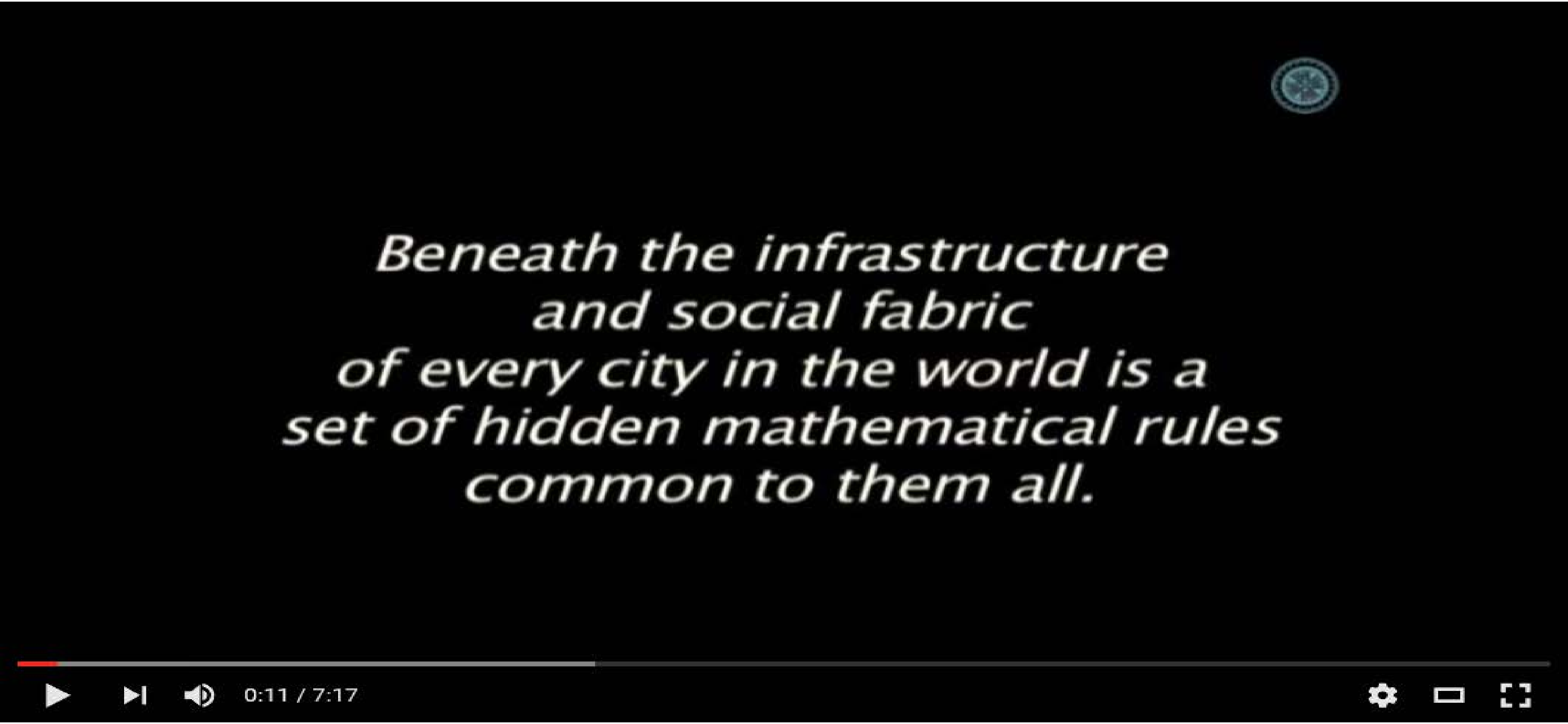
Urban Scaling Laws

Pierre-Alexandre Balland

Cities as complex systems



Body size and metabolic rate

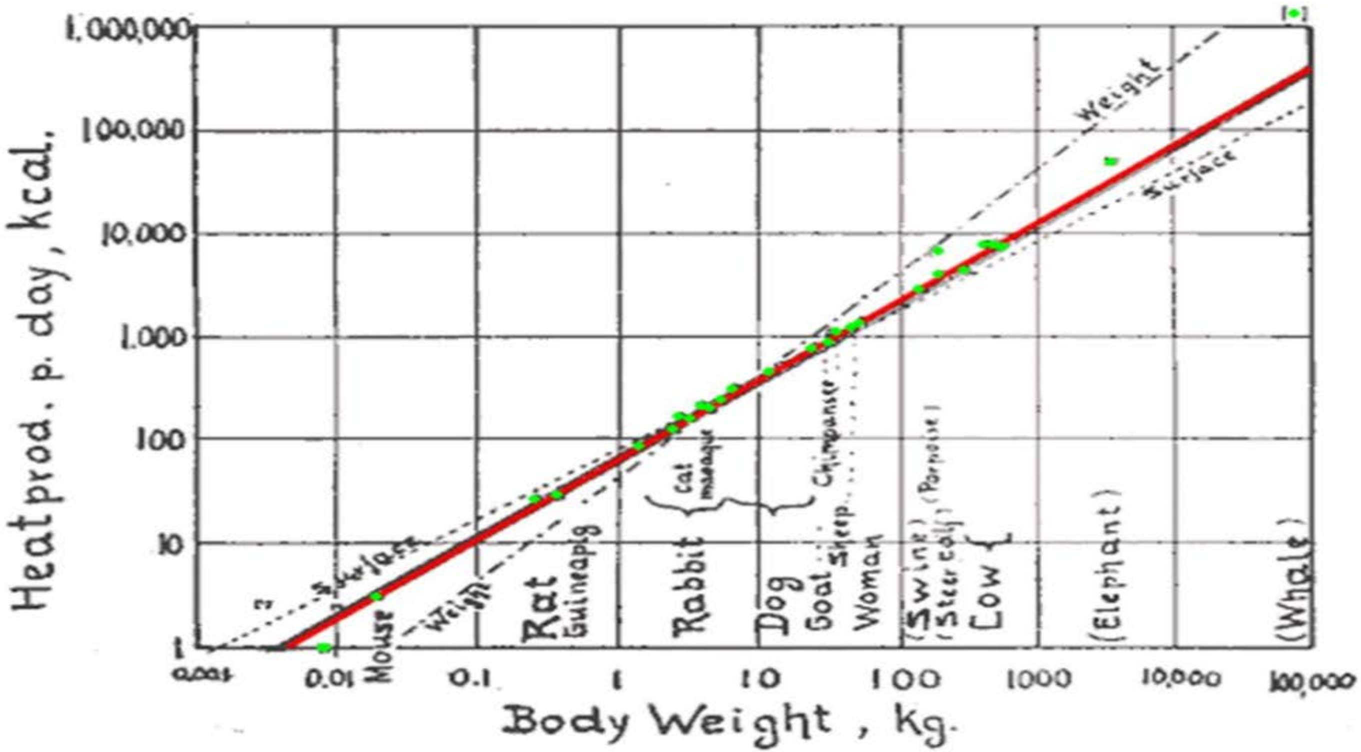


Fig. 1. Log. metabol. rate/log body weight

Kleiber's law and scaling

- Kleiber's law = an animal's metabolic rate *R* follows the ¾ power-law of its body mass *M*

