duration 10 years

Science of Cities / Transforming Economies

Core Team

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Physics/CS

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Postdoc
Applied Math

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Econ Geo

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Collaborators

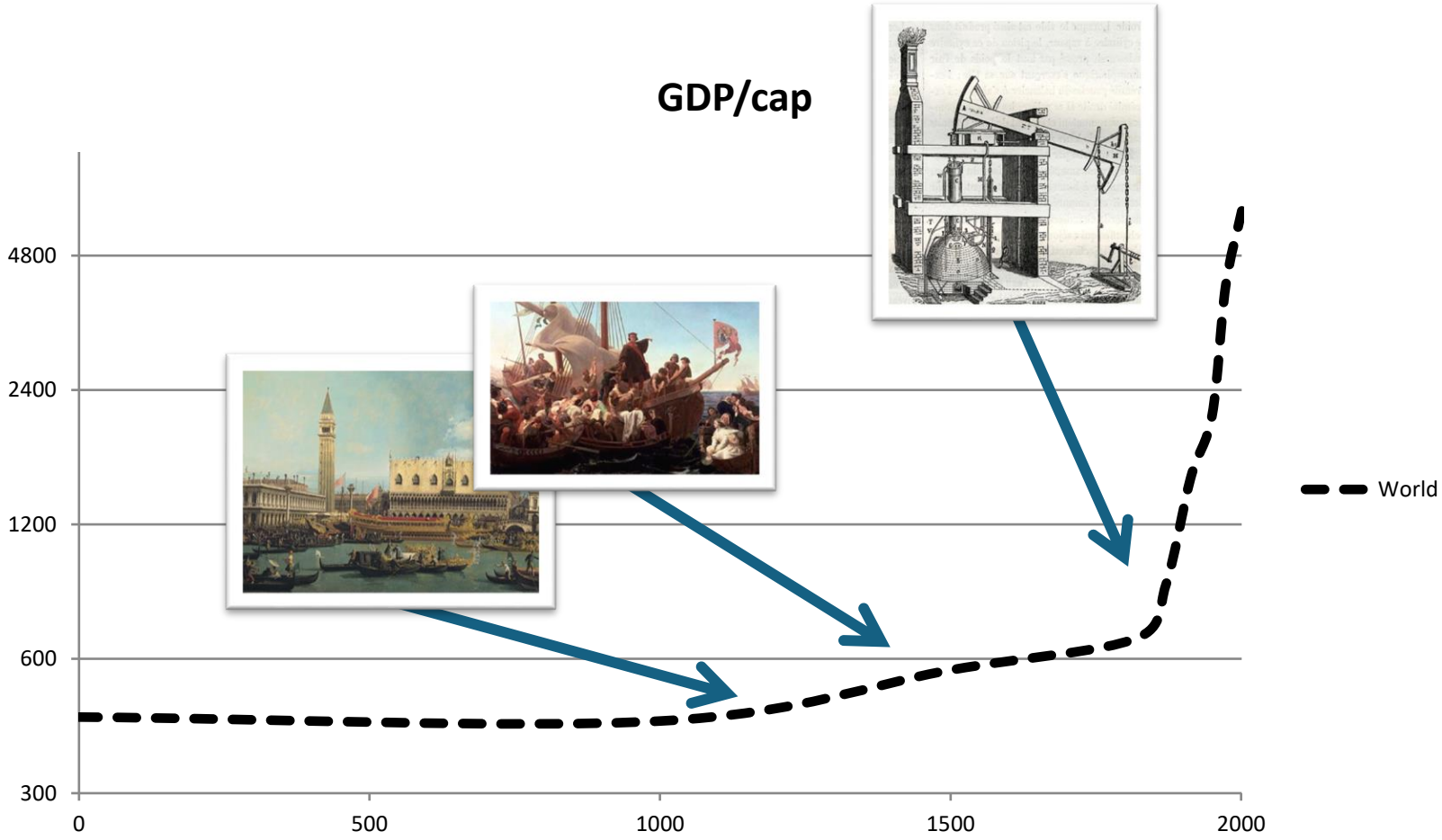
Ljubica Nedelkoska
Economics

Eddie Lee
Physics

Economic growth

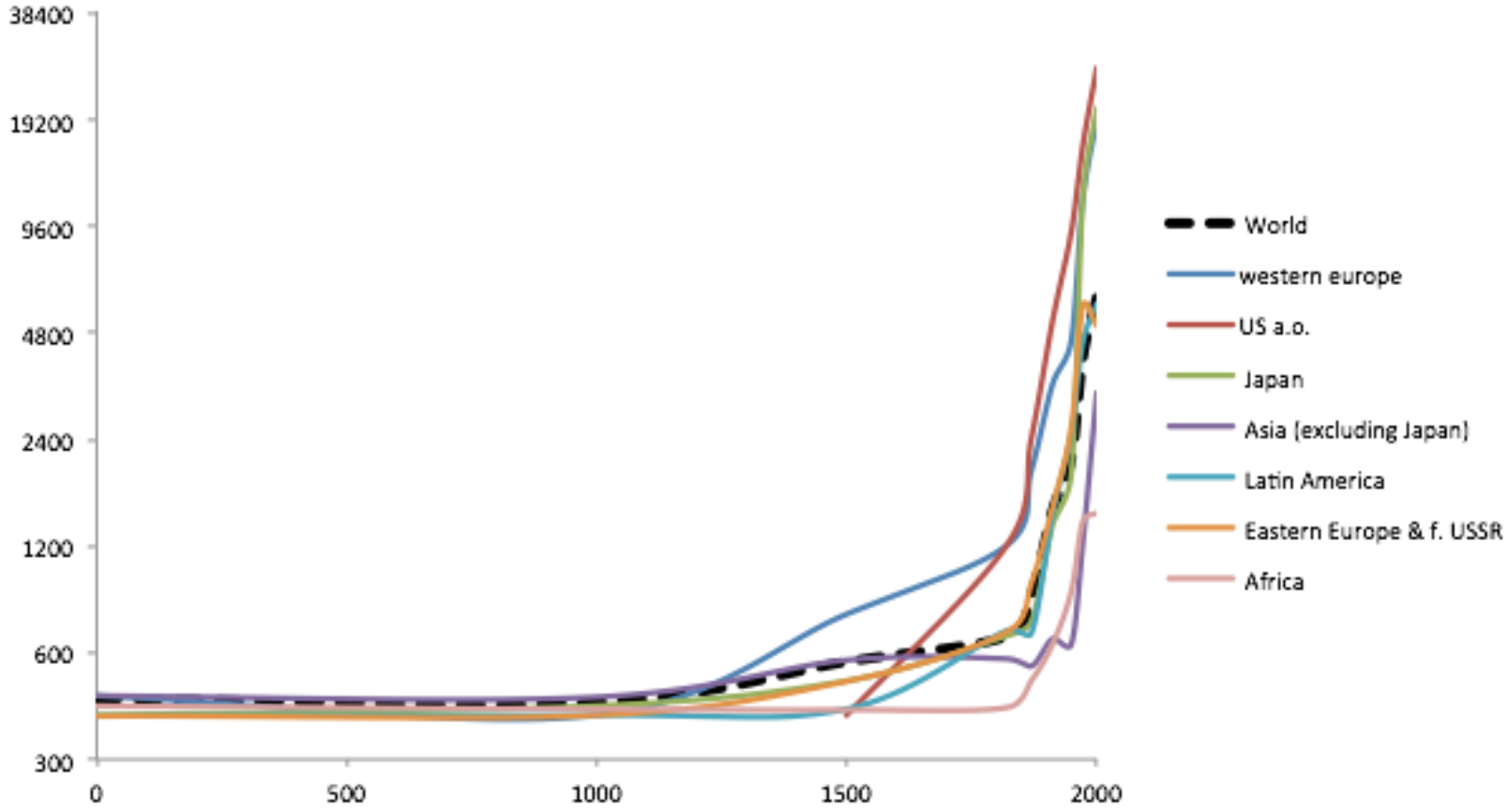
A long run perspective

The great acceleration



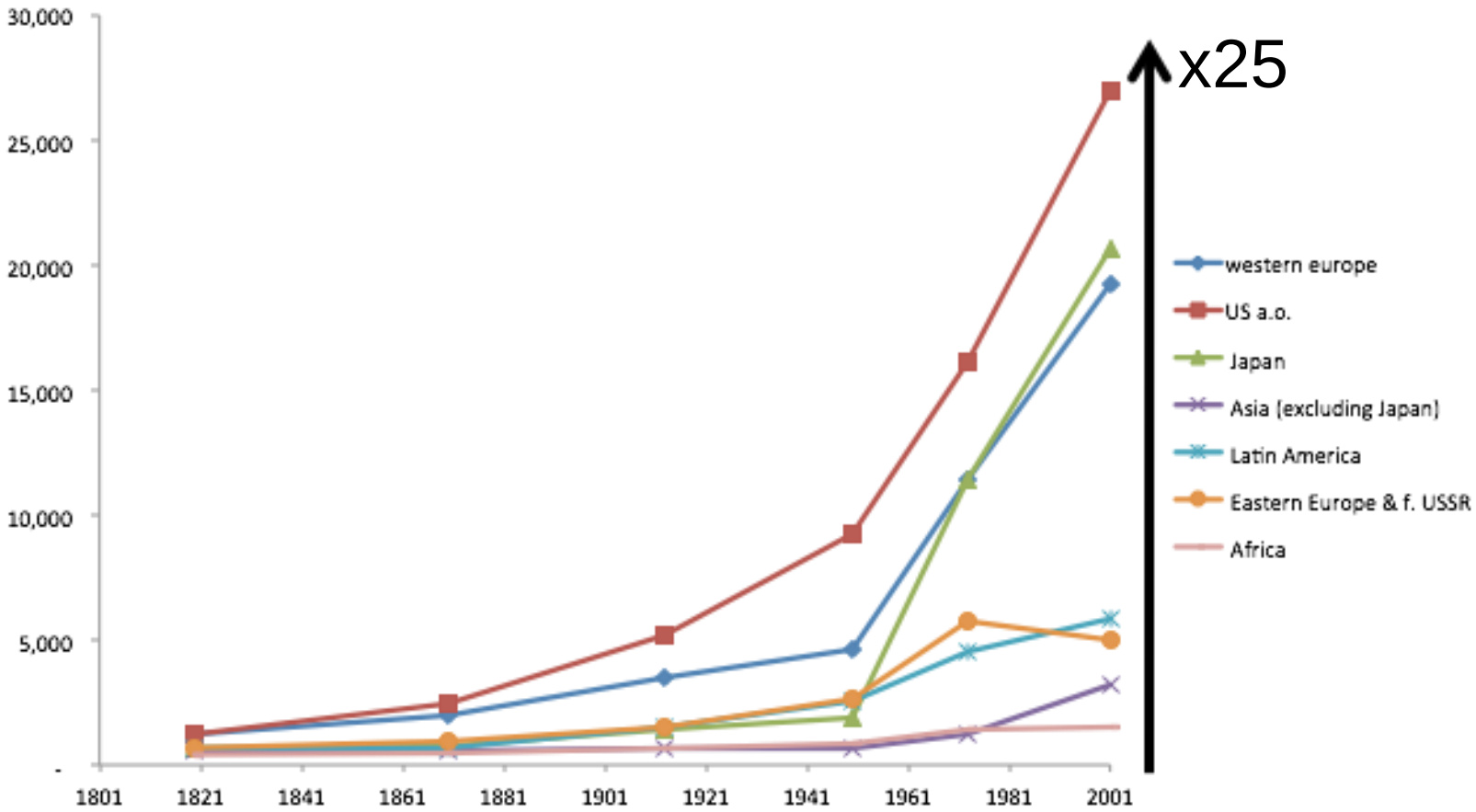
Sources:
Maddison 2001: The world economy a milennial prespective,
Maddison 2005: Measuring and Interpreting World Economic Performance 1500-2001

The great acceleration



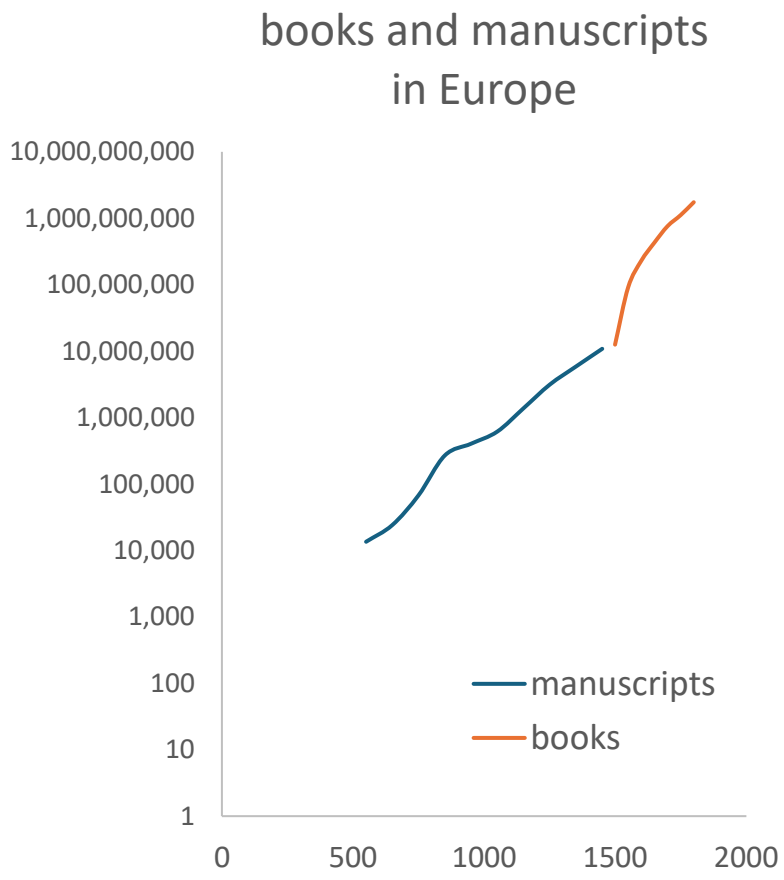
Maddison 2001: The world economy a milennial prespective,
Maddison 2005: Measuring and Interpreting World Economic Performance 1500-2001

The great divergence

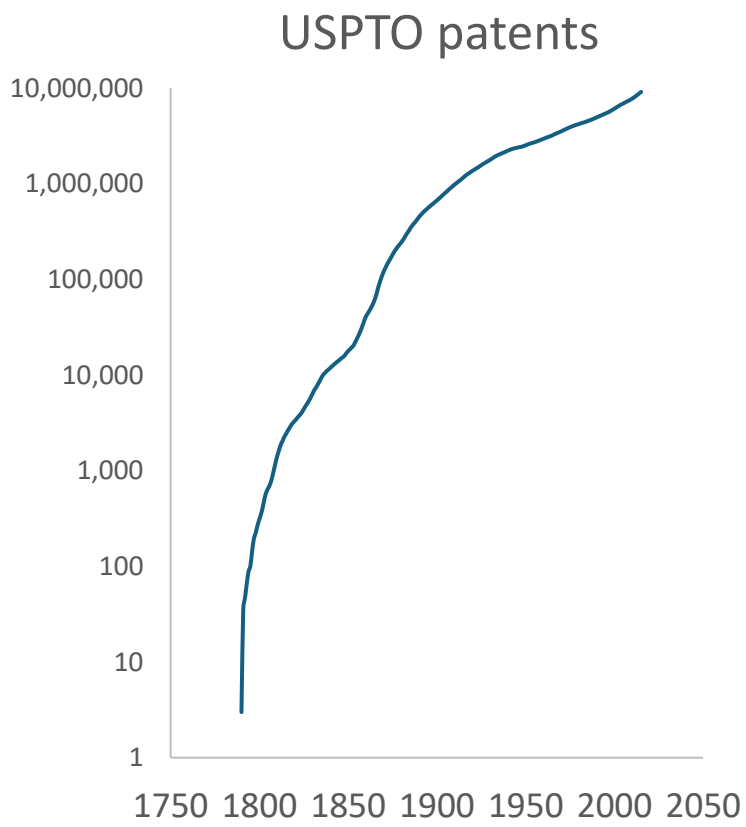


Complexity has been increasing

Global stock of knowledge expands exponentially



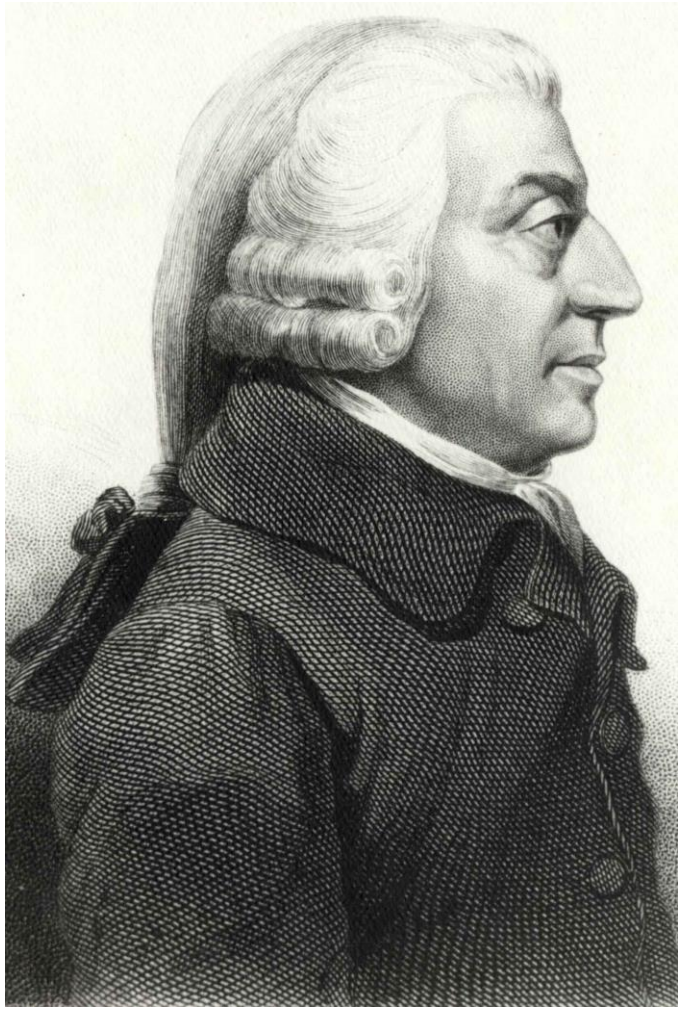
Source:
Buringh & Luiten van Zanden,
Journal of Economic History, 2009



Source:
www.uspto.gov

There is just too much to learn!

Division of labor

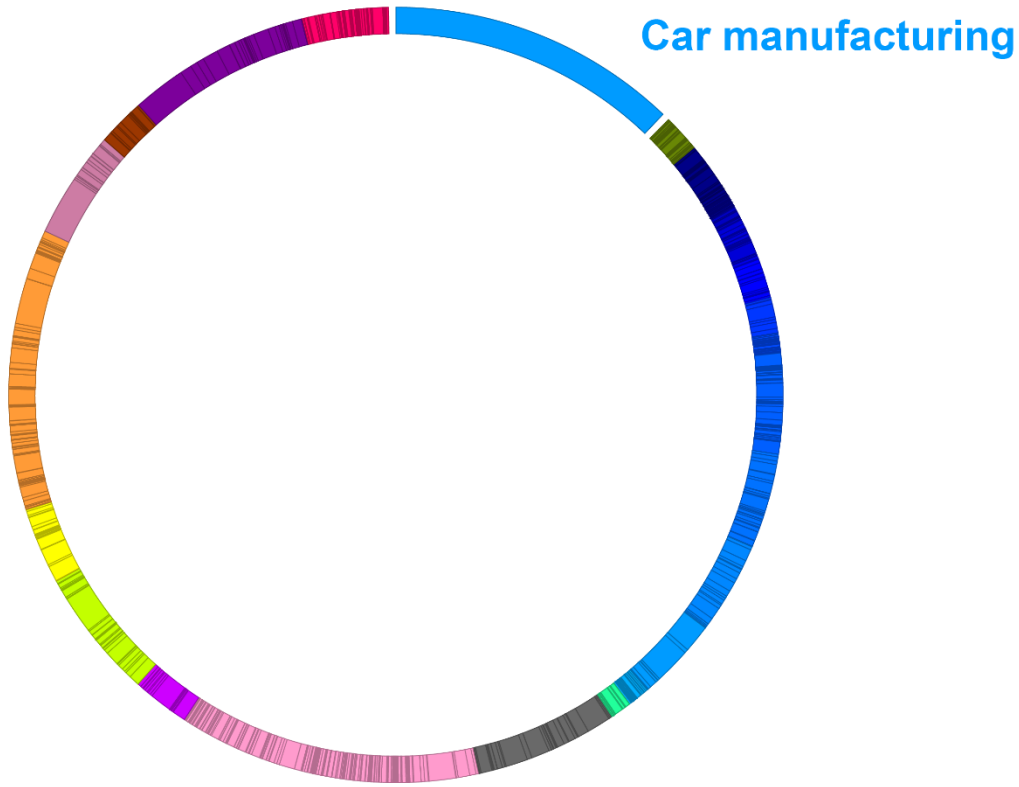


Proposal:

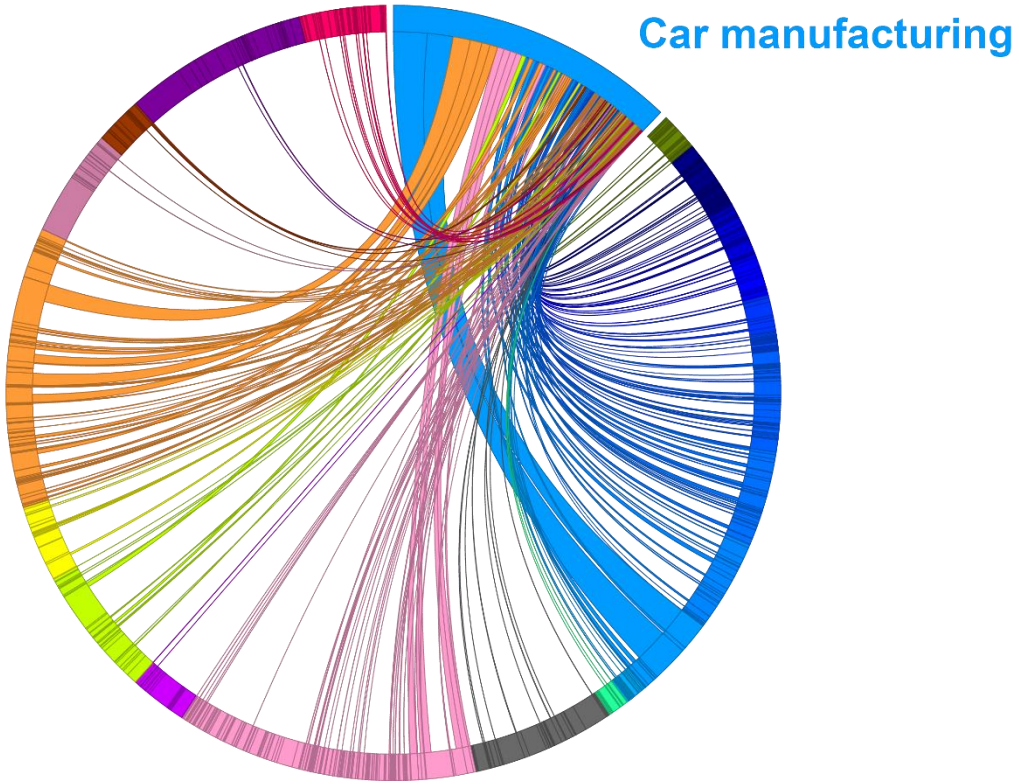
- Society's knowledge keeps growing
- Individual's capacity to comprehend knowledge does not
- Knowledge gets distributed across an expanding array of "experts"
- Division of labor is **not** the world's way to become more efficient, but to deal with the growing body of global knowledge (cf. Jacobs, 1969; Becker et al., 2007)

How specific is human capital?

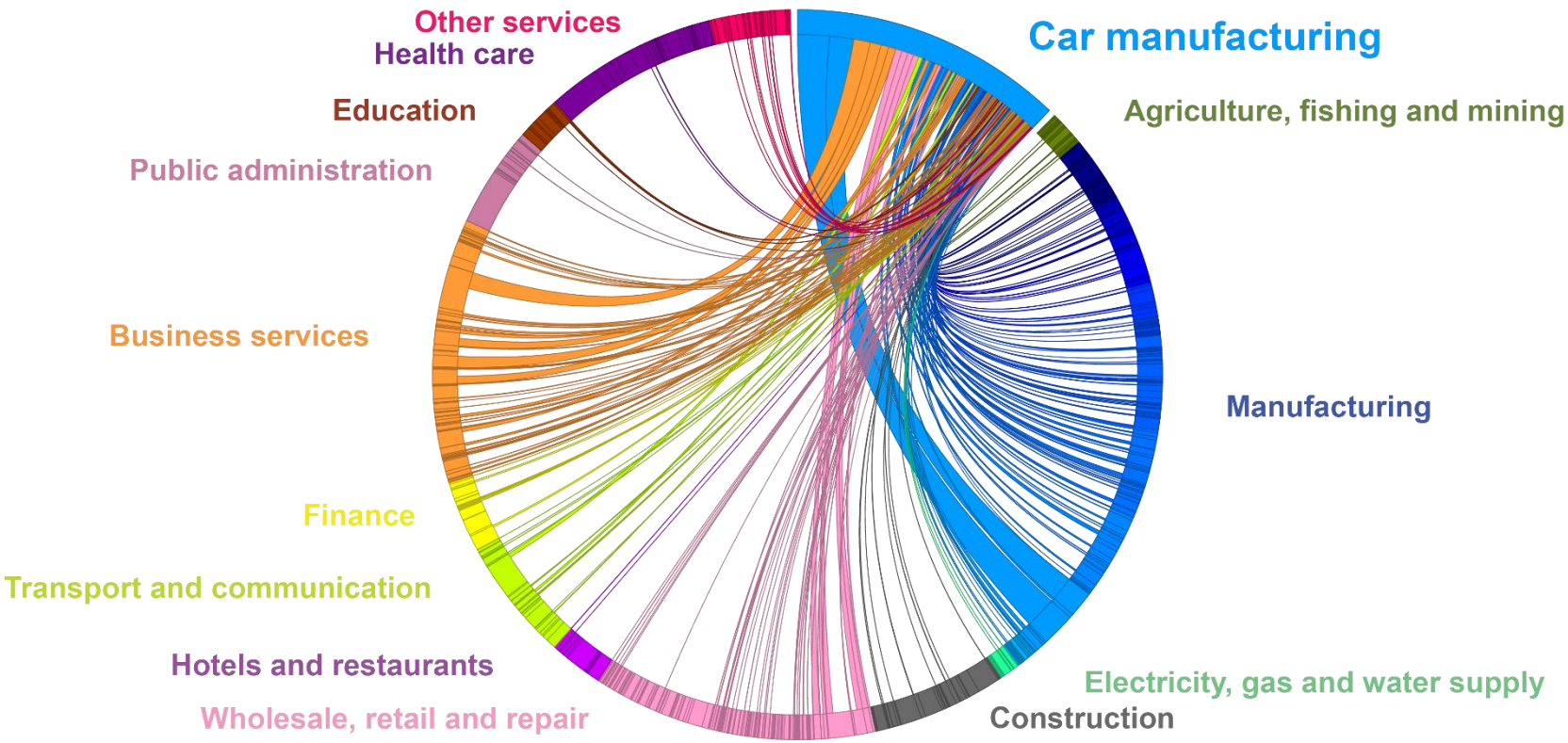
Flows out of car manufacturing



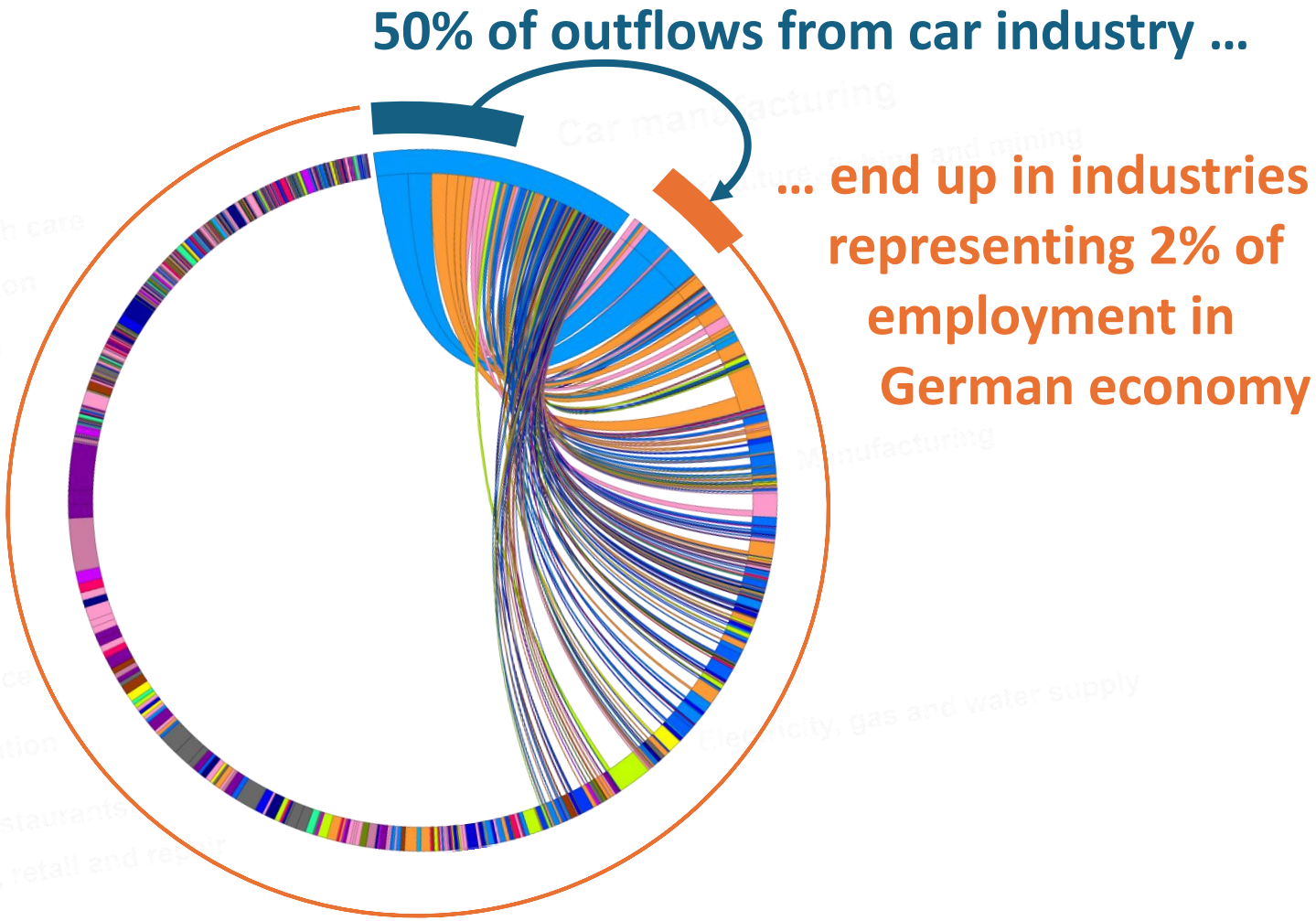
Flows out of car manufacturing



Flows out of car manufacturing

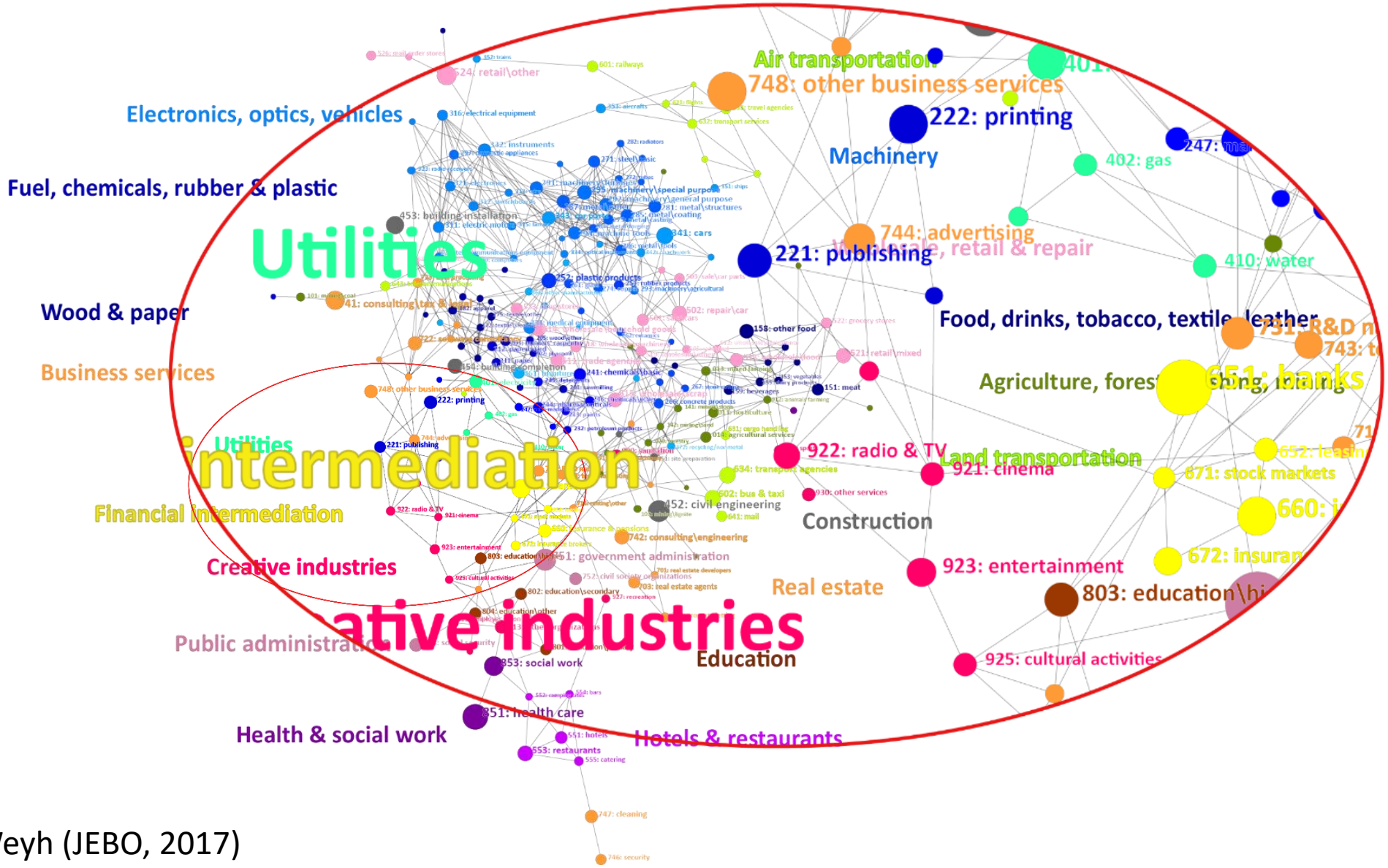


Sort industries



Industry space

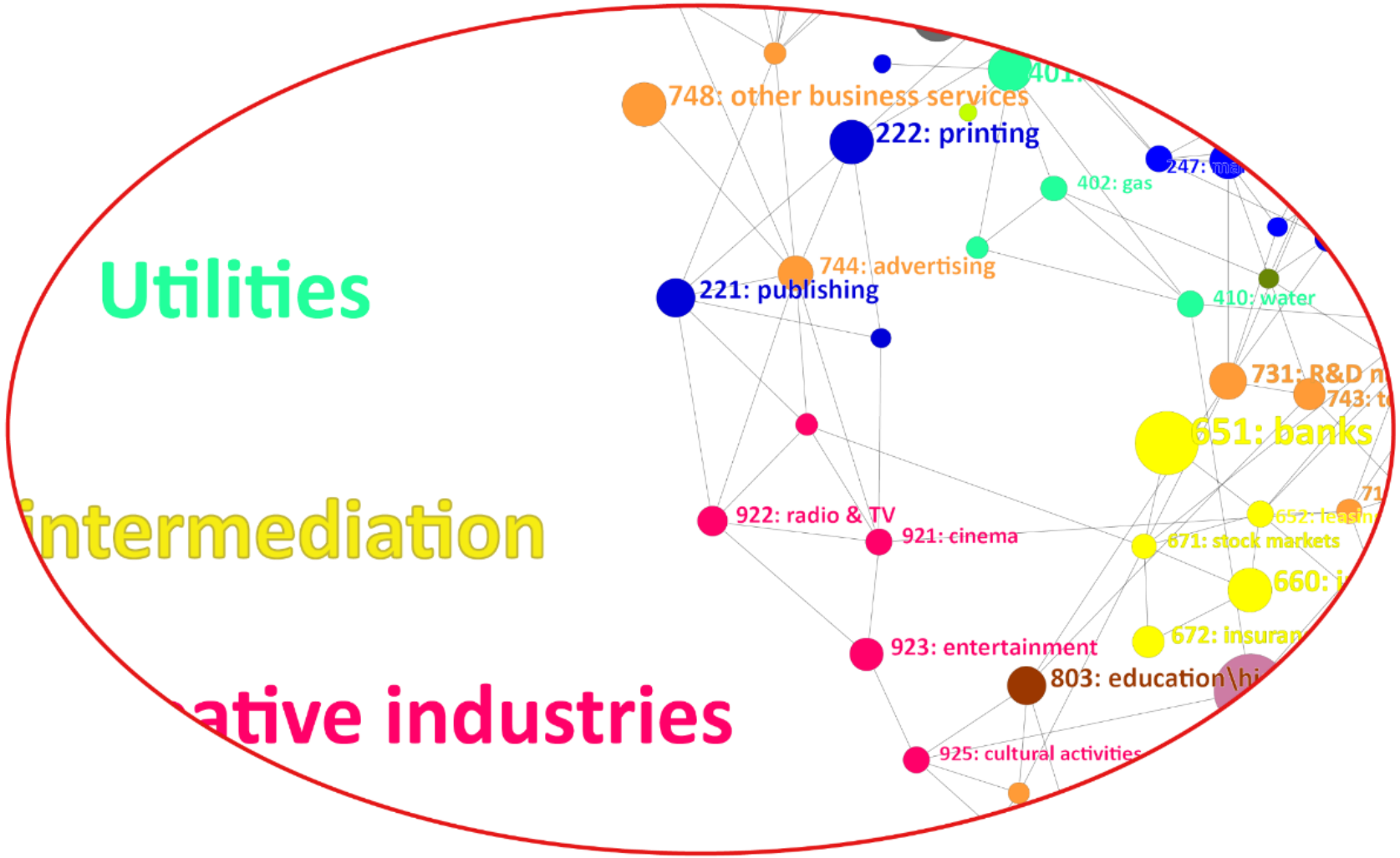
Labor market as a network of human capital linkages



Neffke/Otto/Weyh (JEBO, 2017)

Industry space

Labor market as a network of human capital linkages



Predicts

- Firm diversification (Neffke/Henning, SMJ 2013)
- Inter-firm spillovers (Timmermans/Boschma, JoEG, 2014; Csáfordi et al. 2016)
- Emergence and growth of local industries (Neffke, Otto, Weyh, JEBO 2017)
- Duration of unemployment after displacement in plant closures (Neffke, Otto, Hidalgo, 2017)

How is collective knowledge organized?

Coordinating distributed experitise

Studying the transformation of societies coordinate complexity

- Data requirements
  - Long time periods (processes are slow)
  - Detailed information on capabilities (e.g., micro data)
  - Information on complete teams (i.e., no samples)

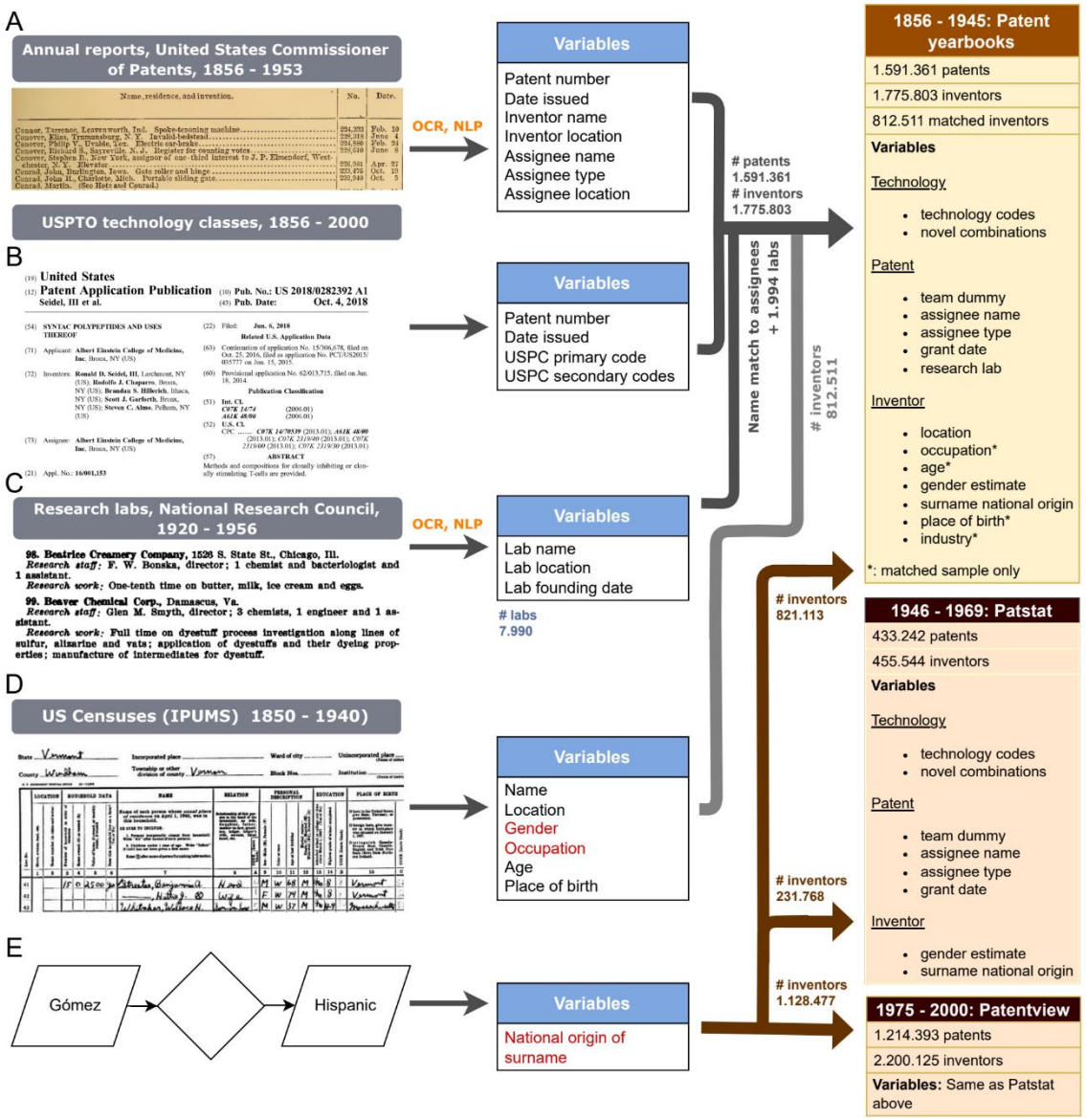
- Combine two large historical datasets
  - US Census 1850 – 1940
  - USPTO 1790 – 2019

Andres Gomez-Lievano

Matté Hartog

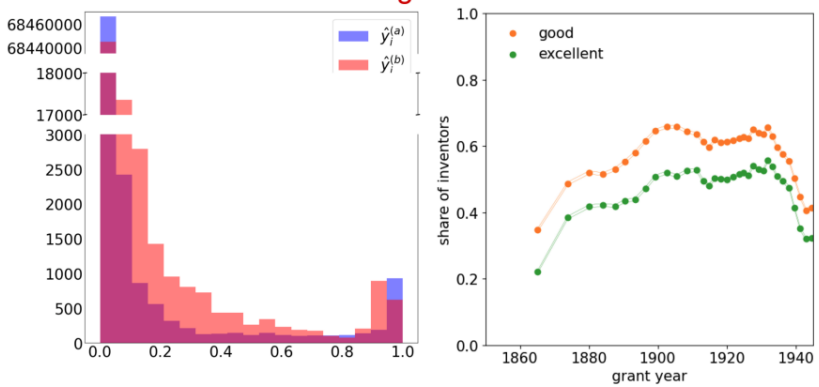
Sultan Orazbayev

Workflow



Inference and matching

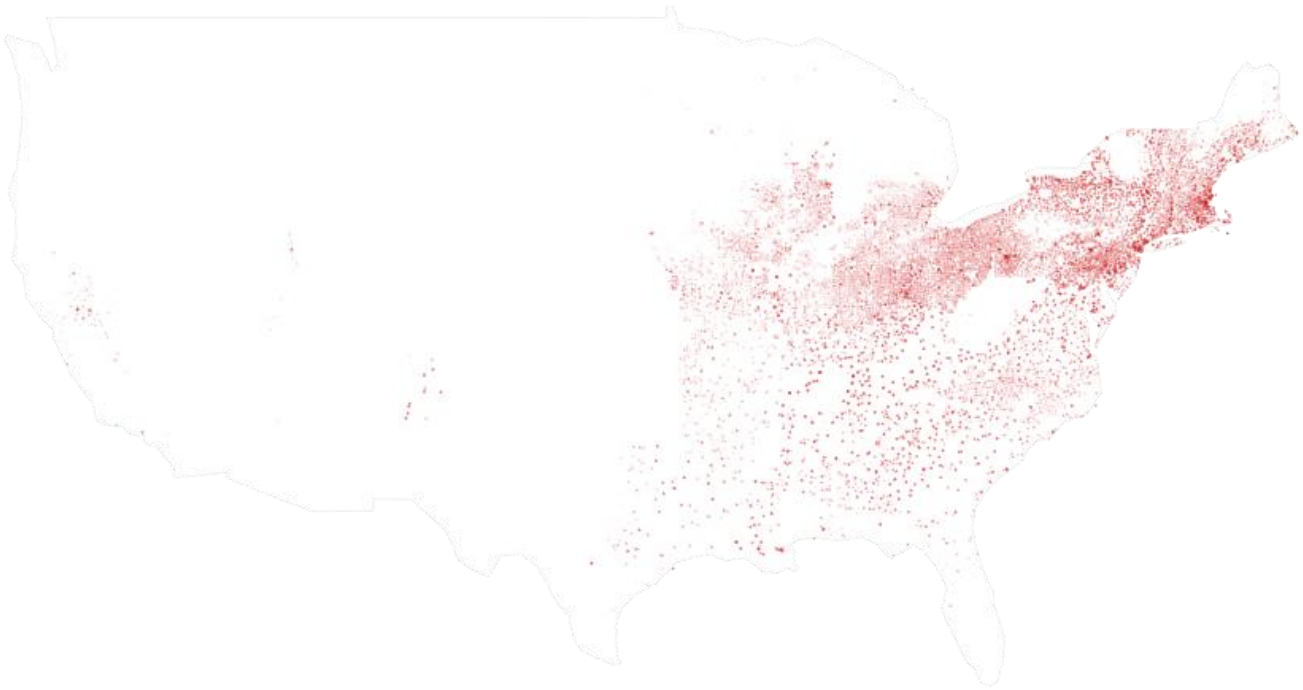
Census matching



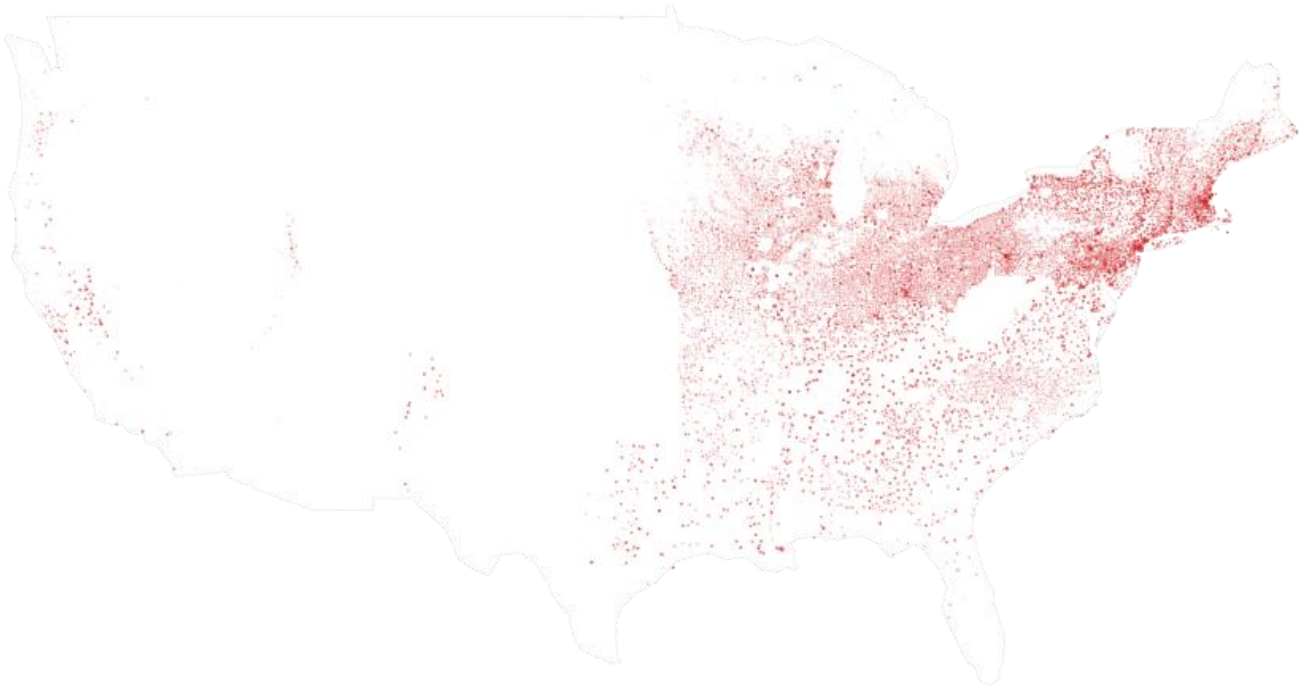
Occupational grouping

“skill relatedness”