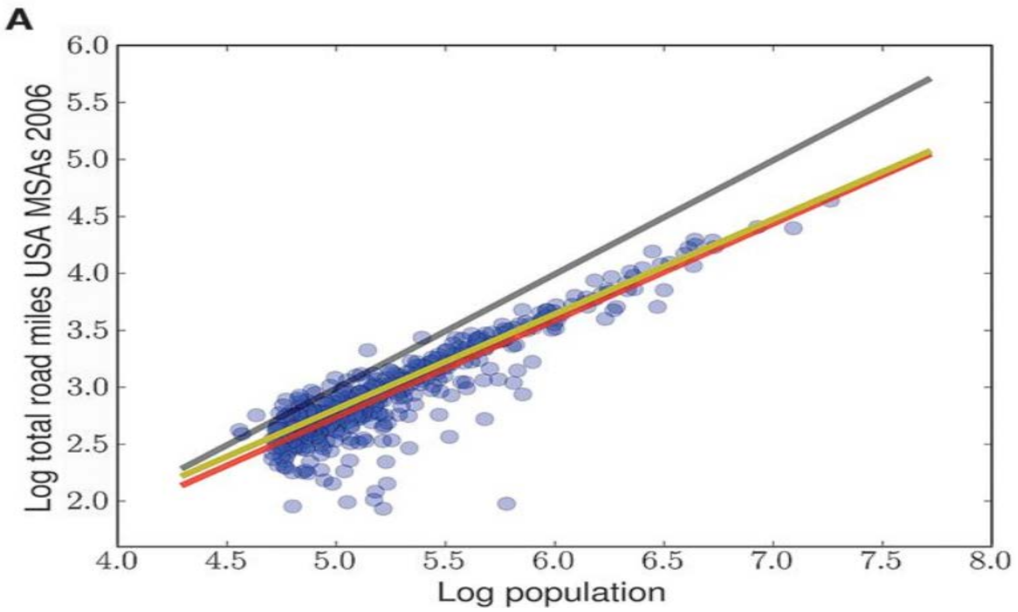
$$R \sim M^{3/4}$$

- A cat is 100 times heavier than a mouse but its metabolism is only 32 times greater
- There is in this case an economy of scale: the bigger and animal the less energy it consumes
- Metabolic rate **scales** to the ¾ power of the animal's mass

Scaling

Scaling defines how the properties of a (spatial) system varies with its size