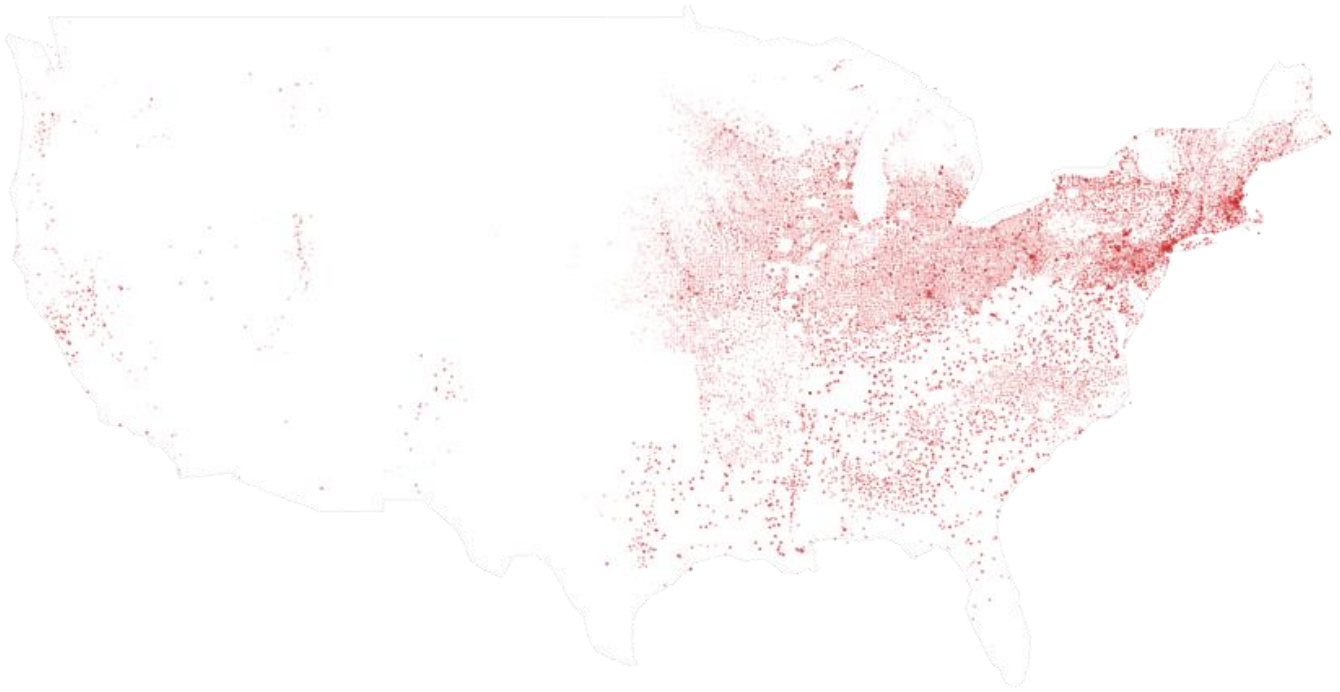
Geocoding (1850)



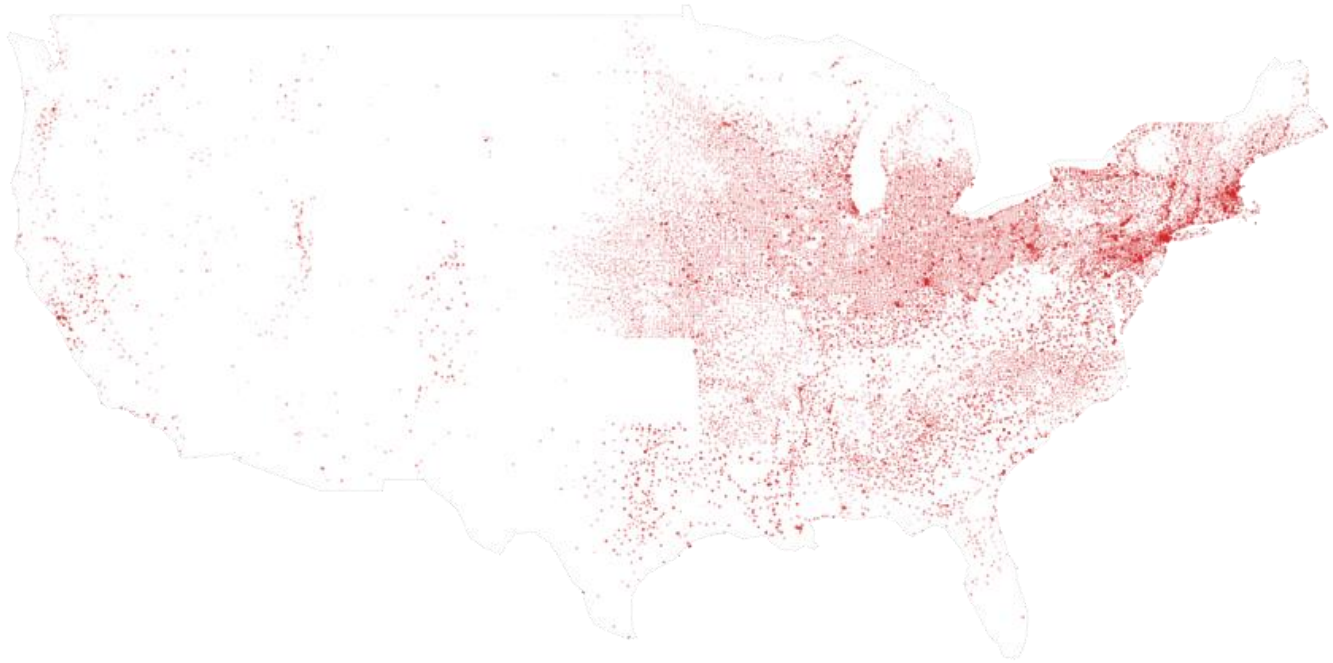
Geocoding (1860)



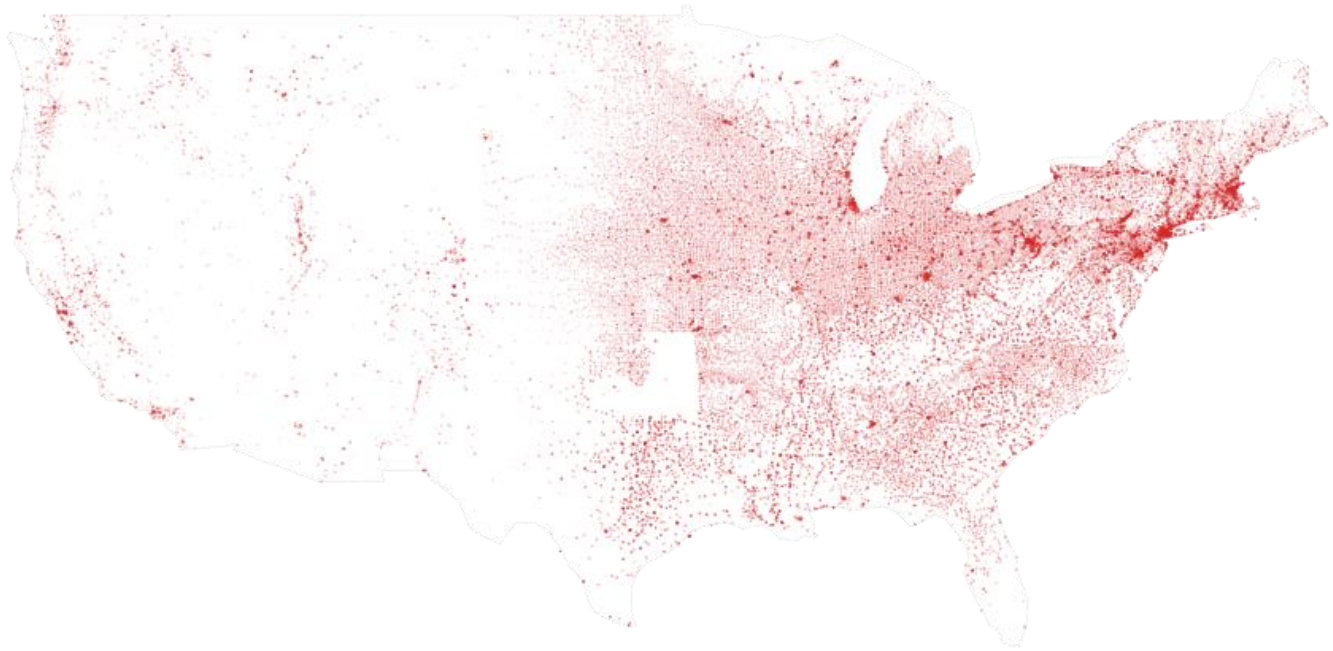
Geocoding (1870)



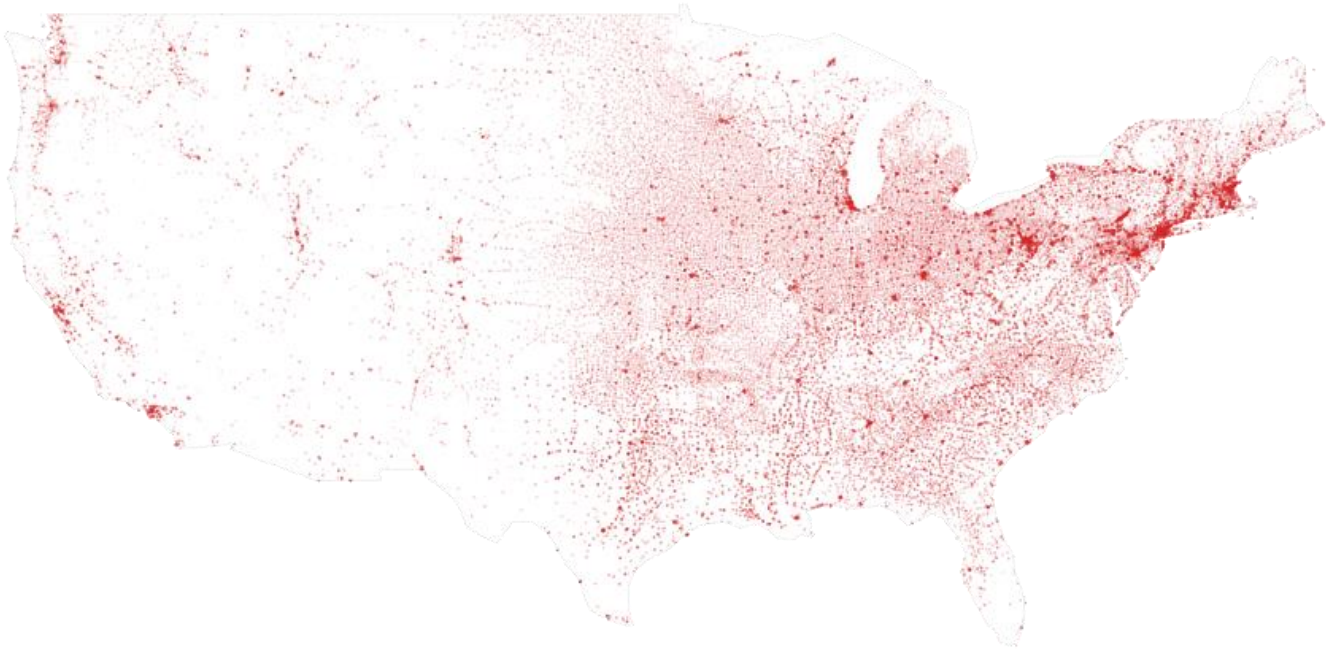
Geocoding (1880)



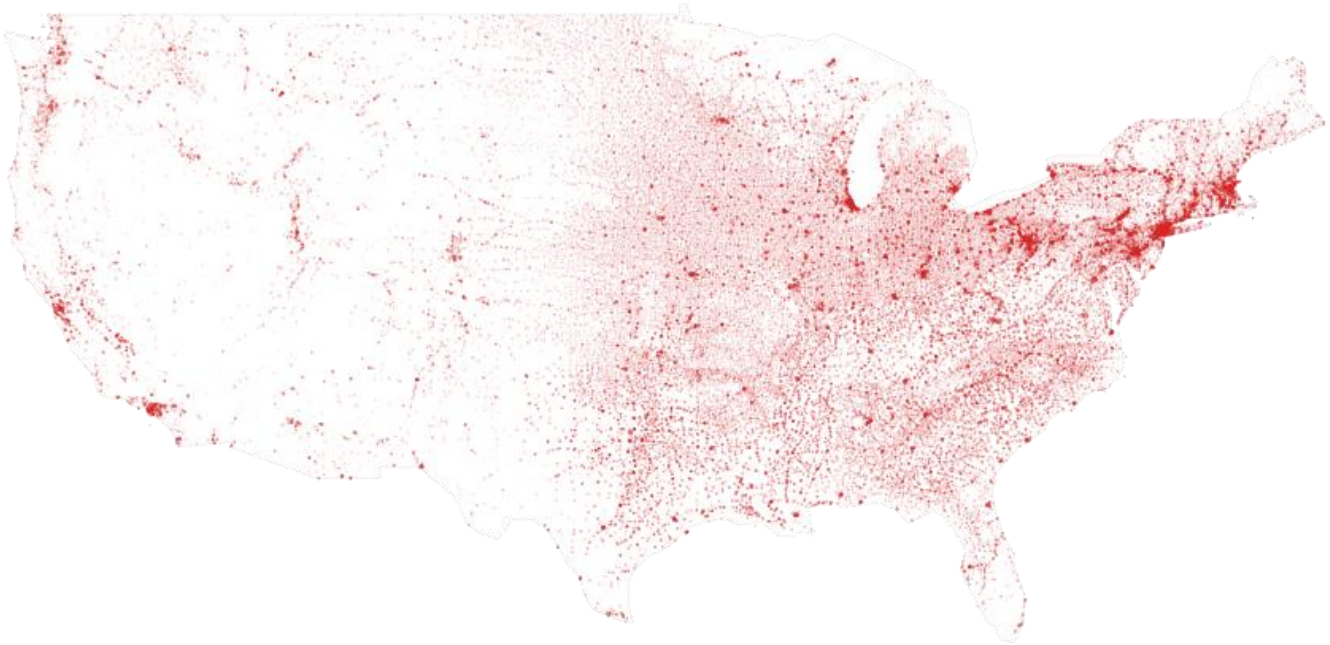
Geocoding (1900)



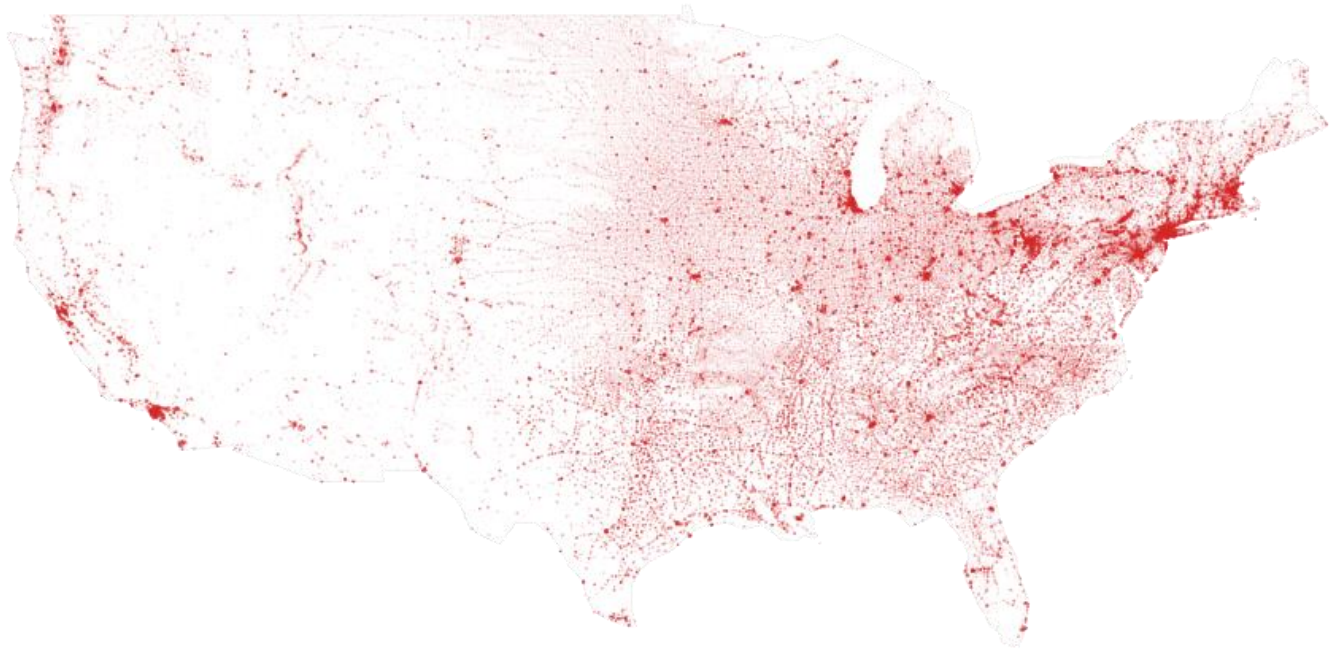
Geocoding (1910)



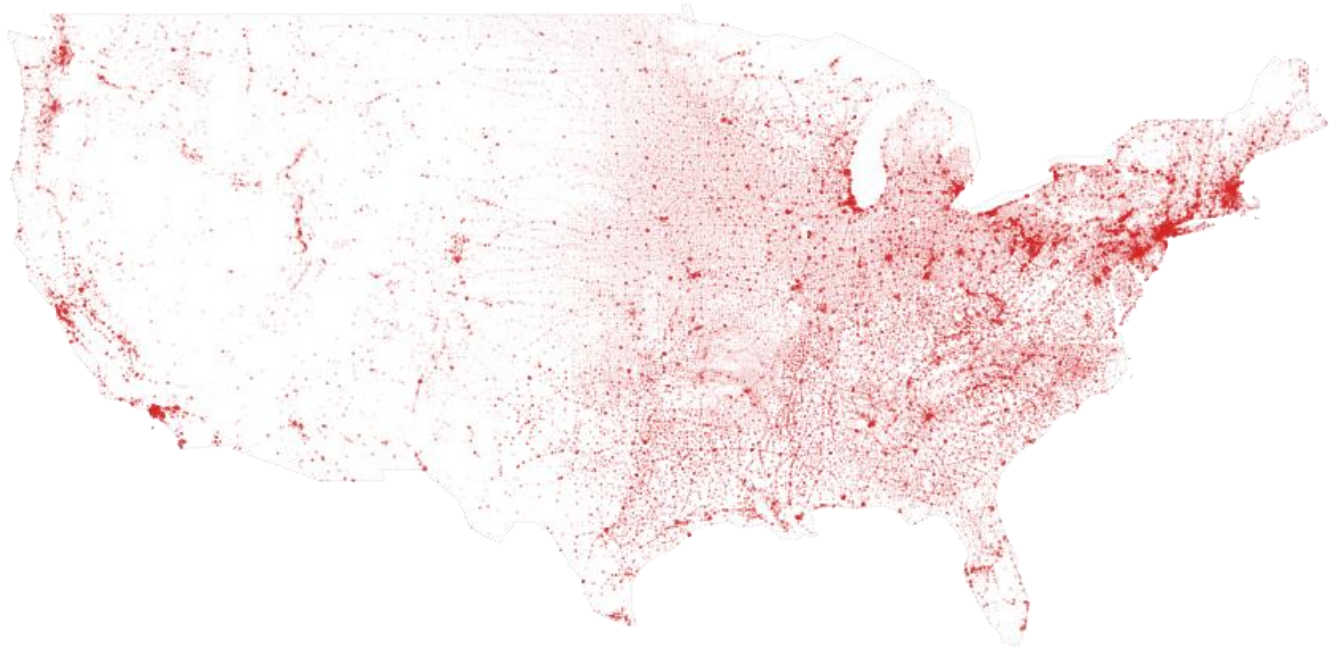
Geocoding (1920)



Geocoding (1930)



Geocoding (1940)



Result

- Matched censuses 1850-1940
  - 650M individuals, linked across waves
  - Occupation, industry, detailed location
  - Age, gender, race (+ some other information)
  - Family relations among them

- USPTO linked to census
  - 4M+ patents
  - 1792-1975
  - Inventors, locations, technology classes
  - ~ 8000 unique R&D labs

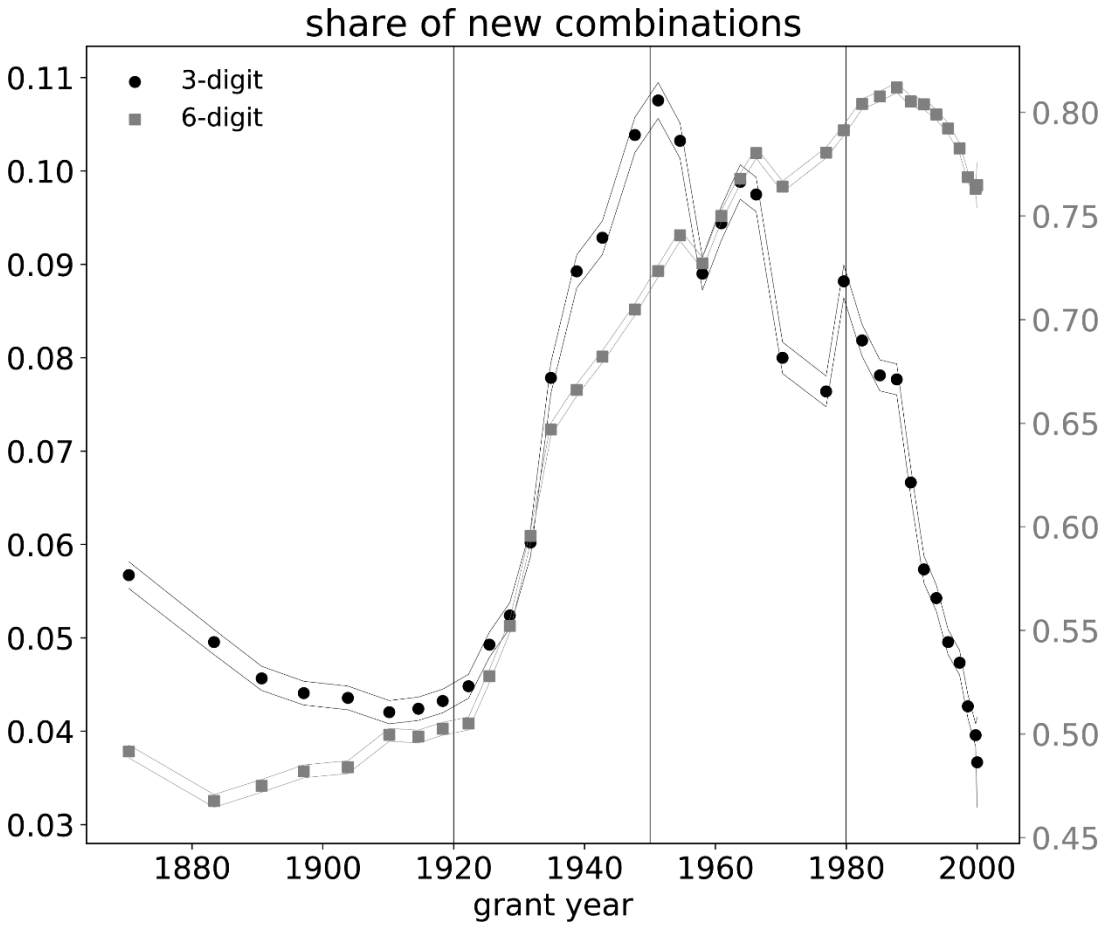
Burden of knowledge:

Gaining new knowledge requires greater investments
in mastering existing knowledge

(1) Changing learning curves
(2) Emergence of specialized inventors
(3) Emergence of teamwork

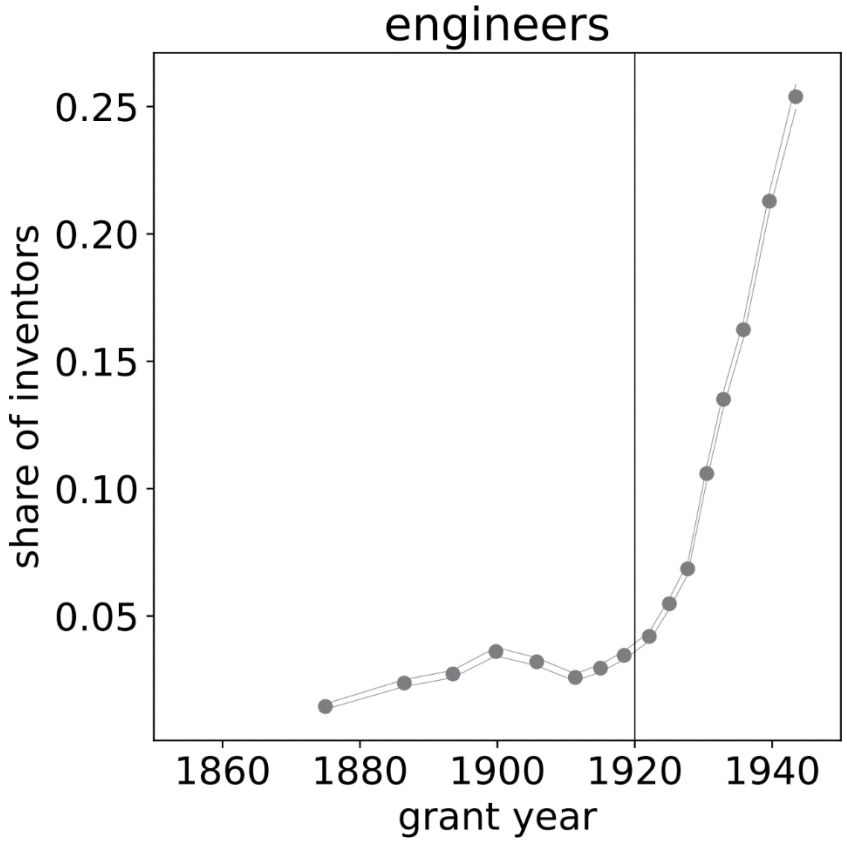
New combinations:

Share of patents with a new combination of technology classes



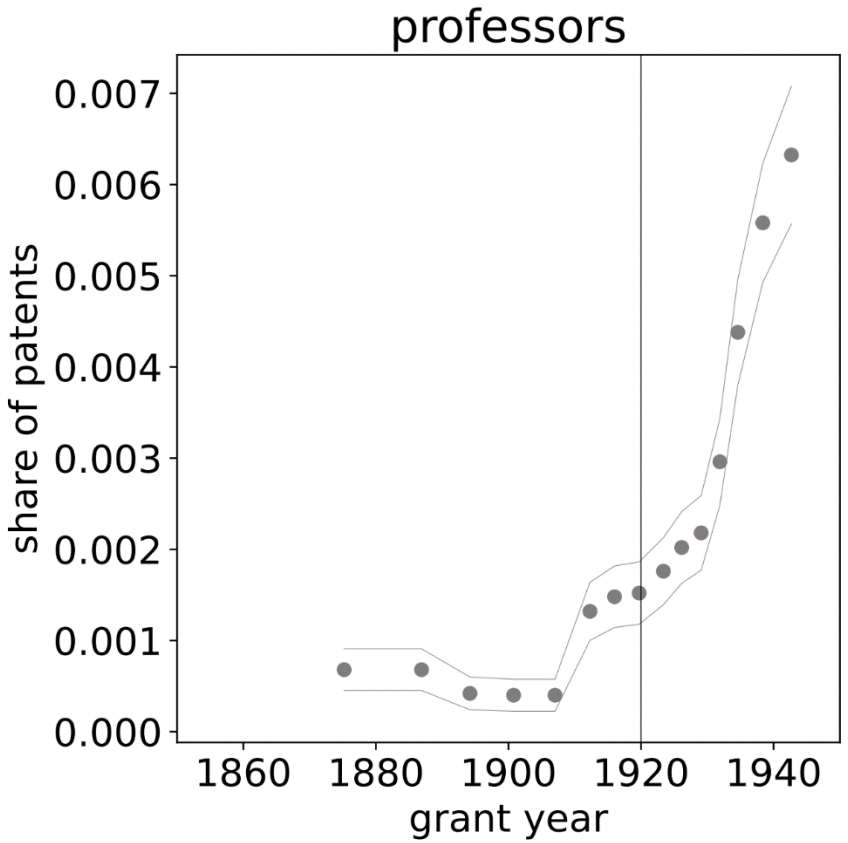
Burden of knowledge

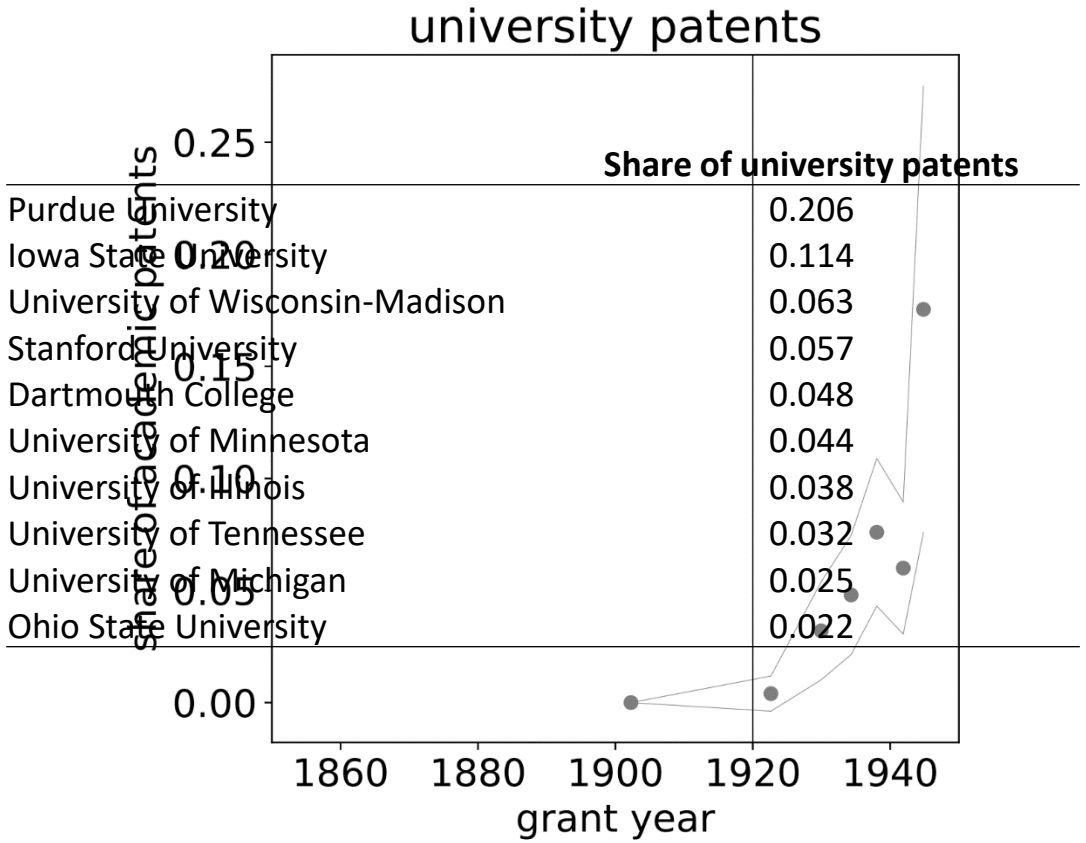
Increasing level of formal skills



Academic patents

Professors and universities

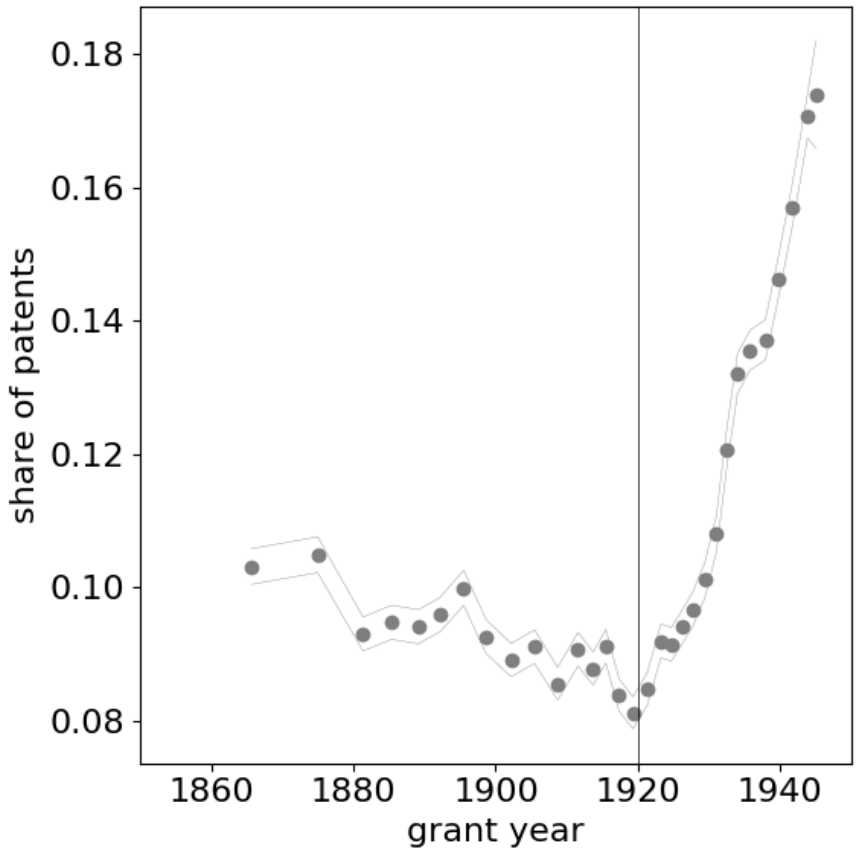




Share of university patents	
Purdue University	0.206
Iowa State University	0.114
University of Wisconsin-Madison	0.063
Stanford University	0.057
Dartmouth College	0.048
University of Minnesota	0.044
University of Illinois	0.038
University of Tennessee	0.032
University of Michigan	0.025
Ohio State University	0.022

Burden of knowledge

The rise of teamwork



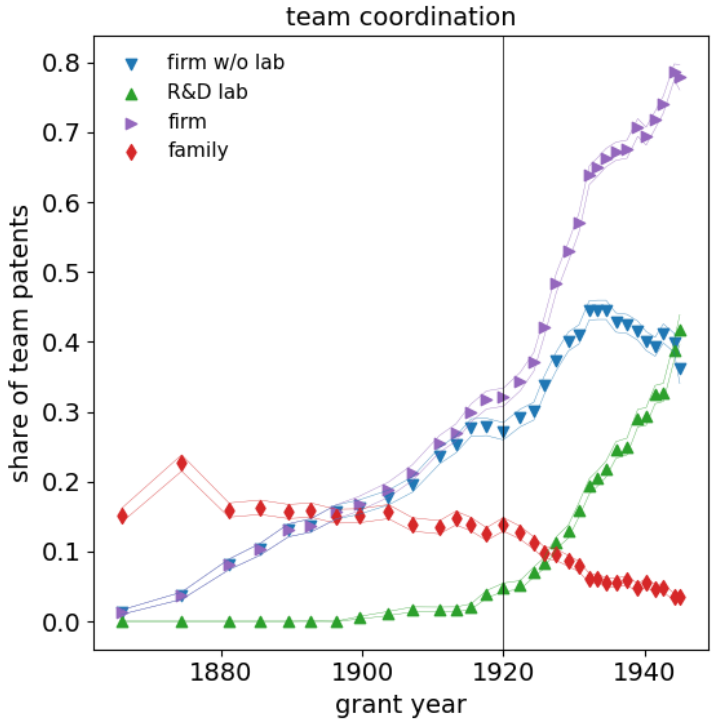
Organizational innovation: Corporate research

(1) Rise of industrial research lab
(2) Labs support team coordination
(3) Lab-based teams create more novelty

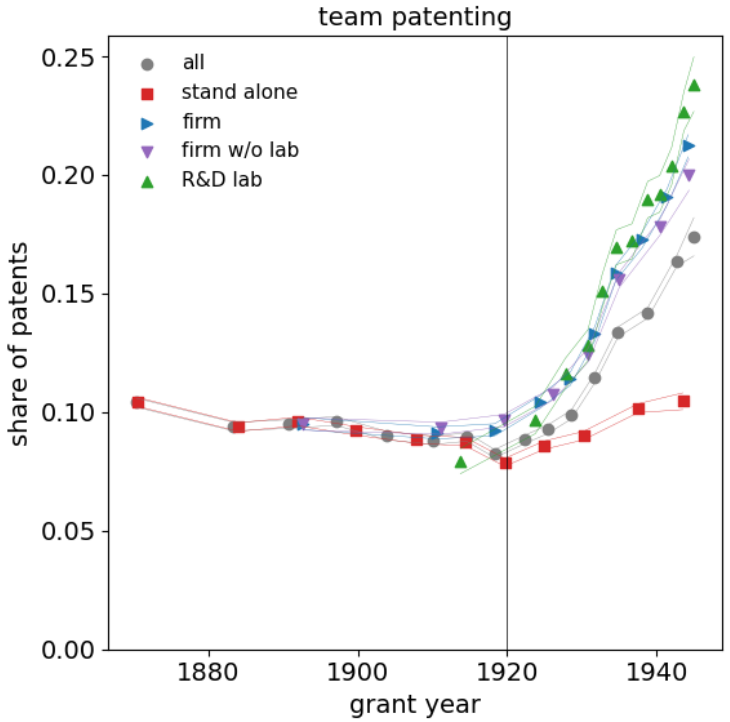
Team coordination

From families to firms and labs

Dominant coordination mechanism

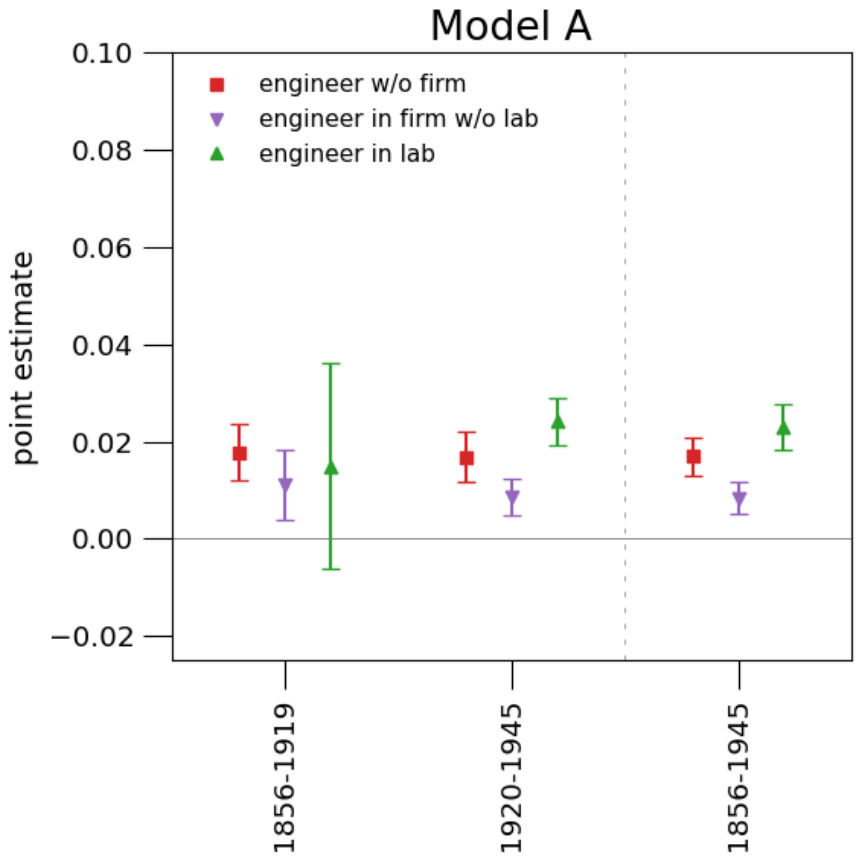


Probability of team patent

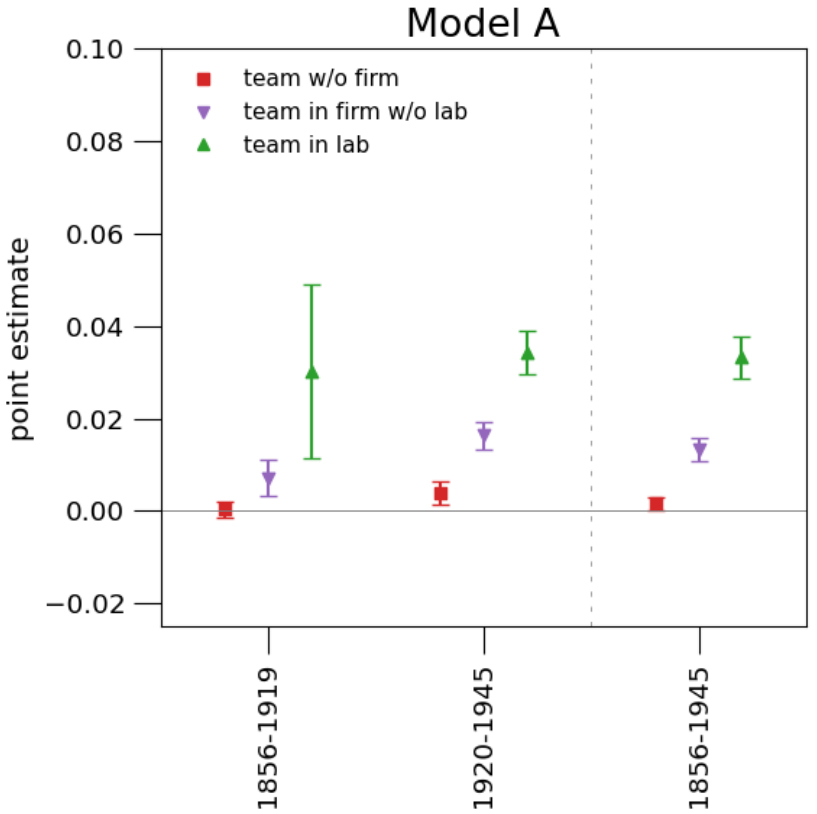


Labor inputs and novelty

Engineers and teams



Engineers

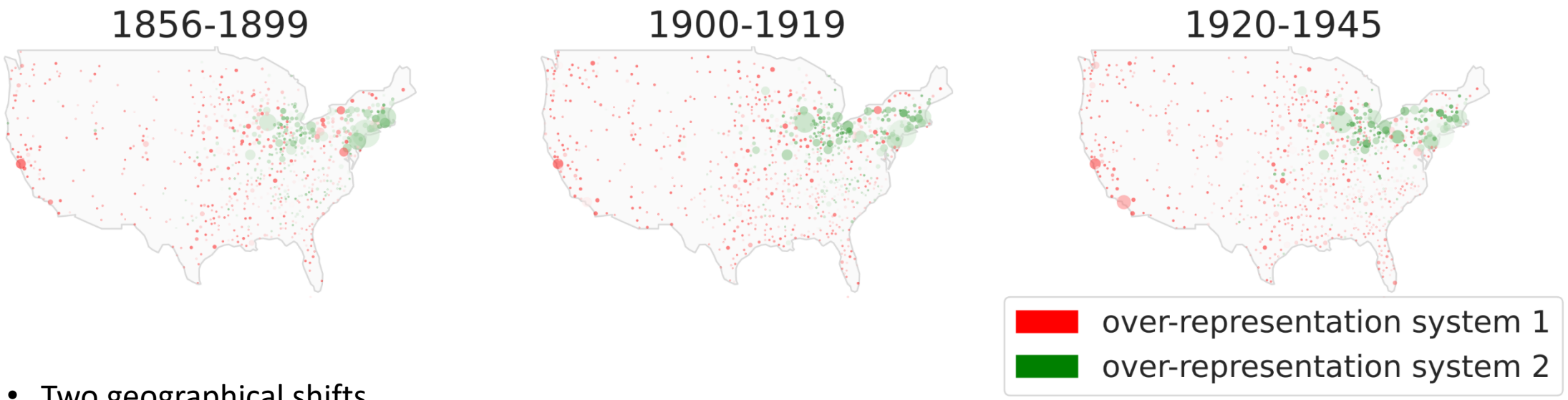


Teams

Consequences for the geography of innovation

Shifts in the geography of invention

System 2: the rise of the Rustbelt



- Two geographical shifts
  - Reconcentration of inventive activity in fewer locations
  - Reconcentration of inventive activity in largest cities
- These shifts are led by system 2 and followed by system 1
  - Until 1925, locational patterns of system 1 and system 2 diverge
  - From 1925 on, spatial convergence of system 1 and system 2

Conclusions

Confluence of shifts in the US innovation system

- In the 1920s, we witness a co-evolution of
  - Explosion of novelty
  - Rise of teams
  - Worker specialization: long learning curves + rise of engineers
  - Organizational innovation: rise of corporate R&D and research labs
  - Shifting geography of innovation
  - (new hurdles for participation in invention for foreign-born inventors and women that last until into the 21st century)

- System 2 performs well until 1950
  - From 1950s on, radically new combinations in decline
  - In the 1970s, system 2 seems to only enhance incremental novelty: Firm-based teams underperform standalone inventors
  - What happened?
    - Decline of research labs? (Arora et al., 2020)
    - Teams are getting too large? (Wu et al., 2019)
    - New organizational innovations required? (online platforms?)

Skill complementarity

Neffke (Science Advances, 2019)

Pittsburgh Symphony Orchestra , Wikipedia, Photo Credit: Michael Sahaida, photographer

Laura Leganza Reynolds

RENDERING TECHNICAL ARTISTS

Jennifer Becker
Jay Carina
Claudia Chung
Humera Yasmin Khan
Michael Kilgore
Ian Steplowski
Mark VandeWettering
Matthew Webb

RENDERING COORDINATOR

Eric Rosales

TECHNICAL DEVELOPMENT

Stephan Vladimir Bugaj
Manuel Kraemer
Ferdi Scheepers
Mark VandeWettering

TECHNICAL PRE-PRODUCTIO

Administrative registry data Sweden

- Time period: (1990/)2001-2010
  - Entire Swedish population
  - Training sample: 75% of workforce
  - Estimation sample: remaining 25%, male, 20-60 yrs old, private sector: 440k individuals.
  - Sociodemographic information, career path, wage, workplace, etc.

- Education coding
  - 500+ combinations 4-digit education type and 1 digit education level
  - Educational levels:

1 primary school	2 different types
2 secondary school	2 different types
3 upper secondary school	123 different types
4 post-secondary school	71 different types
5 tertiary	204 different types
6 PhD	59 different types

Program in animal husbandry

Image: http://www.sn-online.de/Schaumburg/Landkreis/Themen/Thema-des-Tages/Nachfolger

Applied systems science and software engineering

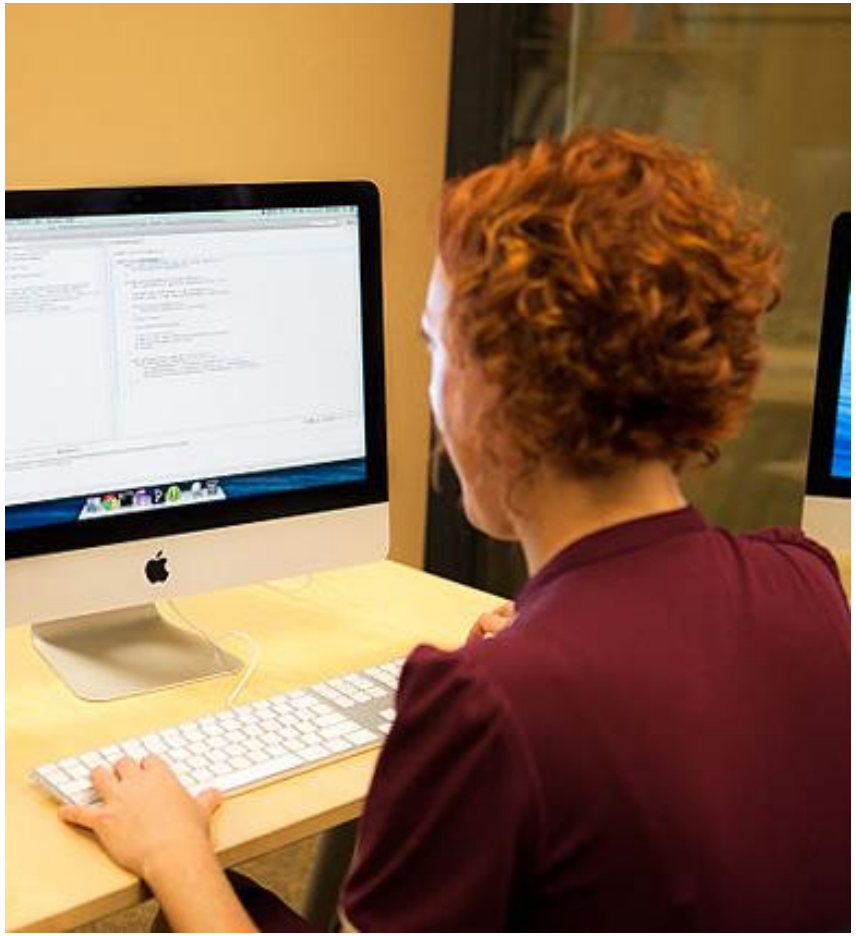


Image: Joonspoon - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=36613680

Nursing, midwifery

Image: http://www.cardiffandvaleuhb.wales.nhs.uk/news/28870

Nursing, geriatric care

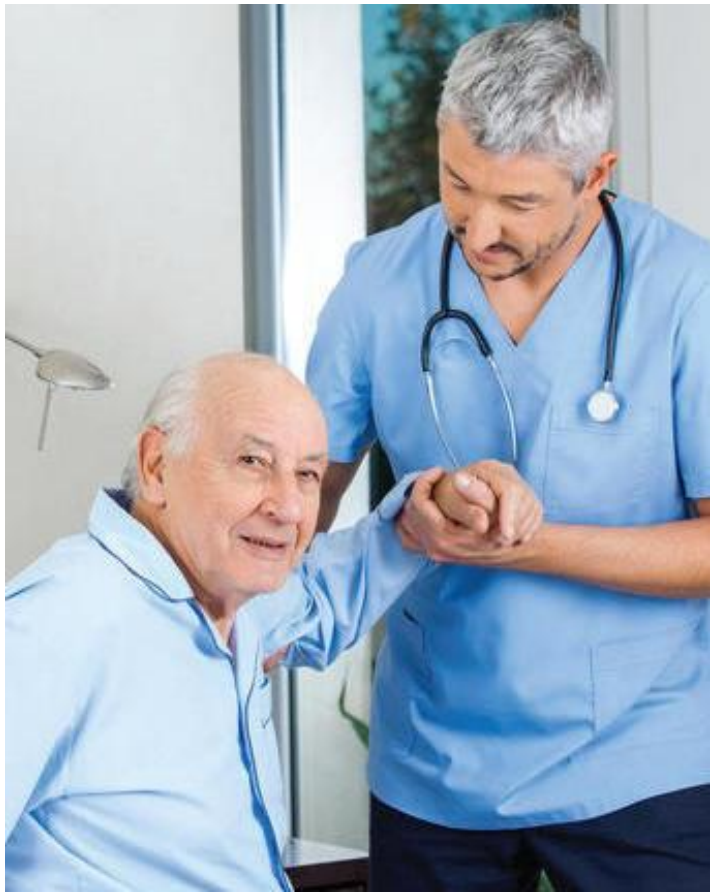
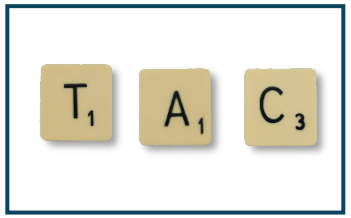


Image: http://strongholdhomehealth.org/

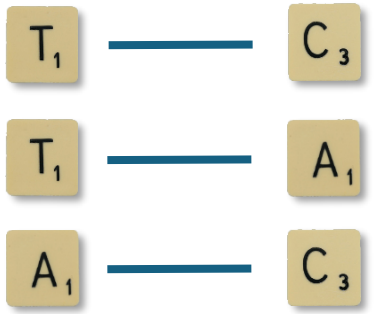
Education-to-education
coworking

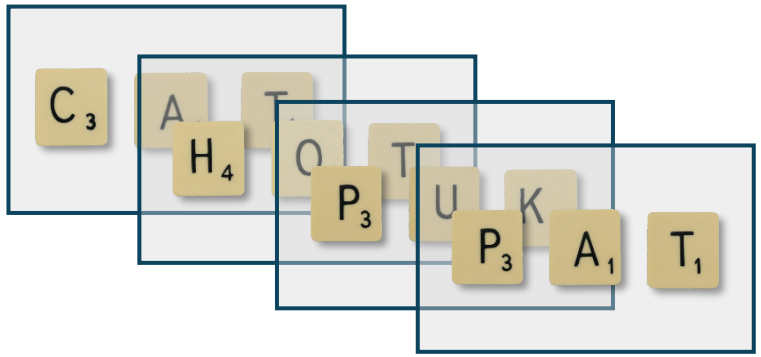
Complementarity: which educations often work together?