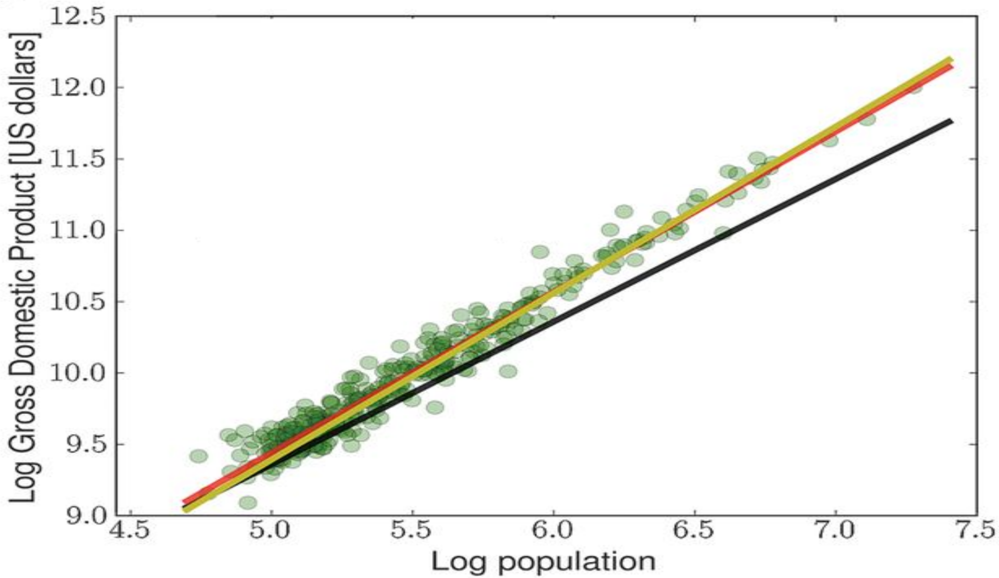
Sublinear scaling in cities (infrastructure)



Bettencourt (2013)

- Linear scaling **β = 1** (black line – proportional scaling)
- Evidence of sublinear scaling with **β = 0.85** (theoretical prediction: **β = 5 / 6**)
- Infrastructure (input) in a city increases at a much lower rate than its population

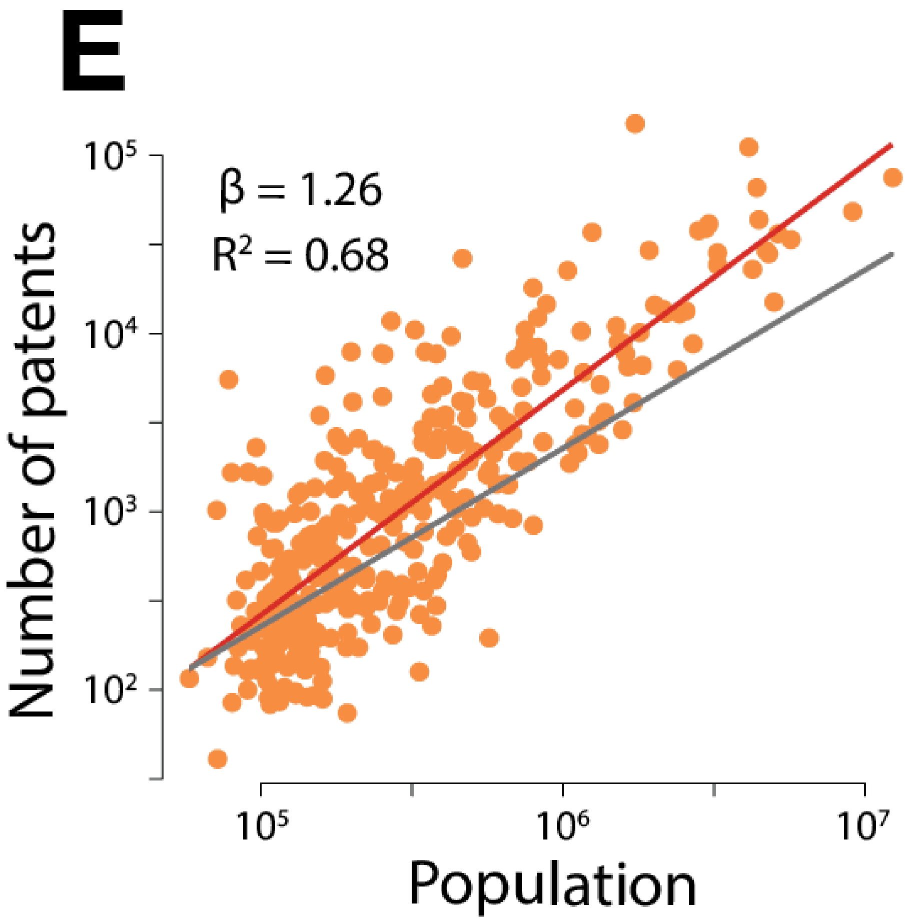
Superlinear scaling in cities (output)