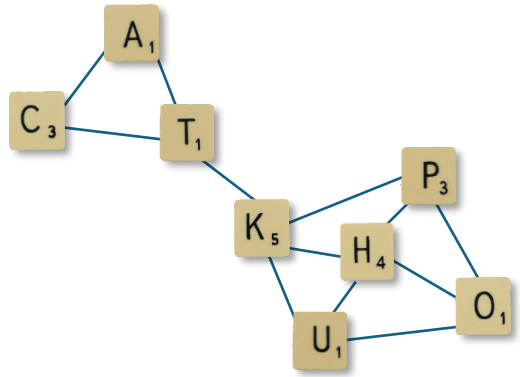
establishment



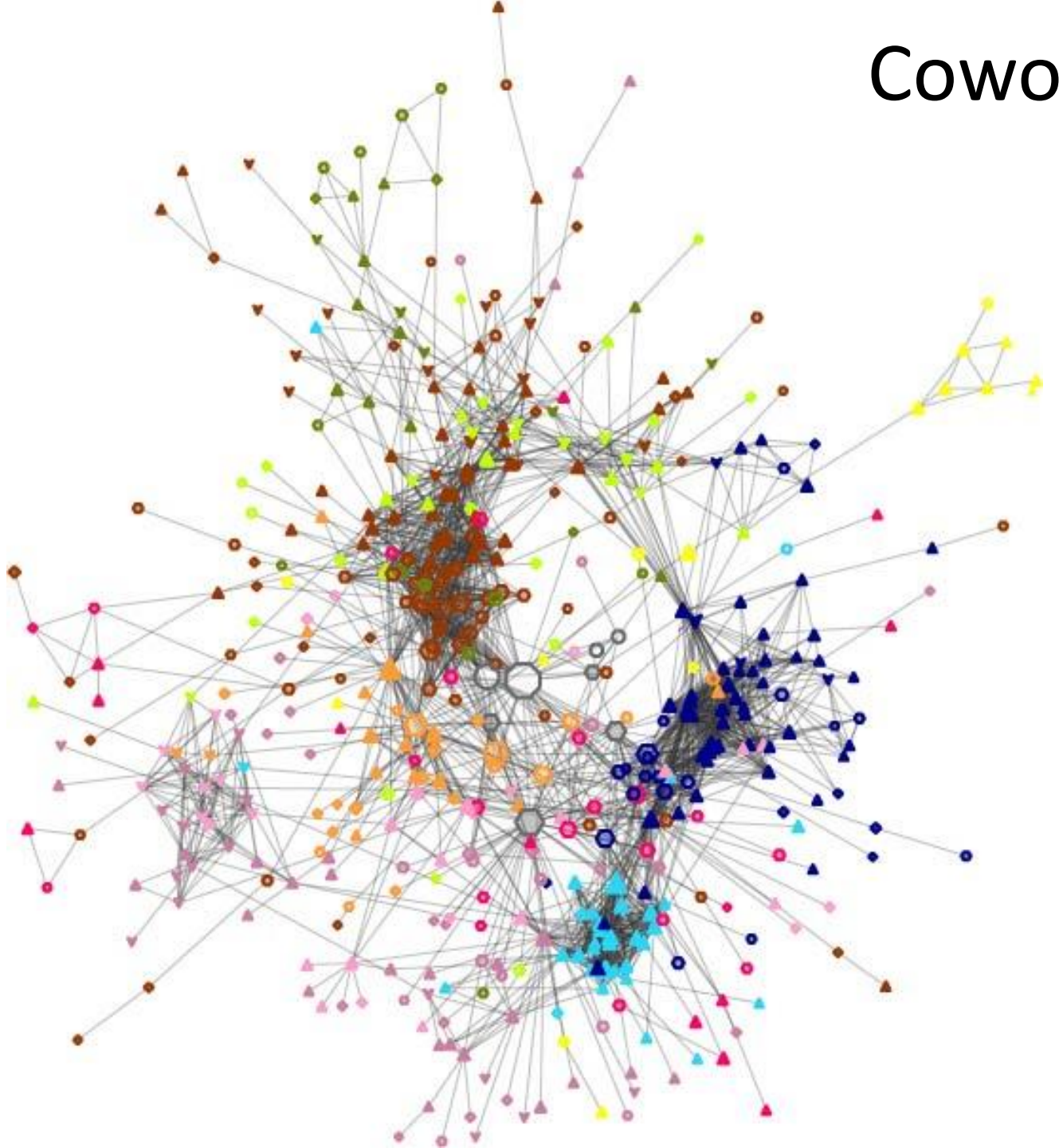
co-occurrences



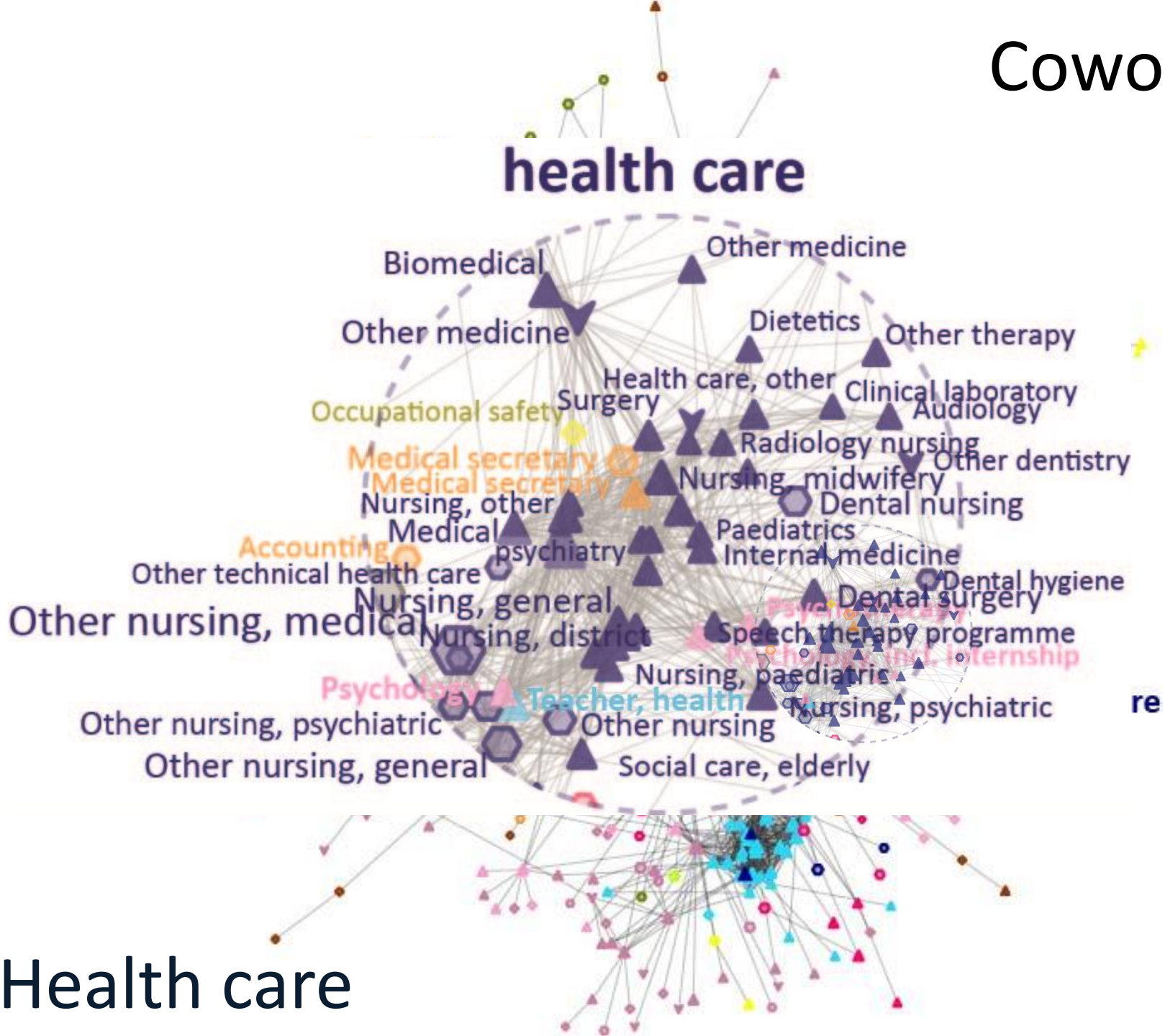




Coworking



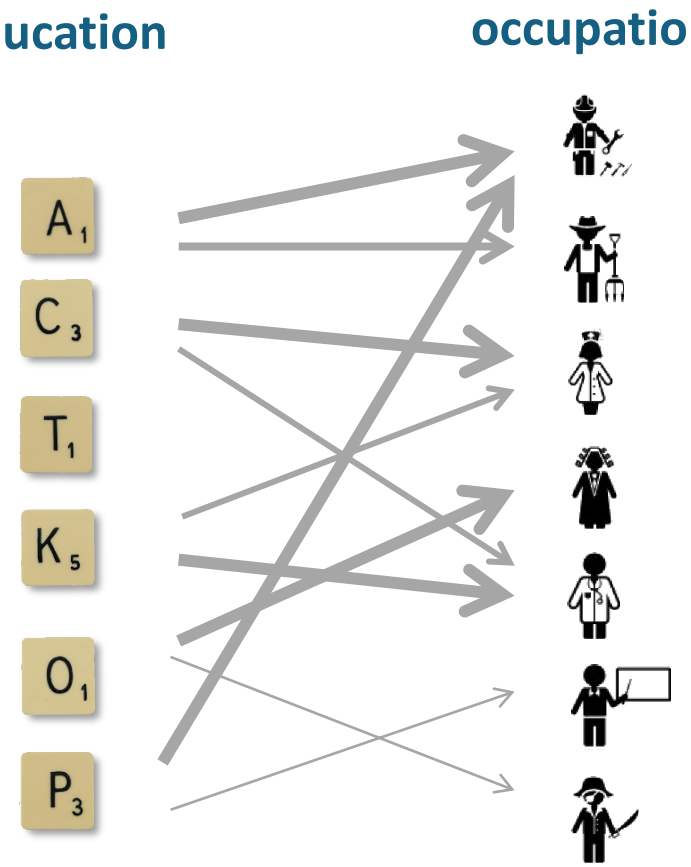
Coworking



Health care

Education-to-education **substitutability**

Substitutability: which educations give access to the same occupations?



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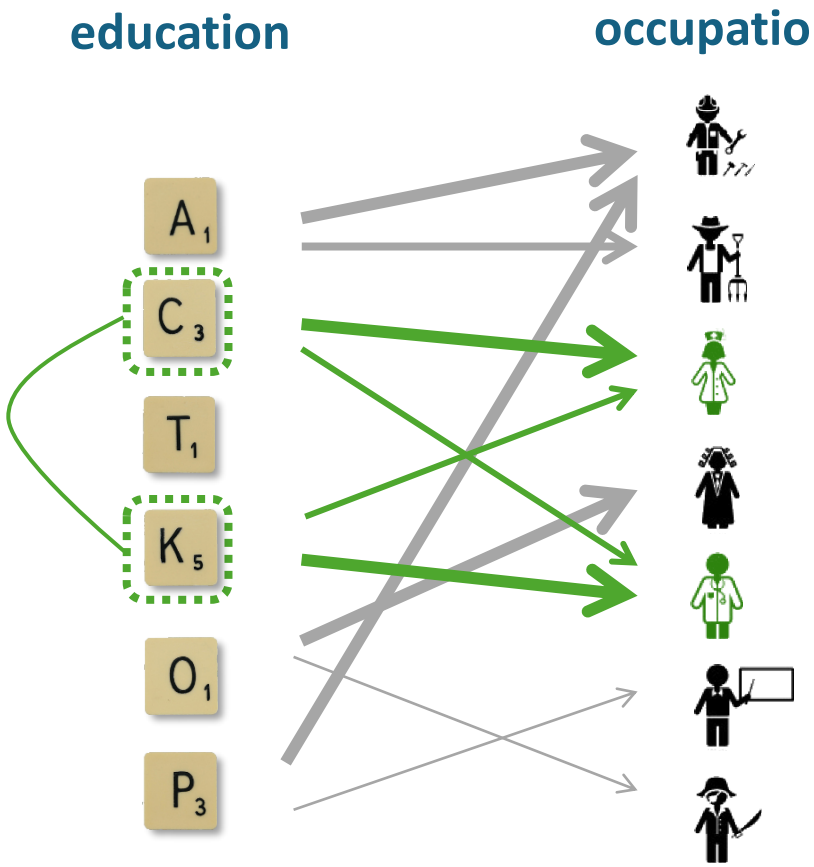
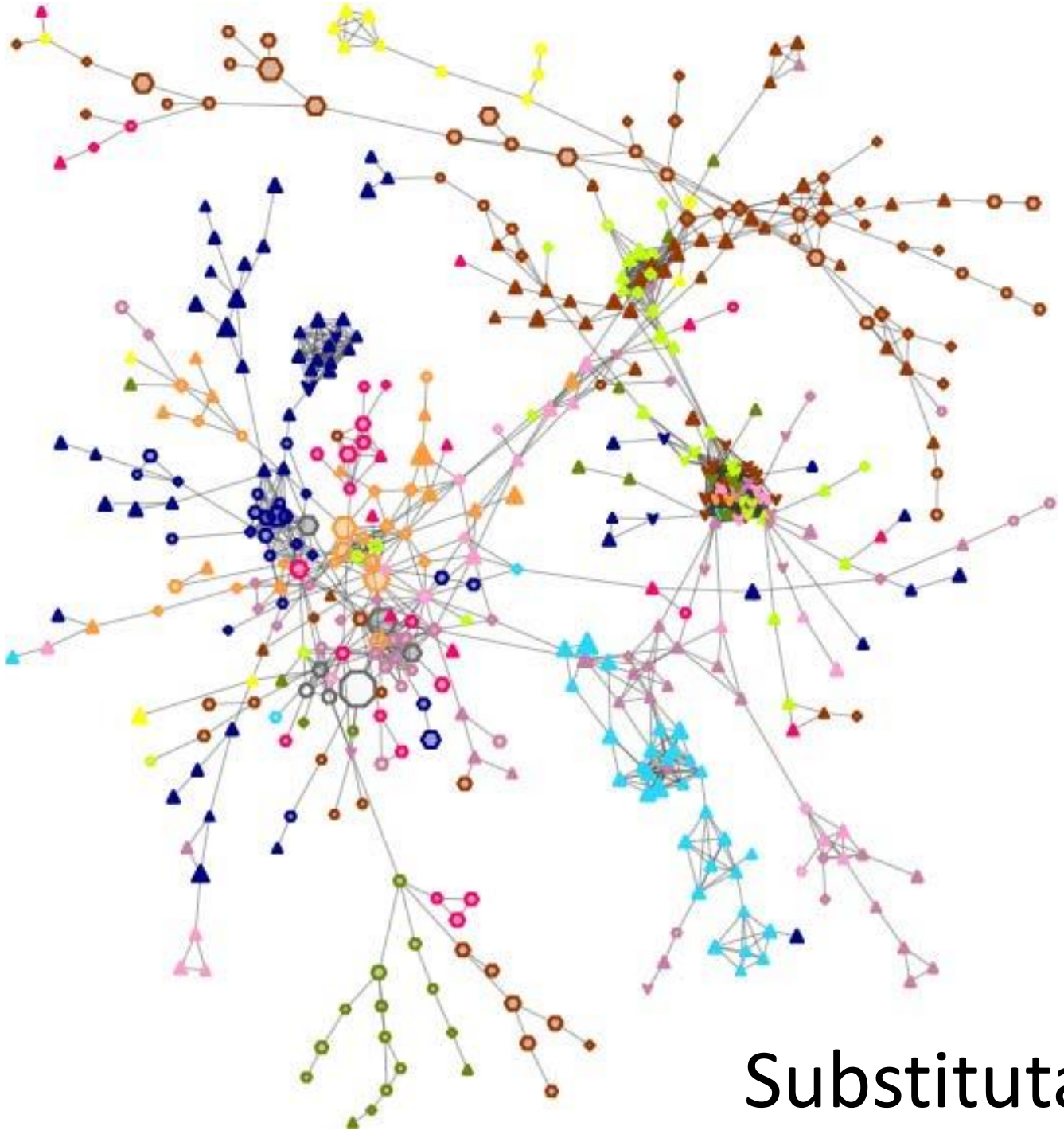
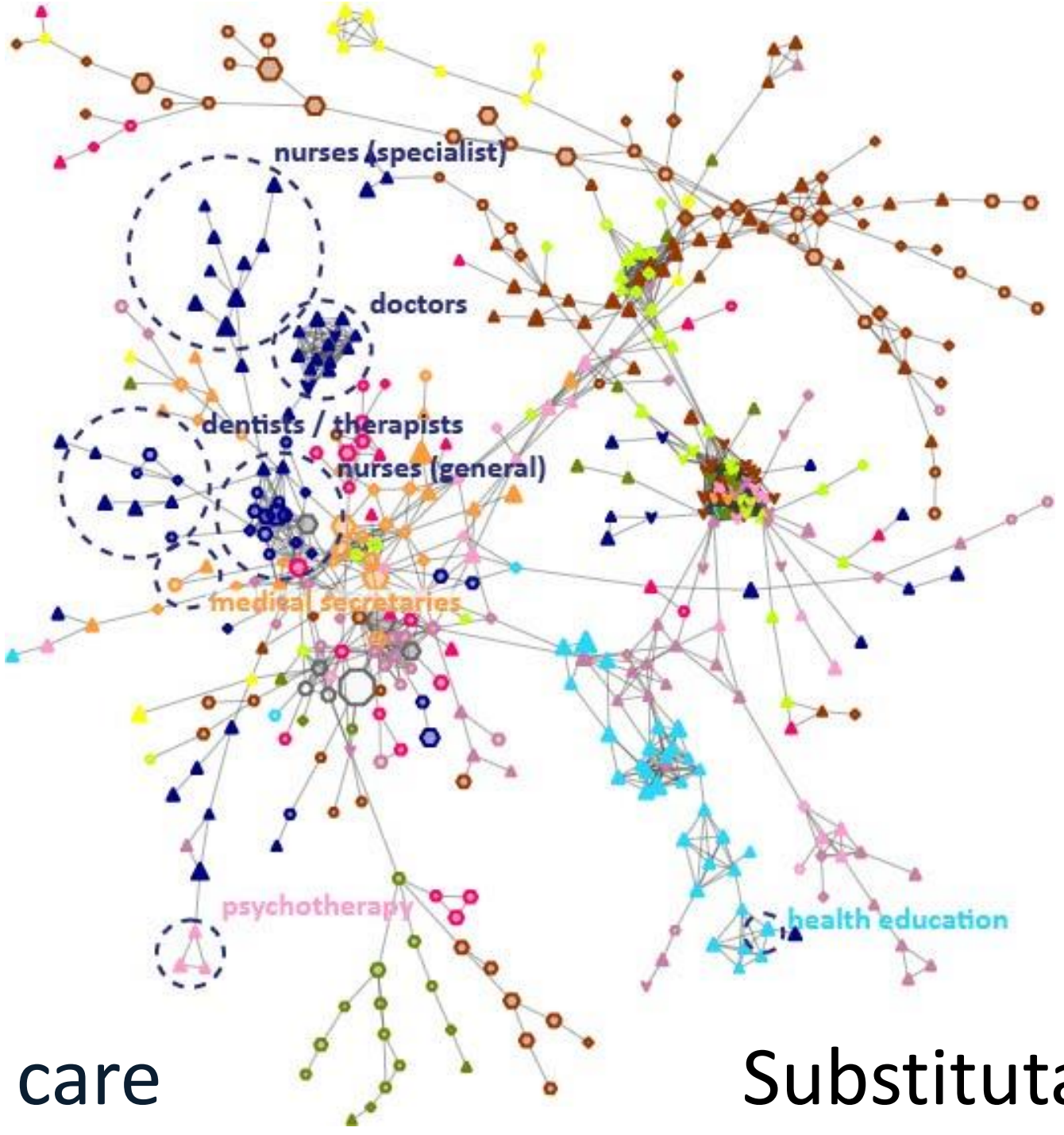




Substitutability

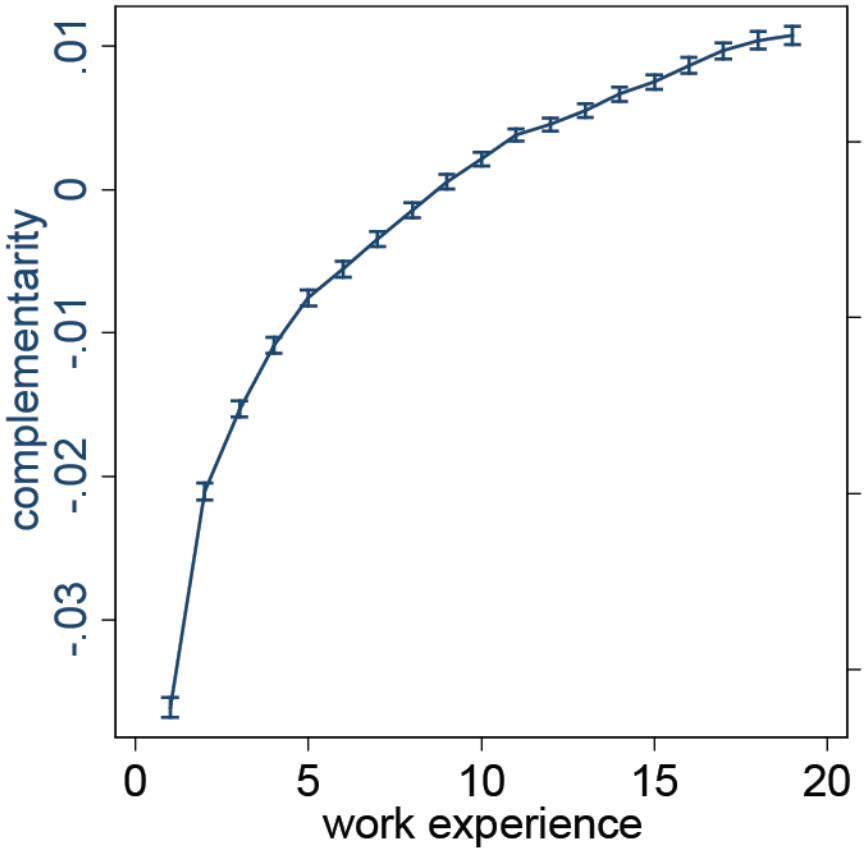


Health care

Substitutability

Work experience

Complementarity and **Wage** curves



Work experience

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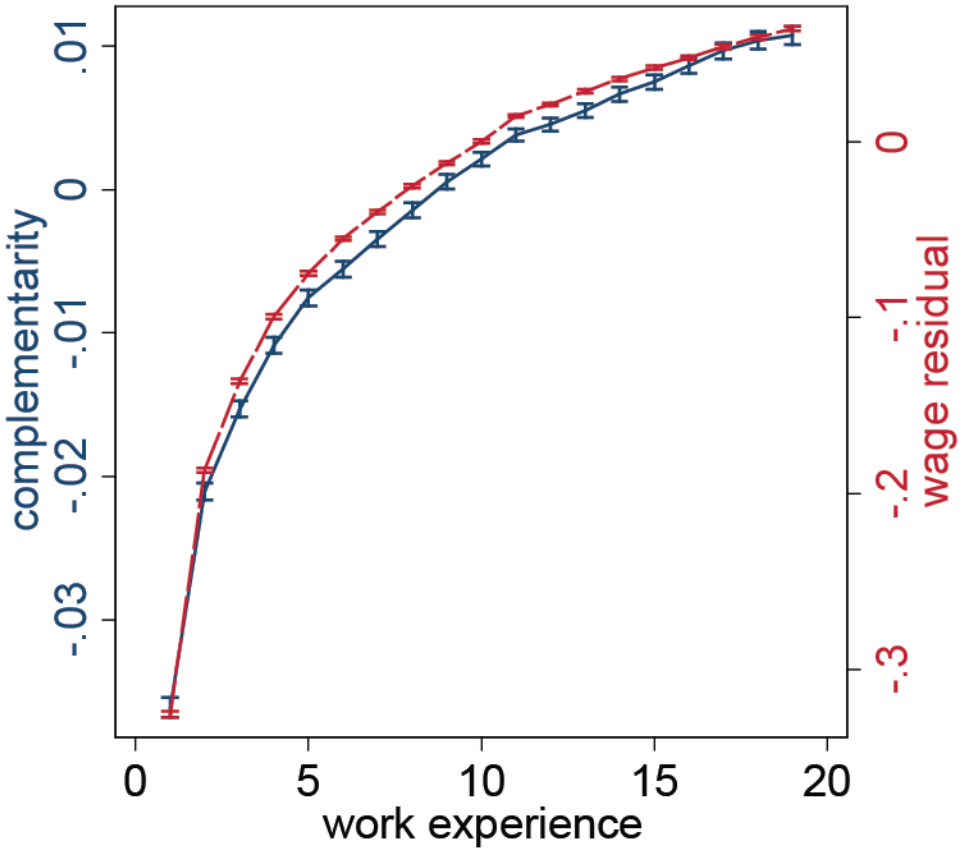
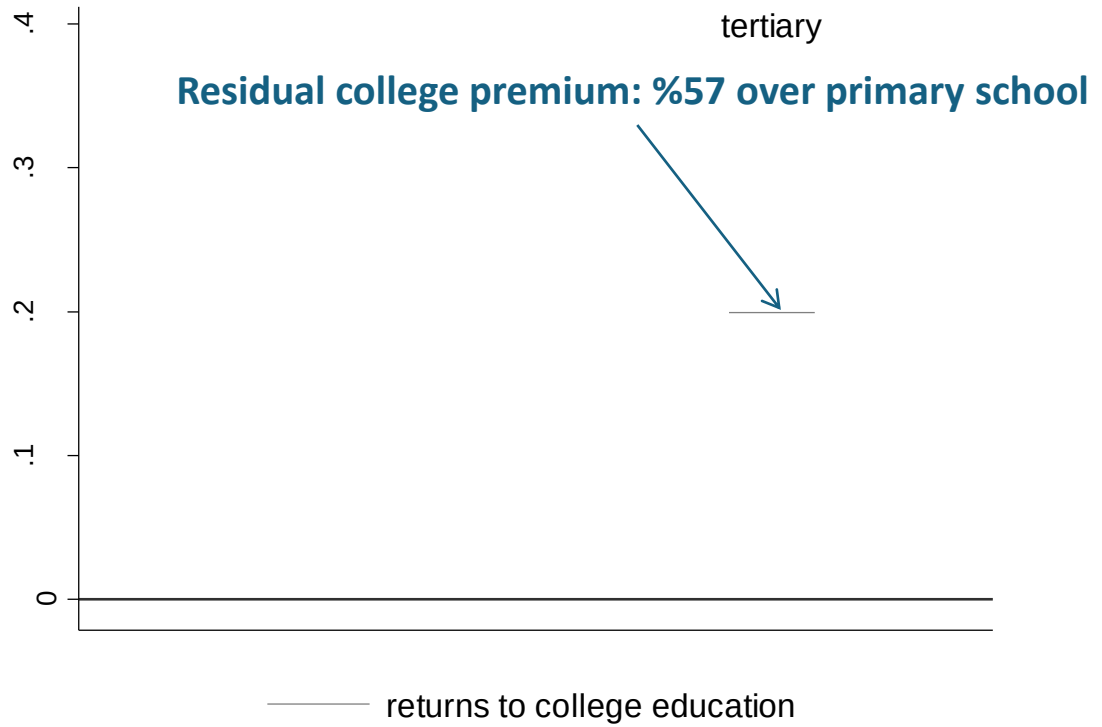


Returns to schooling

Do returns to schooling depend on finding complementary coworkers?



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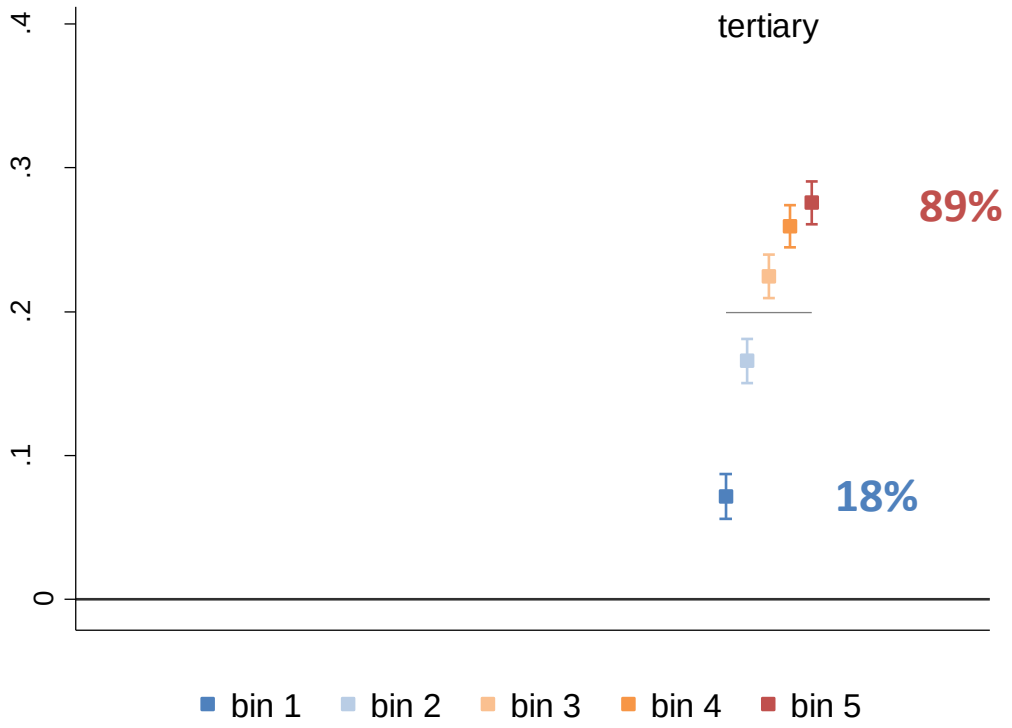

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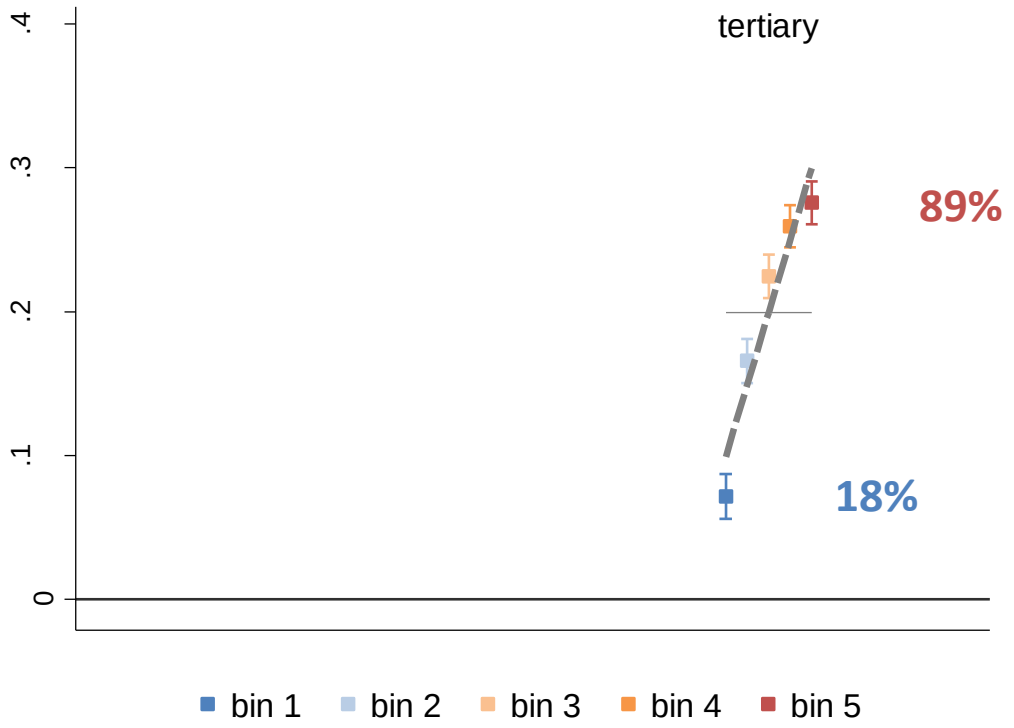

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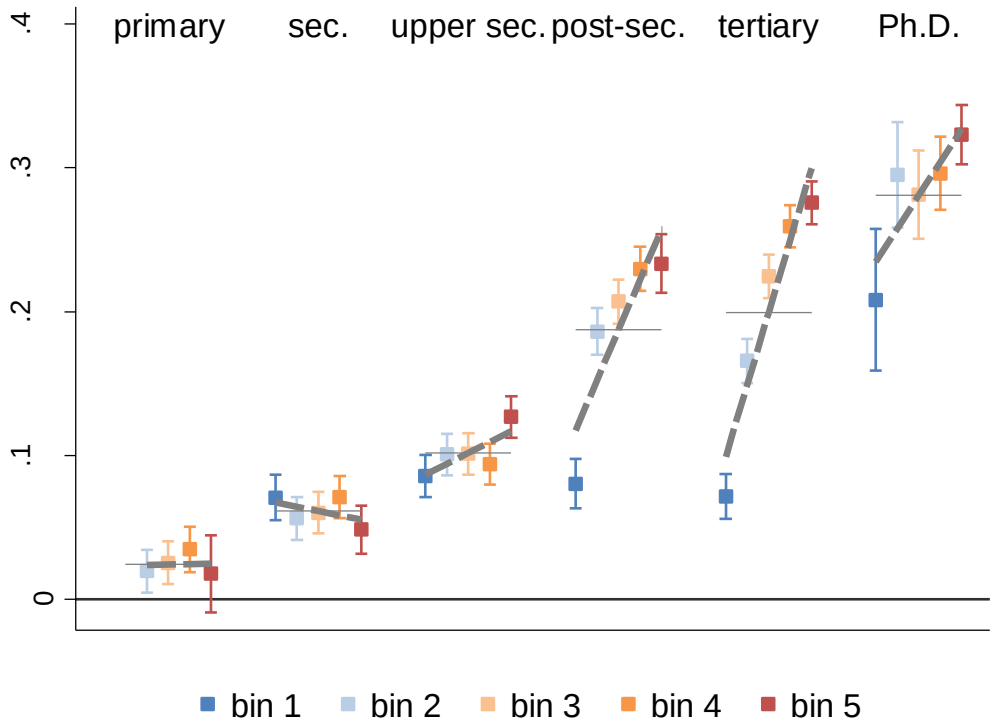

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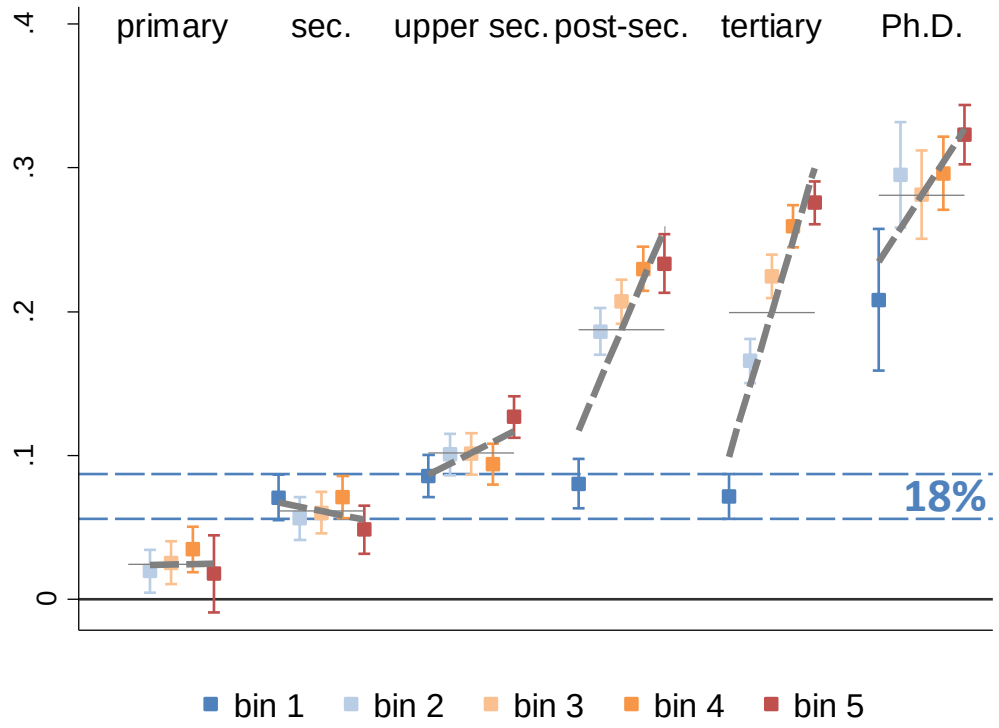
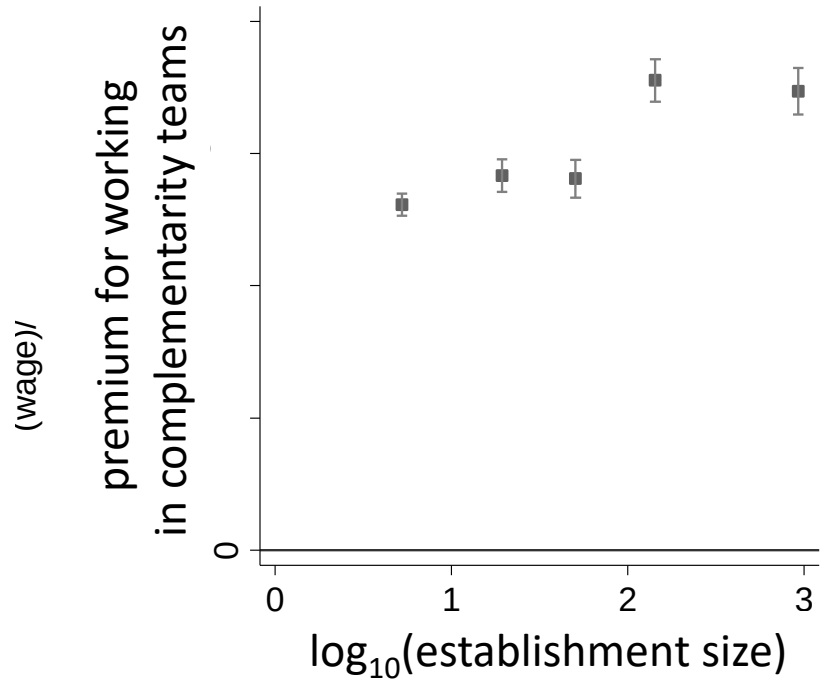
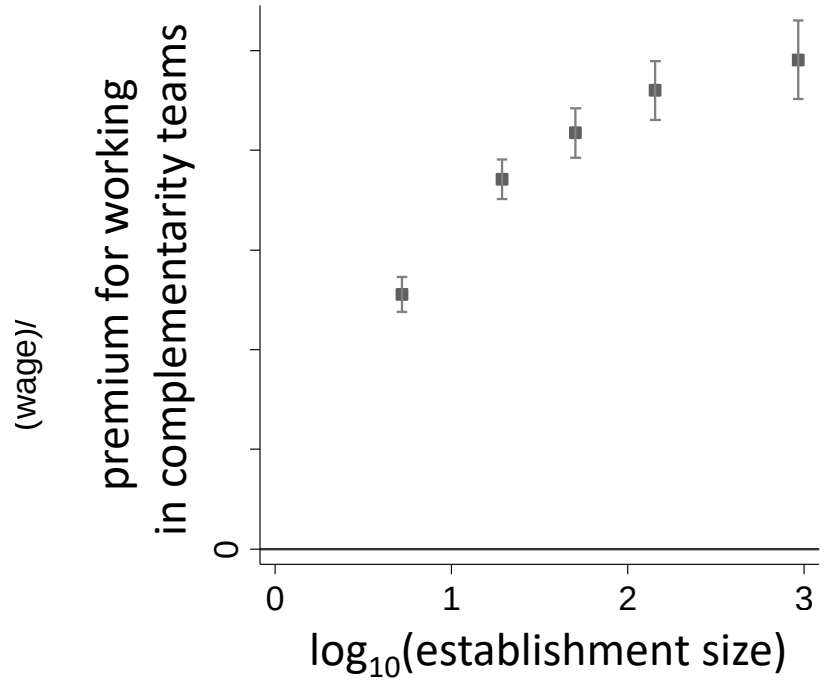


Complementarity premium (OLS)



Complementarity premium (FE)

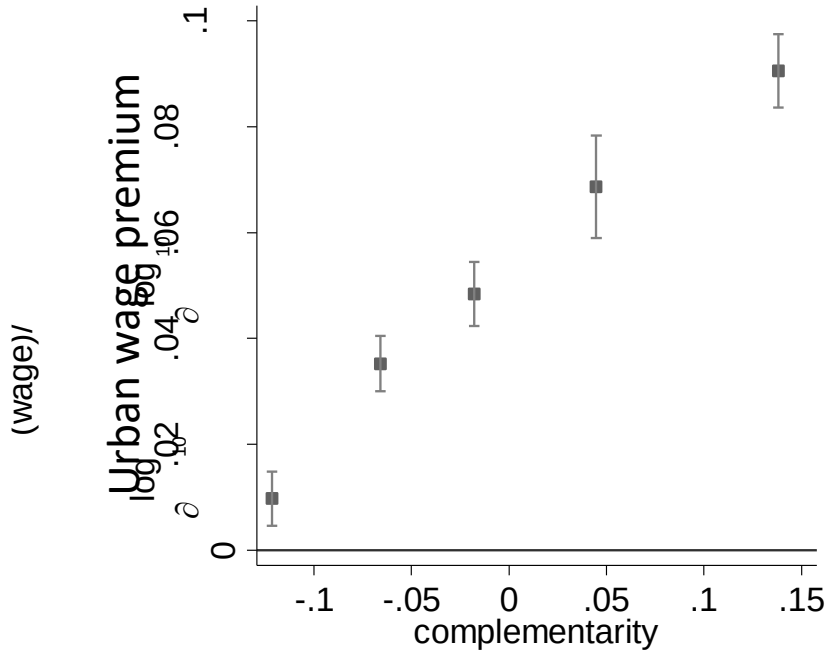


- Why are benefits of complementarity larger in larger establishments?
  - Deeper levels of specialization
  - Stronger interdependencies

Coordination and cities

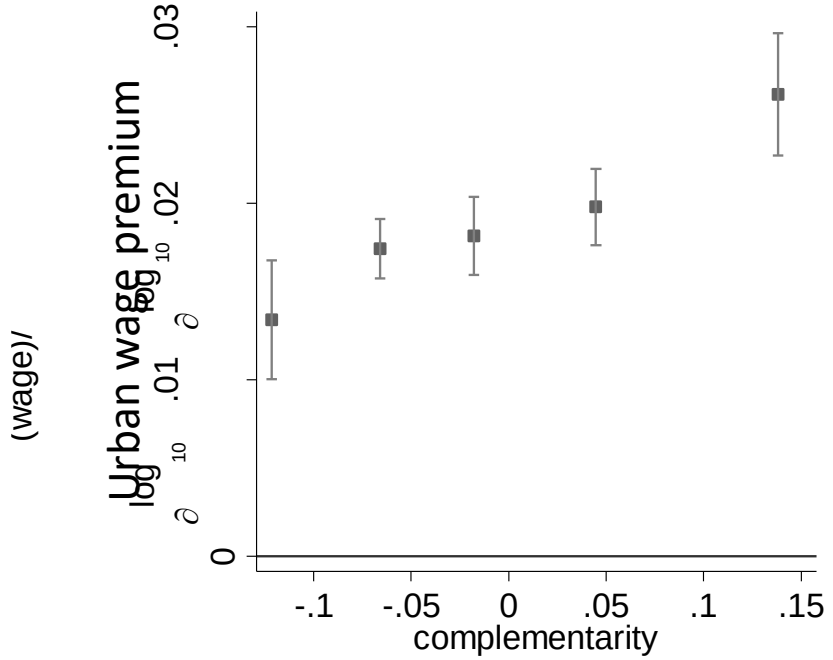
Variation in urban wage premiums (OLS)

Elasticity by complementarity quintile



Variation in urban wage premiums (FE)

Elasticity by complementarity quintile



Conclusions

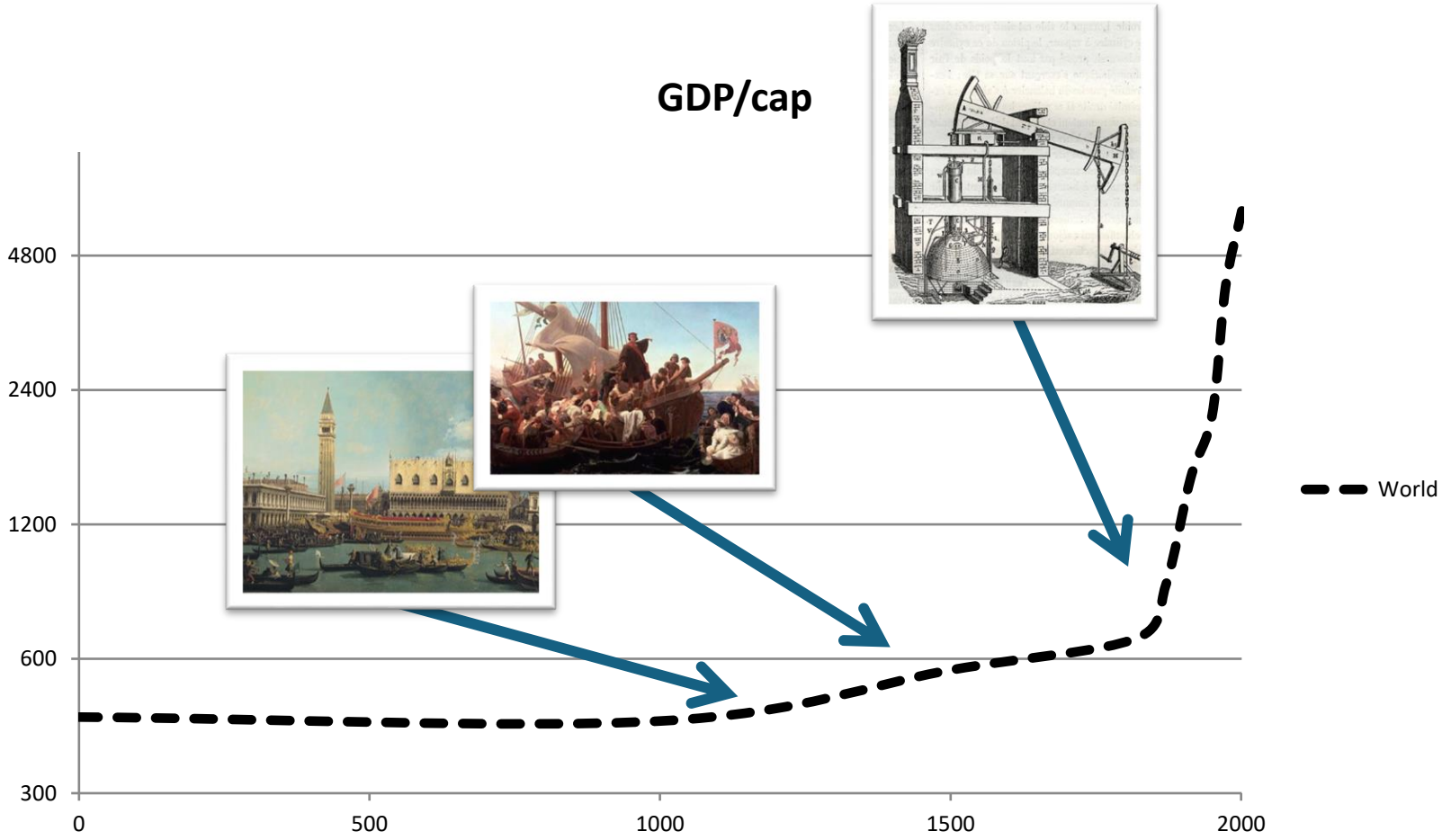
- Growing body of collective knowledge forces us to specialize

- Economy coordinates networks of networks:
  - Skills in individual
  - Expertise in teams
  - Teams in firms
  - Firms in global value chains

- Consequences
  - Need for innovation in how we coordinate human expertise
  - Greater independencies → value of skills depends on who you work with!