Bettencourt (2013)

- Linear scaling **β = 1** (black line – proportional scaling)
- Evidence of superlinear scaling with **β = 1.13** (theoretical prediction: **β = 7 / 6**)
- Economic output in a city increases at a much faster rate than its population

Unequal distribution of econ. activities



Cities as complex systems

- Sublinear scaling of inputs and superlinear scaling of outputs

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- Sublinear scaling of inputs and superlinear scaling of outputs
- Despite their apparent complexity and diversity, a set of simple mathematical rules is common to all cities

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Cities as complex systems

- Sublinear scaling of inputs and superlinear scaling of outputs
- Despite their apparent complexity and diversity, a set of simple mathematical rules is common to all cities
- Superlinear scaling is unknown in the biological world
- Are cities our greatest invention?

Origins of these scaling relations

- *“A city is first and foremost a social reactor [...] it works like a star, attracting people and accelerating social interaction and social outputs in a way that is analogous to how stars compress matter and burn brighter and faster the bigger they are.”* (Bettencourt – Wired magazine, 2013)

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- Role of spatially-constrained social interactions between individuals (fuelled by density of population)

- As the number of firms or individuals increases in a city the number of potential interactions within this city increases decreases

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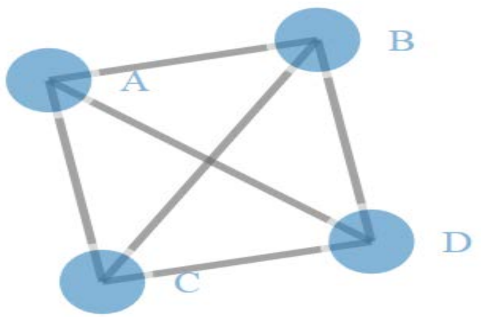
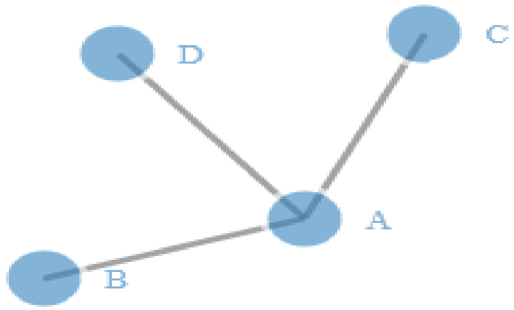
- As the number of firms or individuals increases in a city the number of potential interactions within this city increases superlinearly with **β = ?**

Network density





$$Network\ \ density = \frac{Actual\ \ connections}{Potential\ \ connections}$$

$$Potential\ \ connections = \frac{n^*(n-1)}{2}$$

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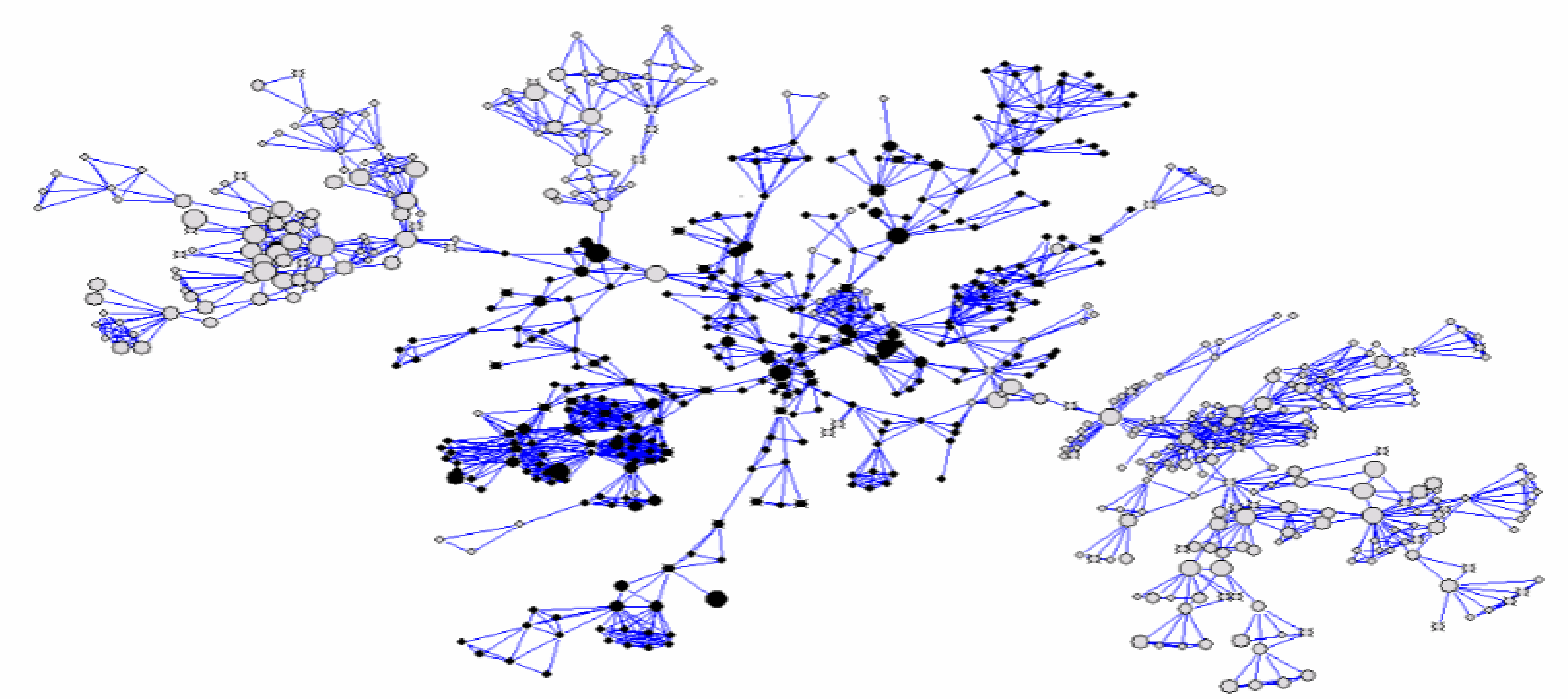
- Role of spatially-constrained social interactions between individuals (fuelled by density of population)

- As the number of firms or individuals increases in a city the number of potential interactions within this city increases superlinearly with **β = 2** (n*n) in the case of an undirected network