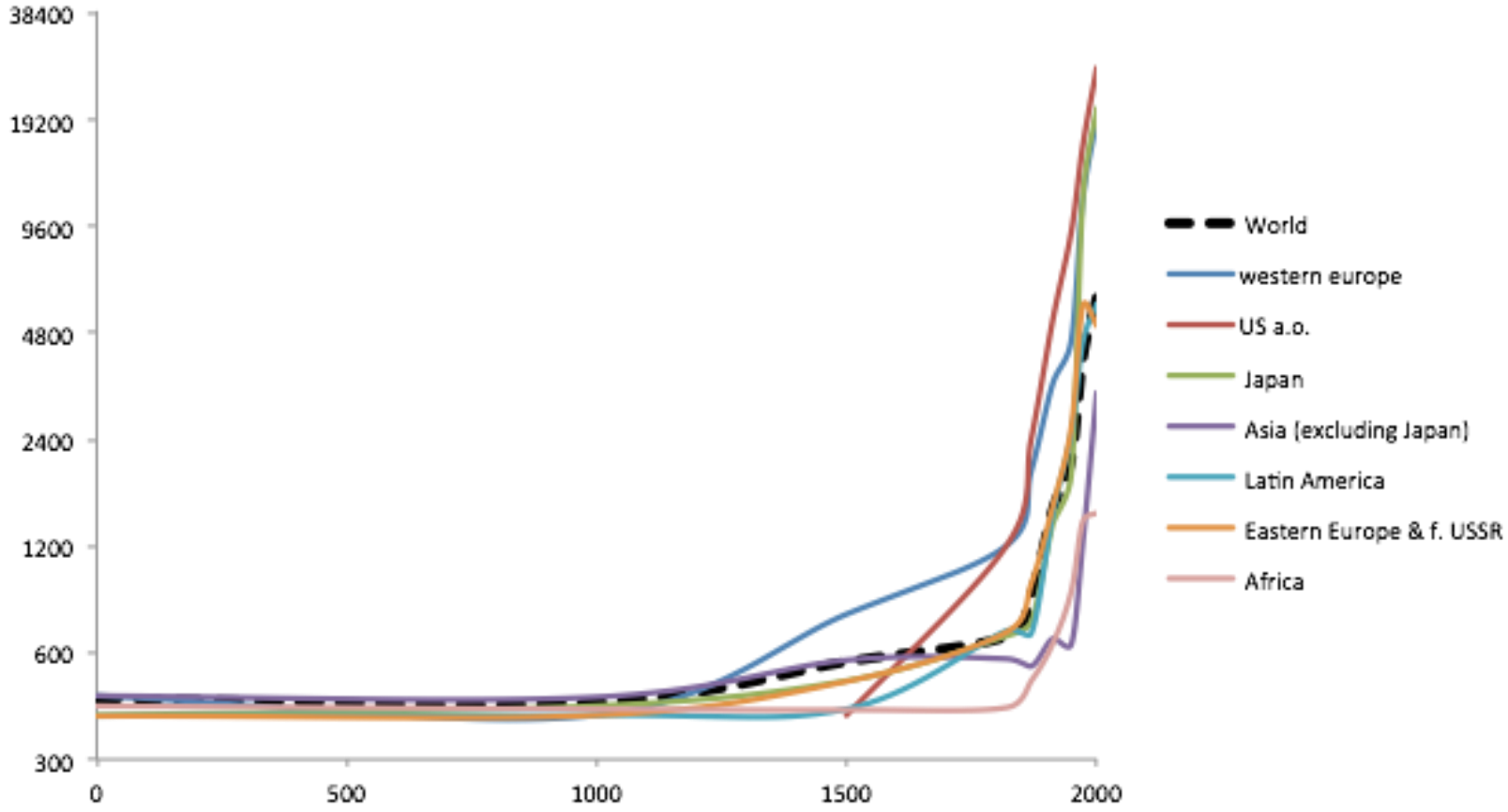
- Complexity Science
  - High resolution data on skills and capabilities
  - Networks that reveal coordination of distributed expertise
  - Complexity Science Hub → PhD and postdoctoral opportunities

Economic growth – a long-run perspective



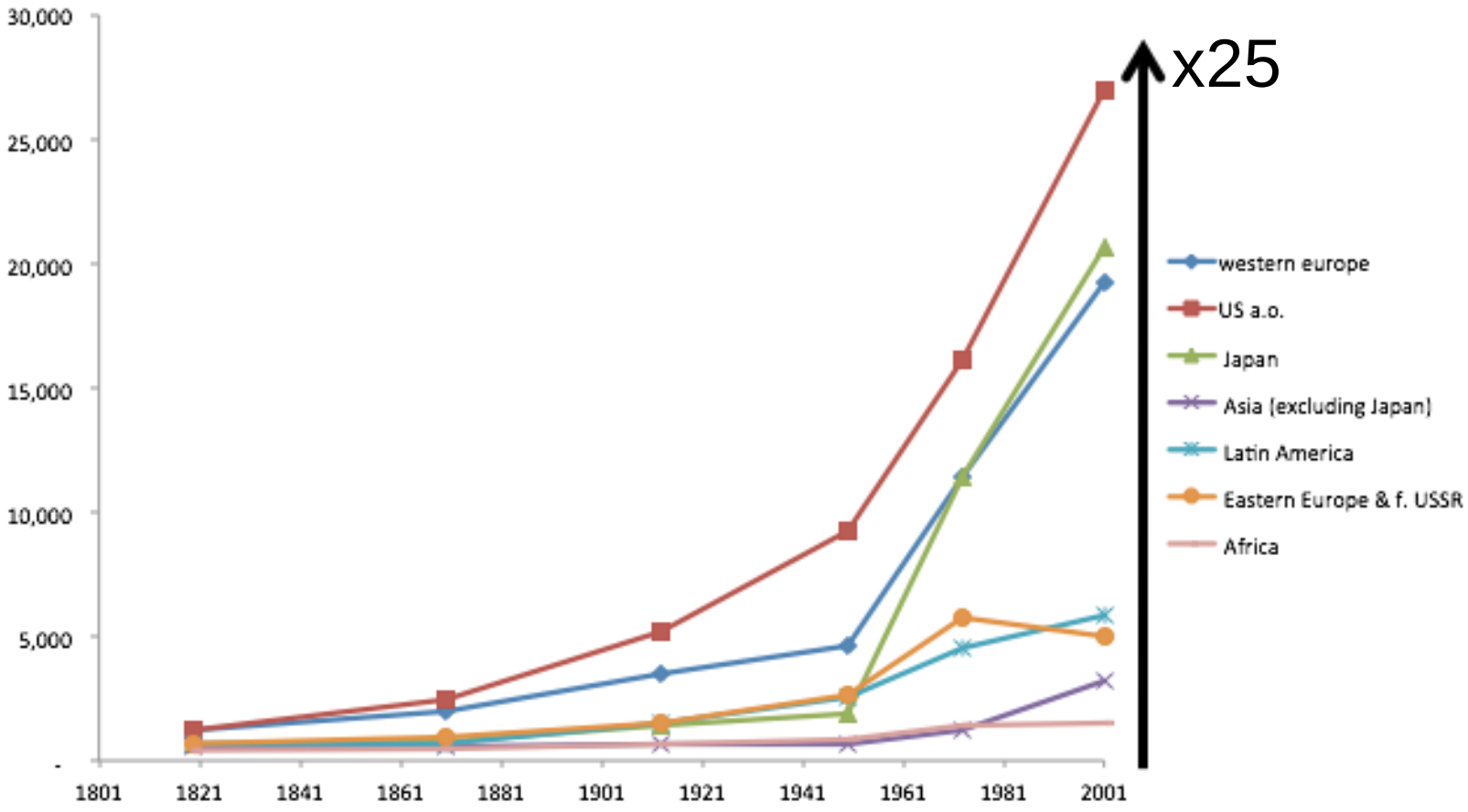
Sources:
Maddison 2001: The world economy a milennial prespective,
Maddison 2005: Measuring and Interpreting World Economic Performance 1500-2001

The great acceleration



Maddison 2001: The world economy a milennial prespective,
Maddison 2005: Measuring and Interpreting World Economic Performance 1500-2001

The great divergence



Production in a world of economic complexity

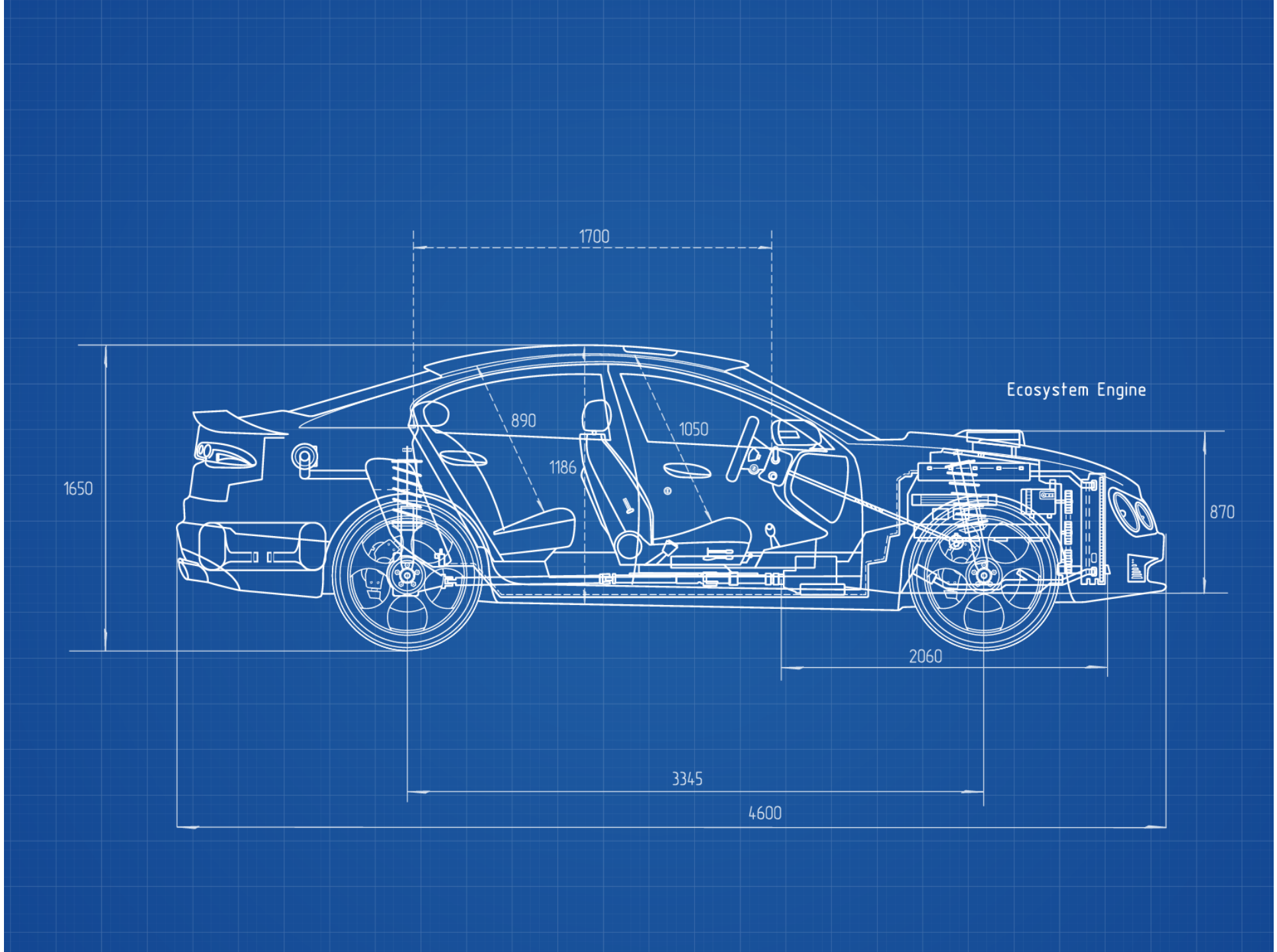
Abandoning the traditional production function

$$Y = K^{1-\alpha} L^{\alpha} A$$

stuff

How to make a car?

(stuff := car)


1700
Ecosystem Engine
890
1050
1186
1650
870
2060
3345
4600

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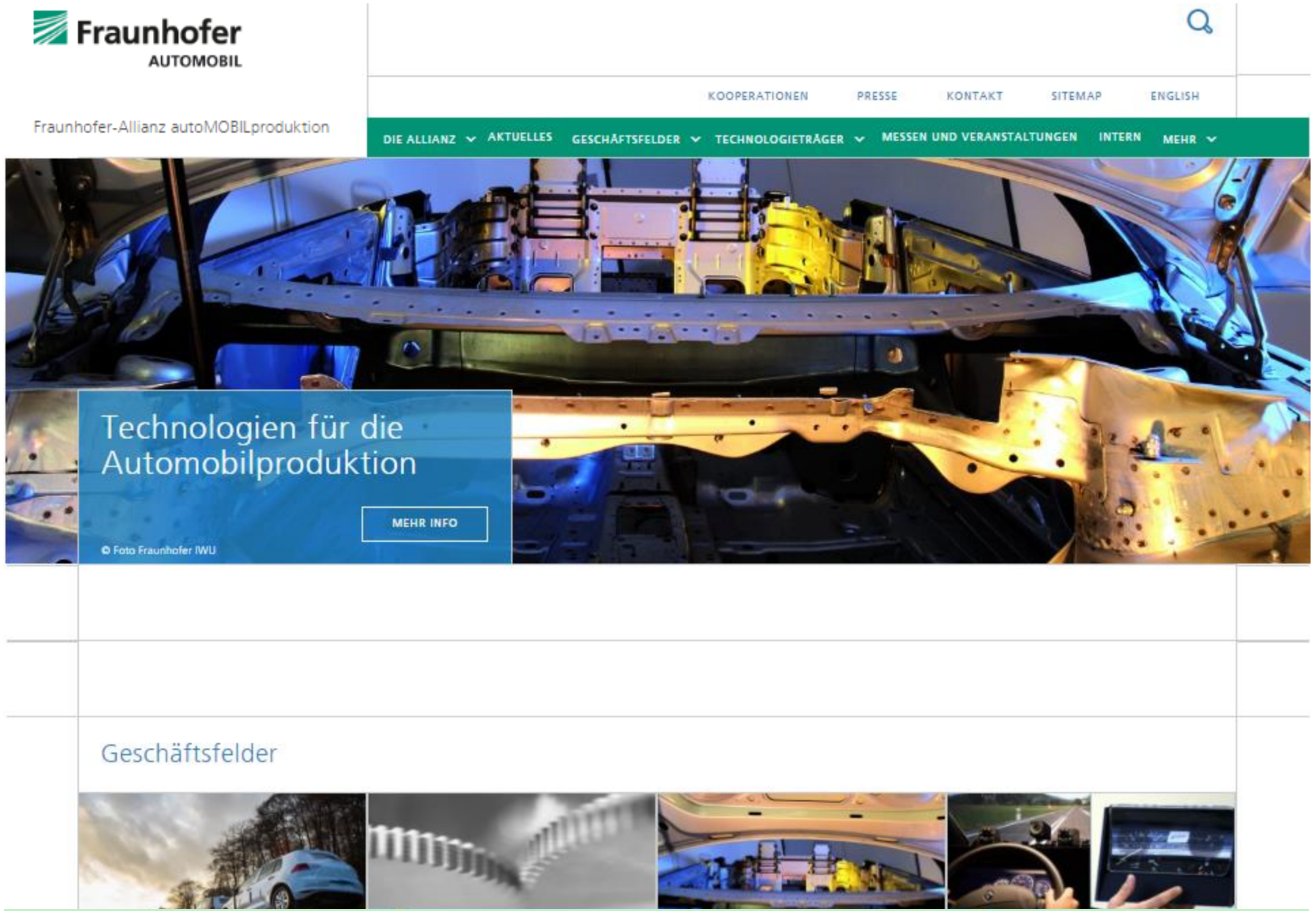
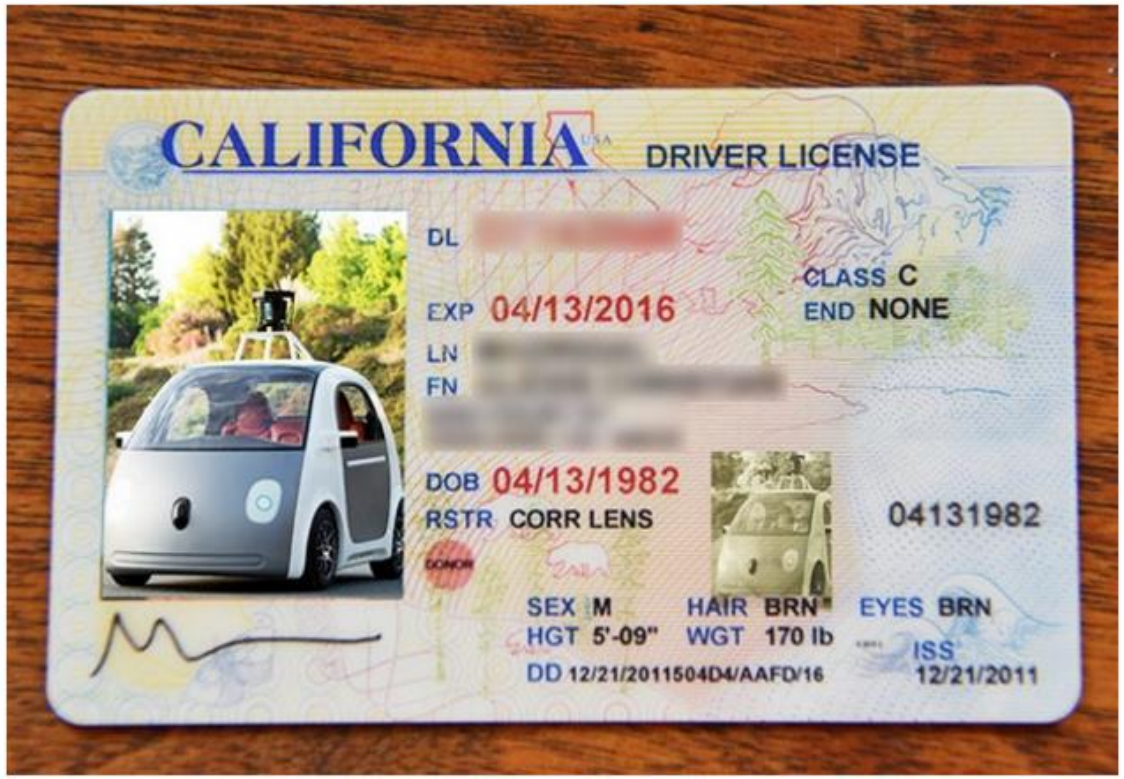


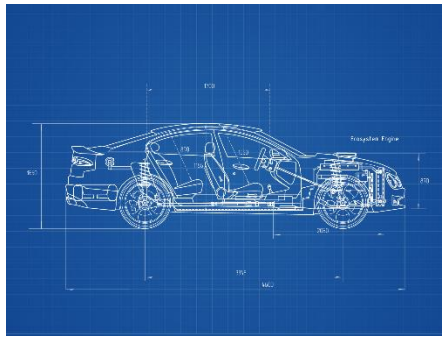
http://www.automobil.fraunhofer.de/

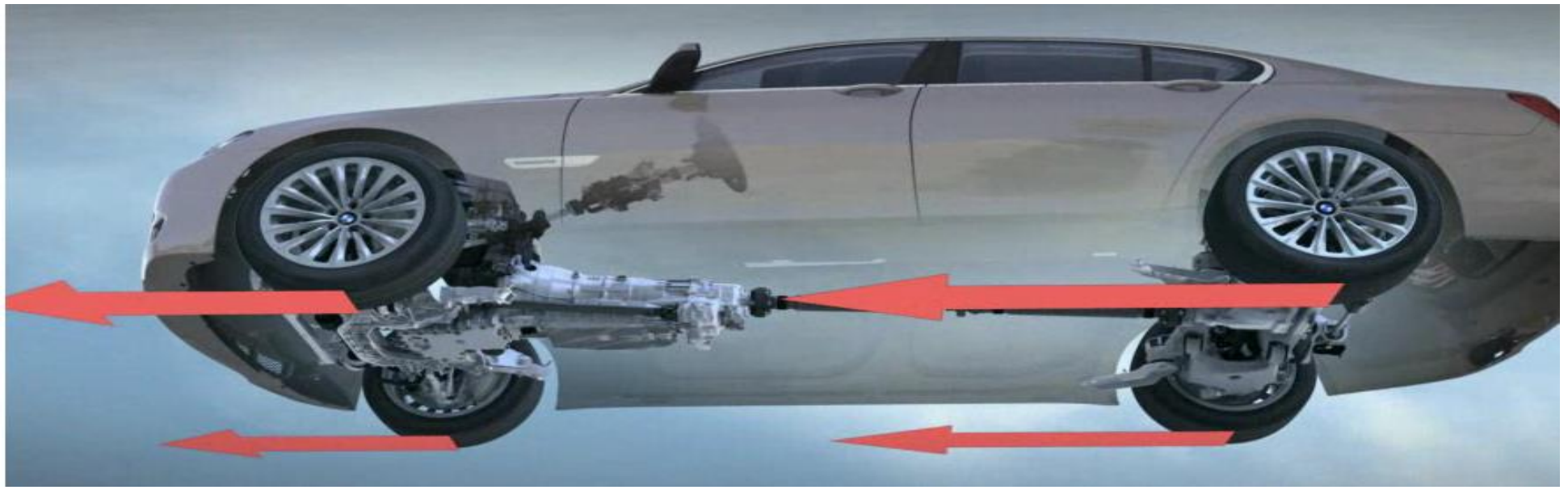
If a Self-Driving Car Gets in an Accident, Who—or What—Is Liable?

The carmaker, the car owner, or the robot car itself? On the surprisingly not-crazy argument for granting robots legal personhood.



Credits: The Atlantic: https://www.theatlantic.com/technology/archive/2014/08/if-a-self-driving-car-gets-in-an-accident-who-is-legally-liable/375569/





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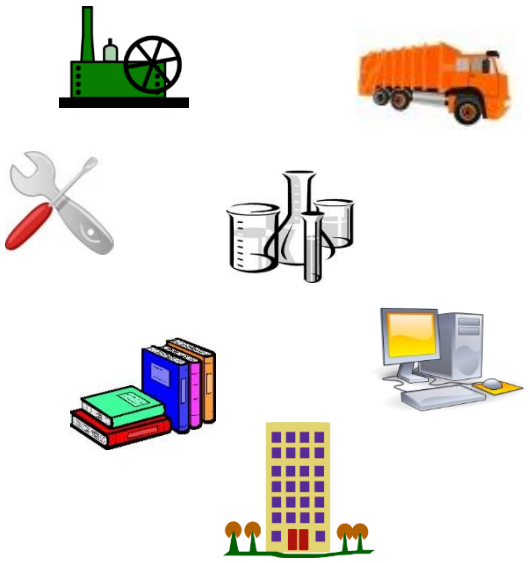
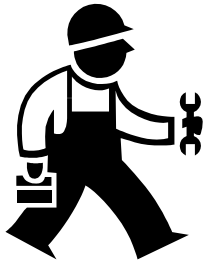
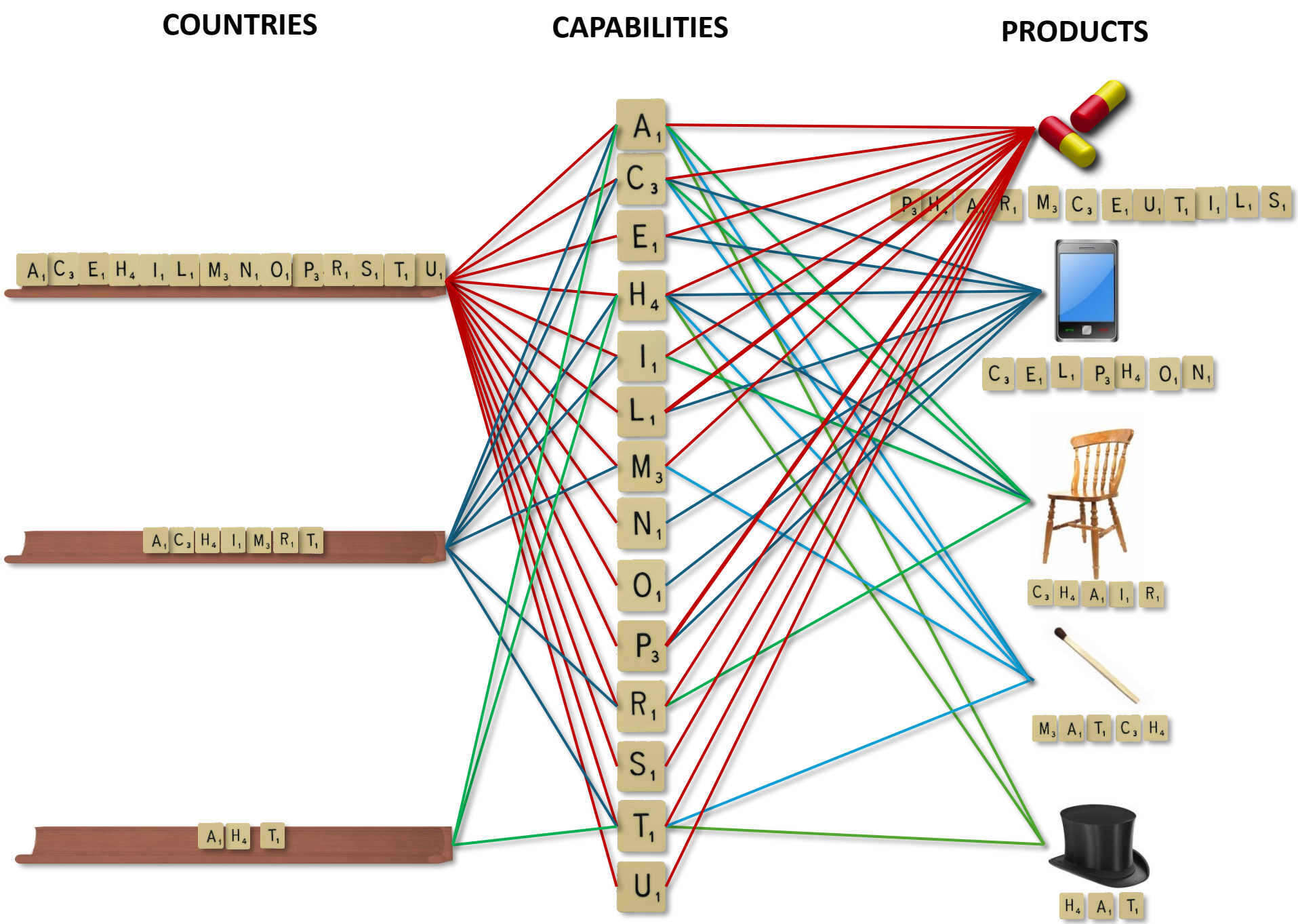




SCRABBLE

Hidalgo et al. (2007, Science)
Hidalgo, Hausmann et al. (2011, Atlas)
Hausmann & Hidalgo (2011, JEG)
Gomez, Patterson & Hausmann (2016, NHB)

Model of production



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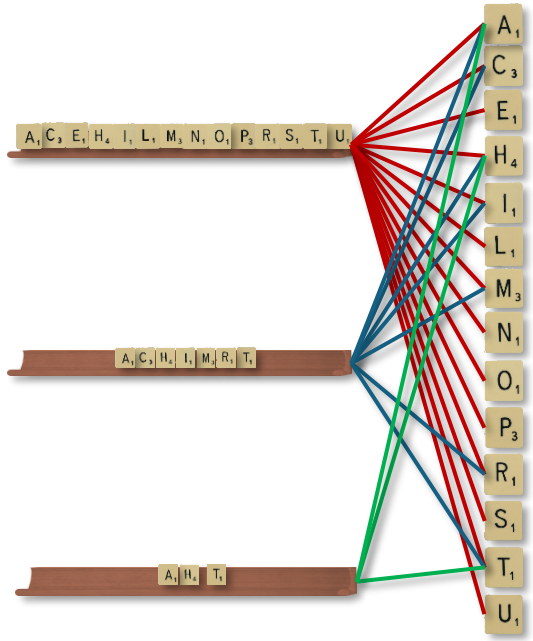
How does production work?

C_{ca}

countries × capabilities



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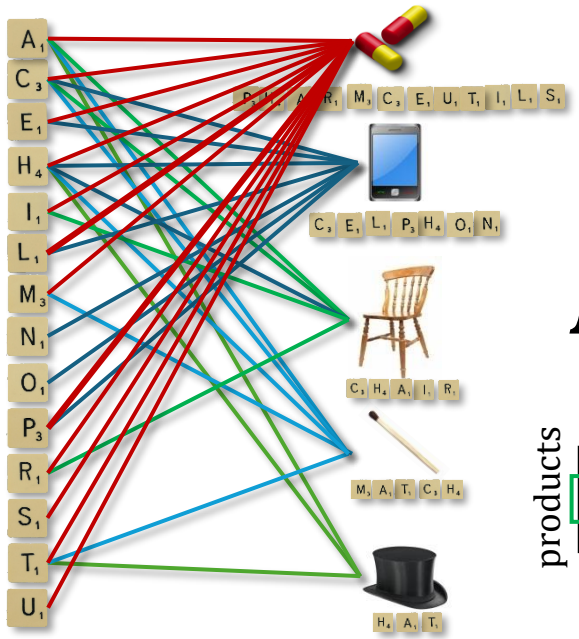
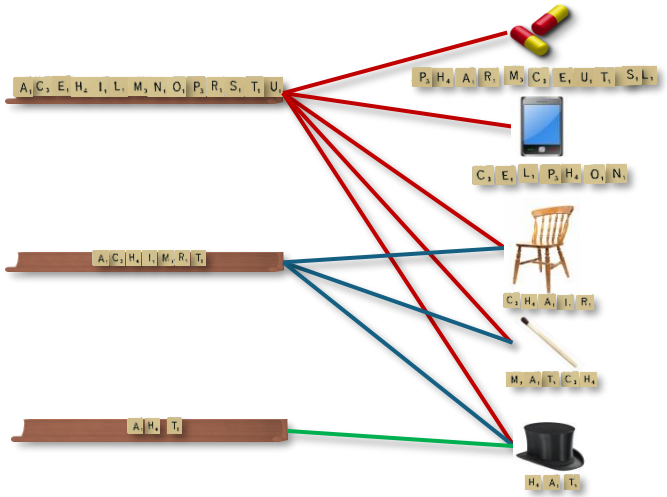


P_{pa}

products × capabilities

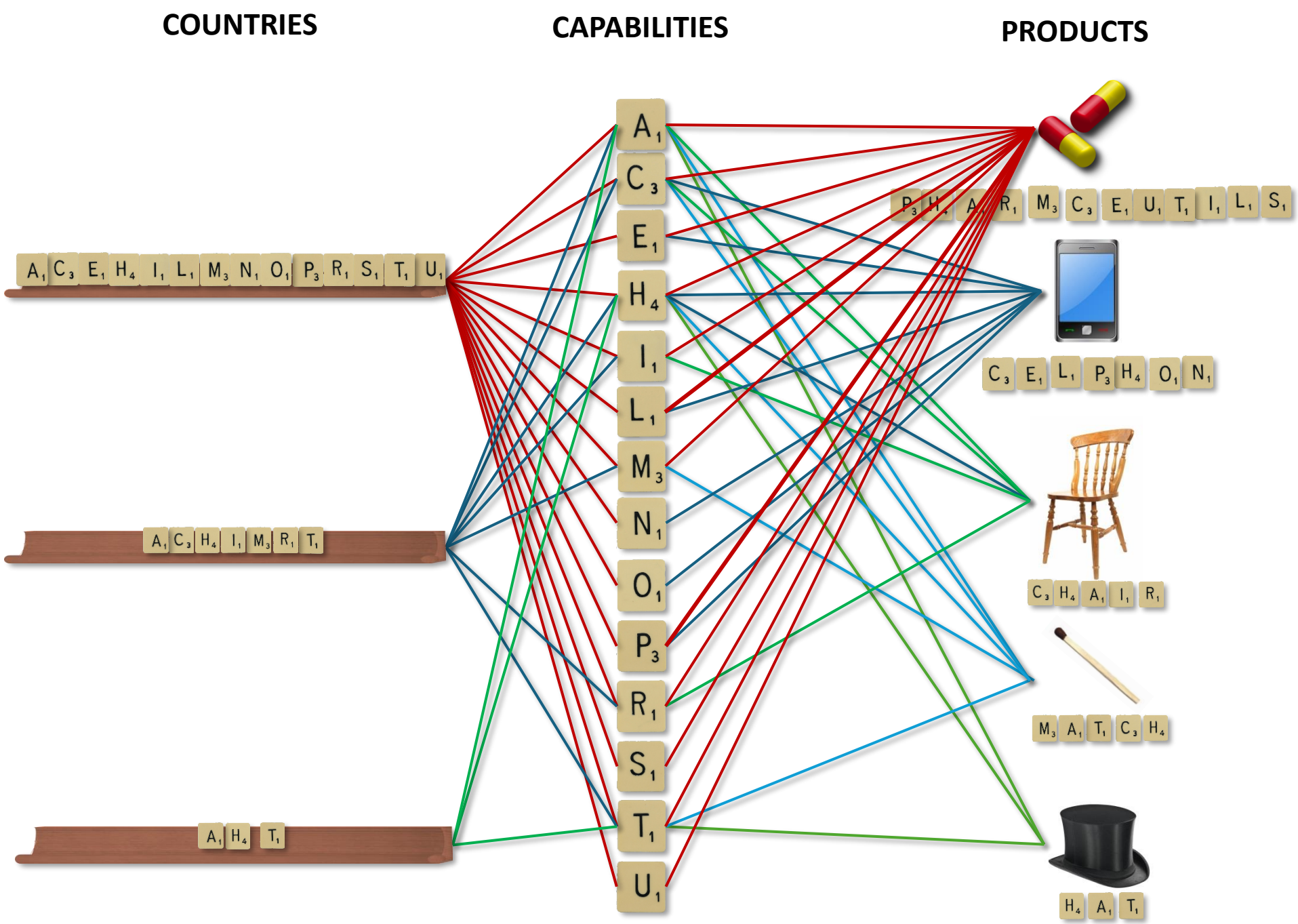
M_{cp}

countries × products



Production:

$[M_{cp}] = 1$ if $\vec{P}_p$ is a subset of $\vec{C}_c$



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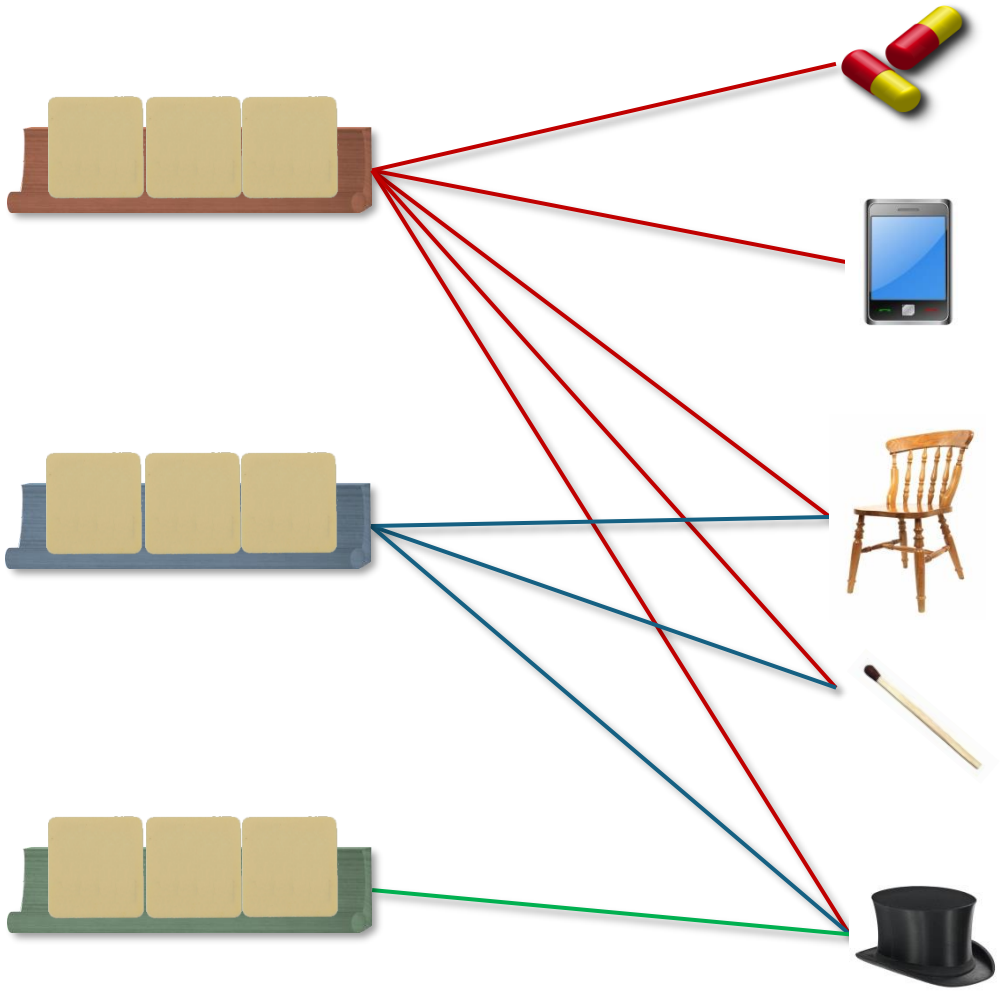
The world as we observe it (the M_{cp} matrix)

COUNTRIES **PRODUCTS**



Traditional view

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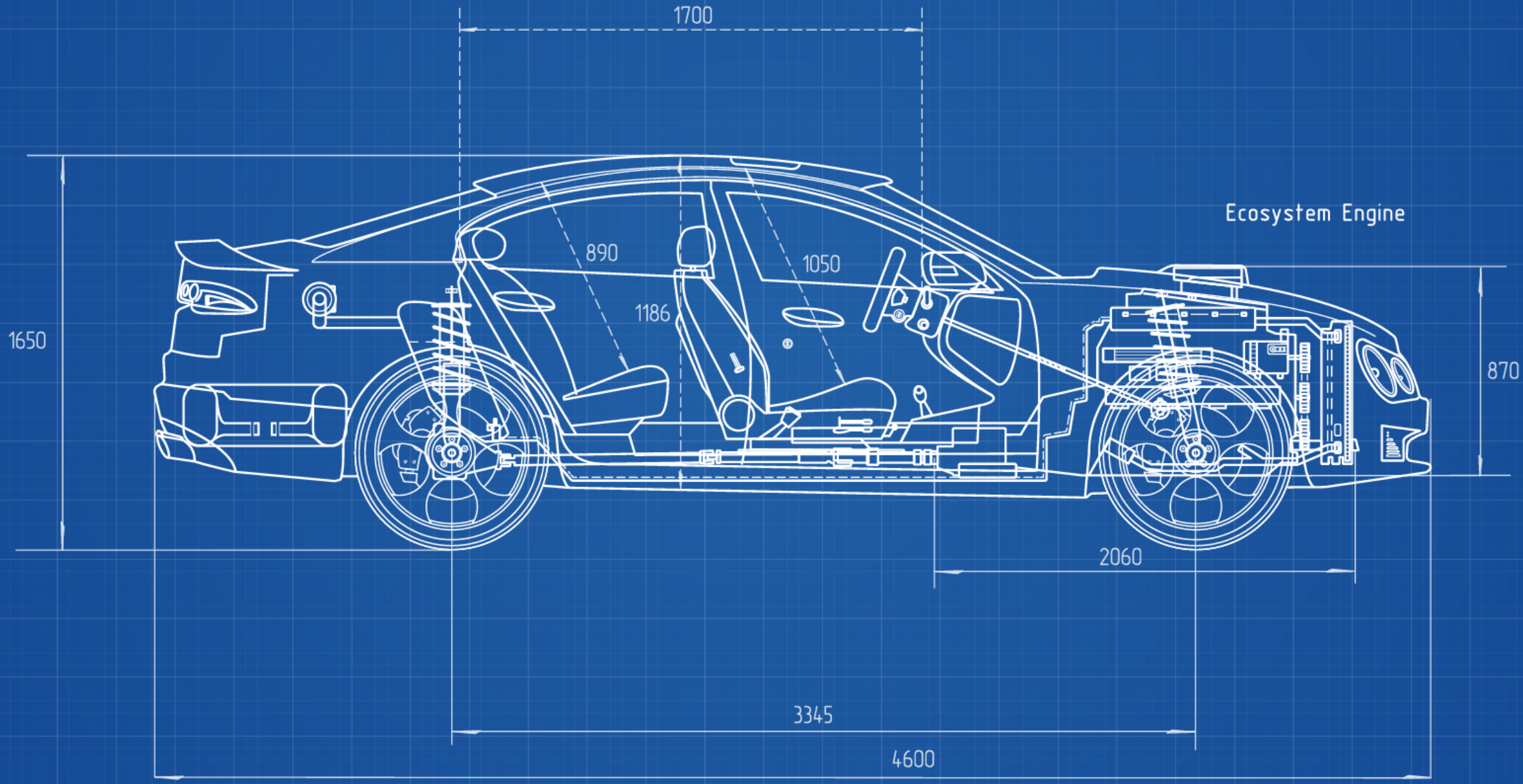
1700
1650
890
1186
1050
Ecosystem Engine
870
2060
3345
4600

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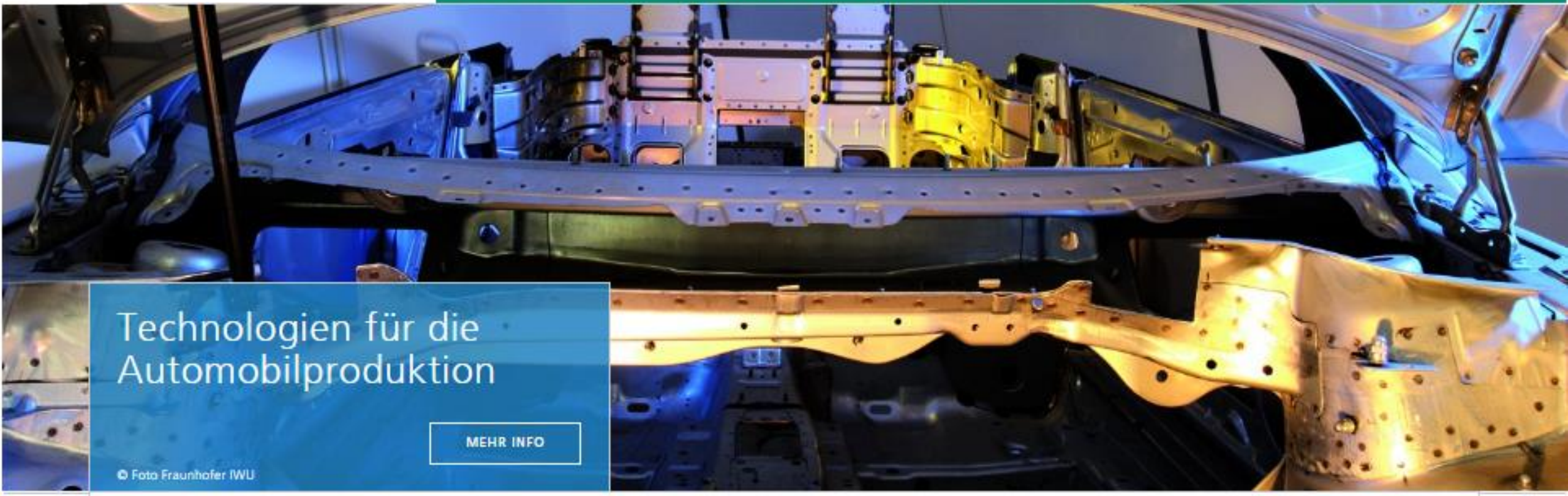

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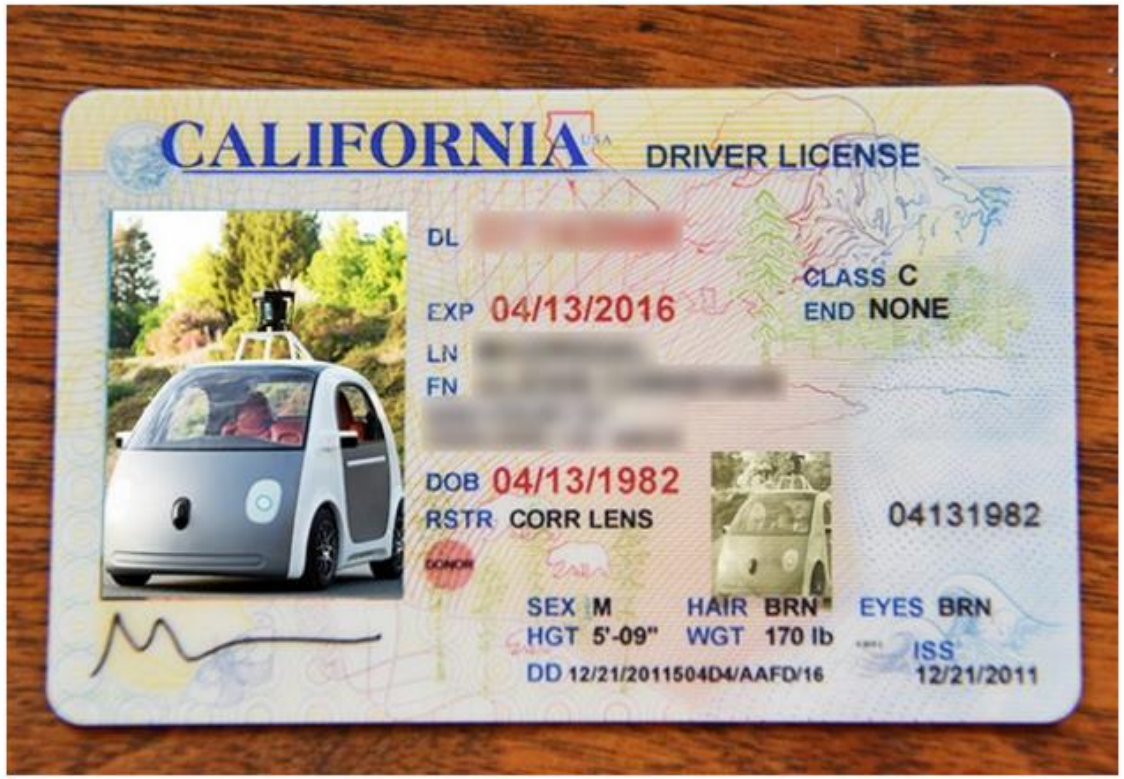

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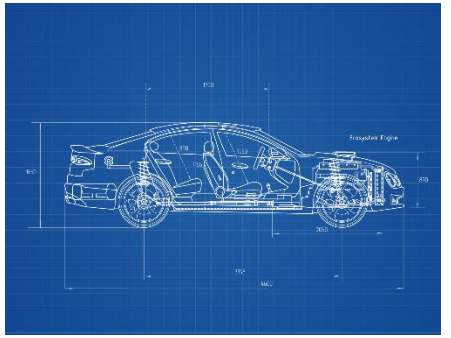

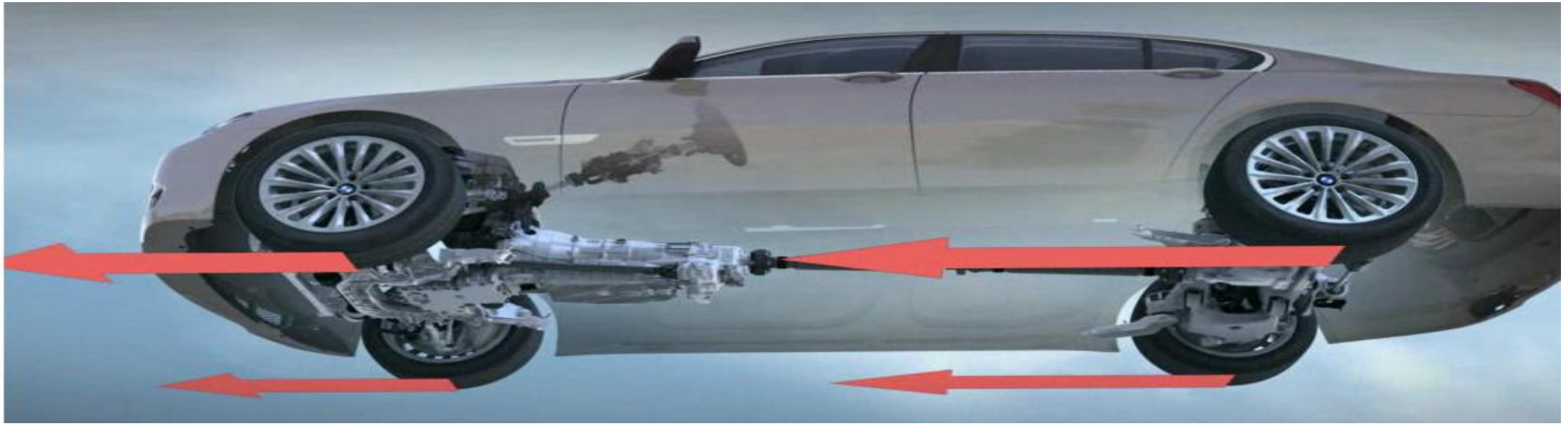

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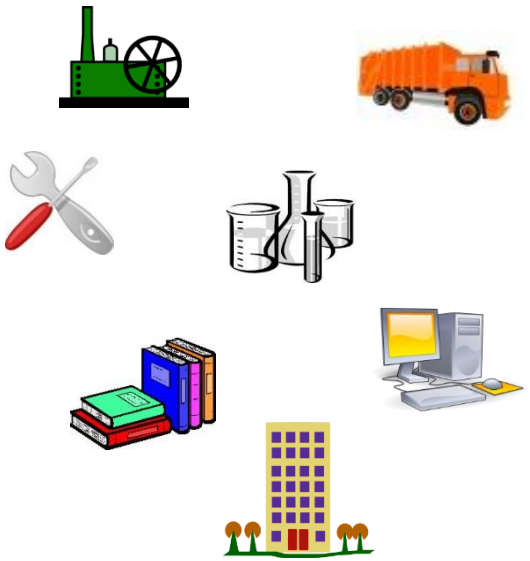

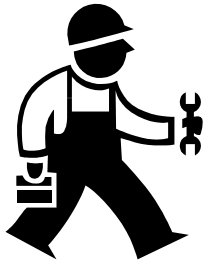

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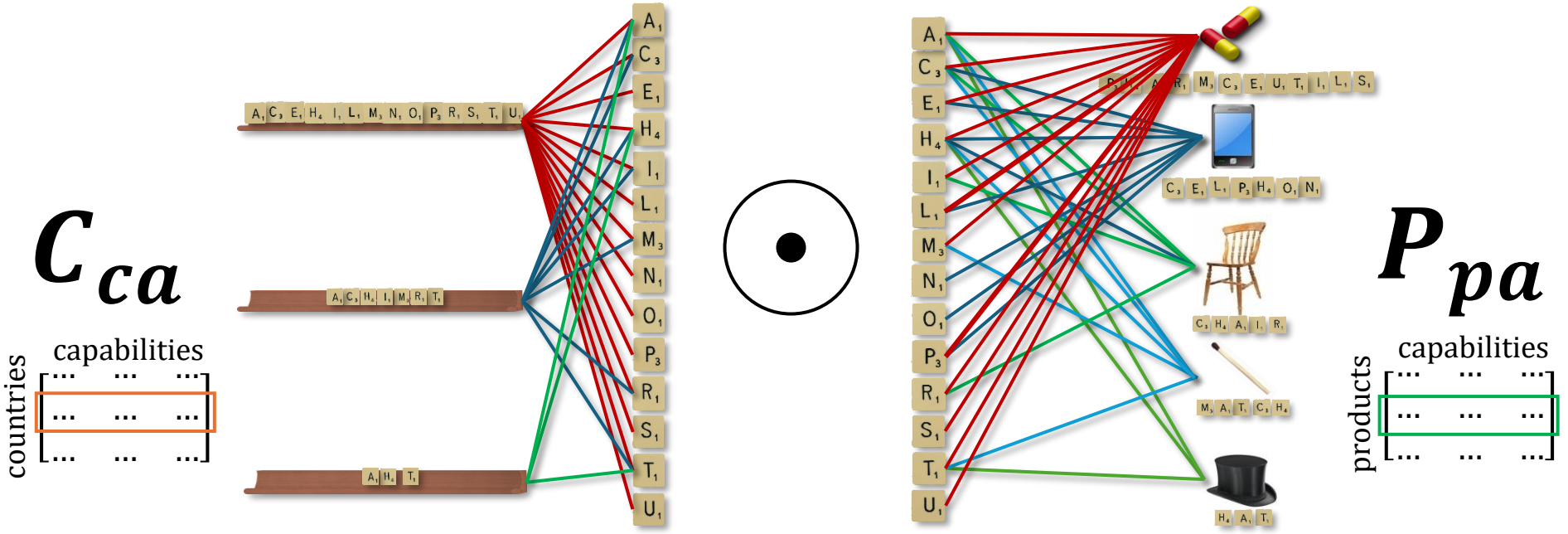

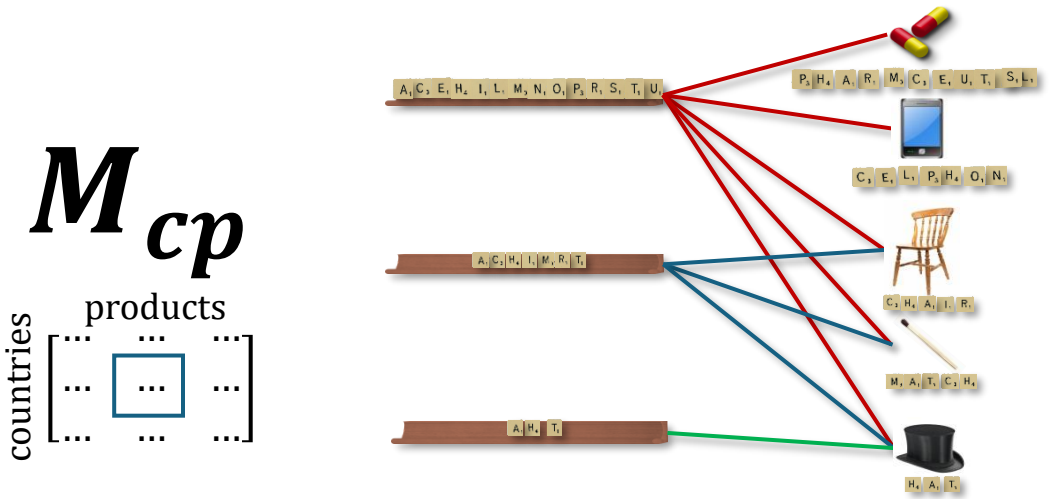

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