A regional system of innovation

Inter-firm network in the Silicon Valley



Fleming & Frenken 2007

Communication network

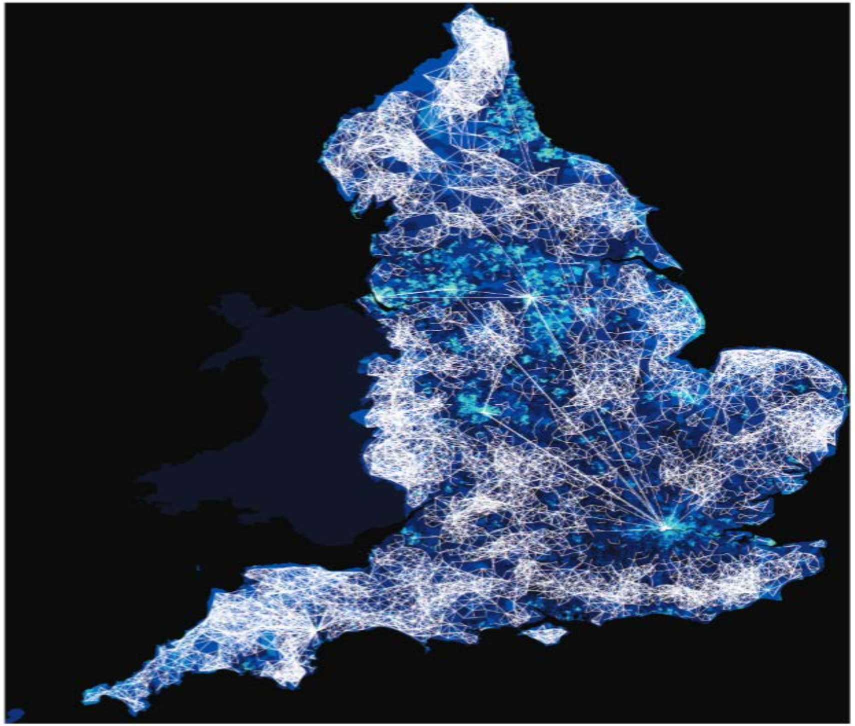
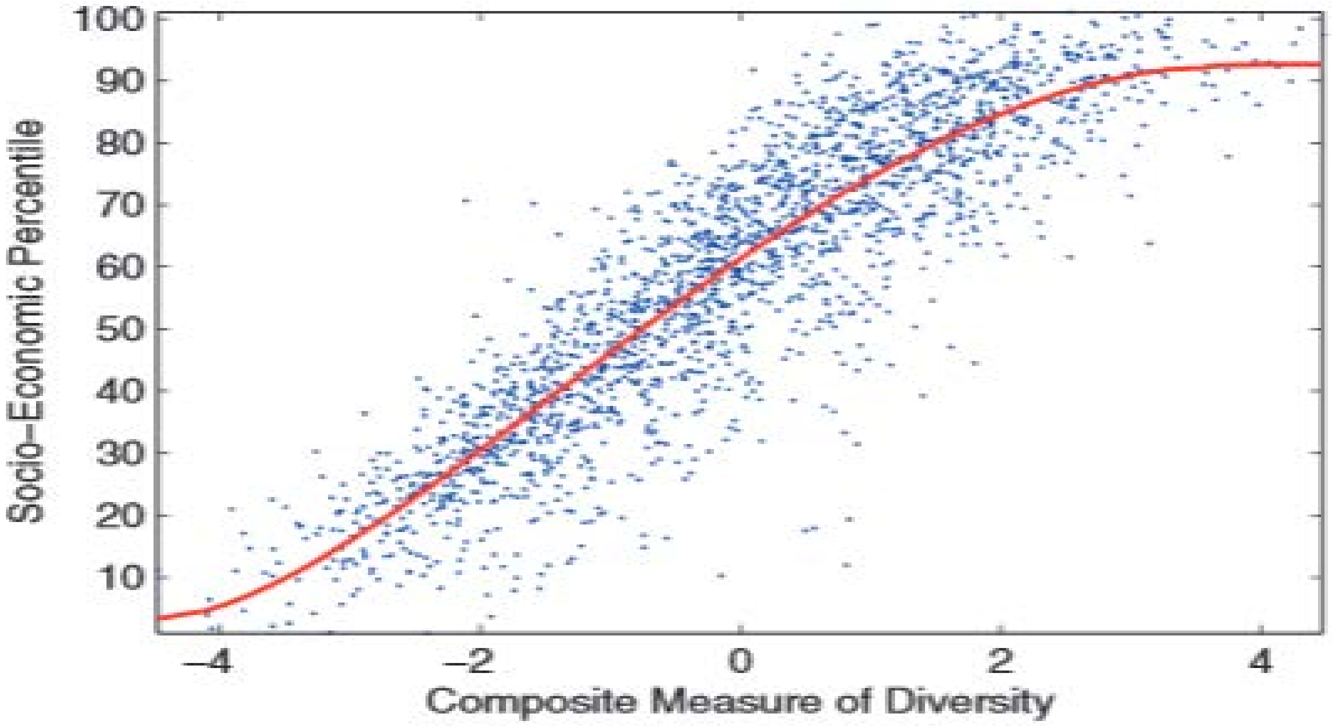


Fig. 1. An image of regional communication diversity and socioeconomic ranking for the UK. We find that communities with diverse communication patterns tend to rank higher (represented from light blue to dark blue) than the regions with more insular communication. This result implies that communication diversity is a key indicator of an economically healthy community. [(*29*) Crown copyright material is reproduced with the permission of the Controller of Her Majesty's Stationery Office]

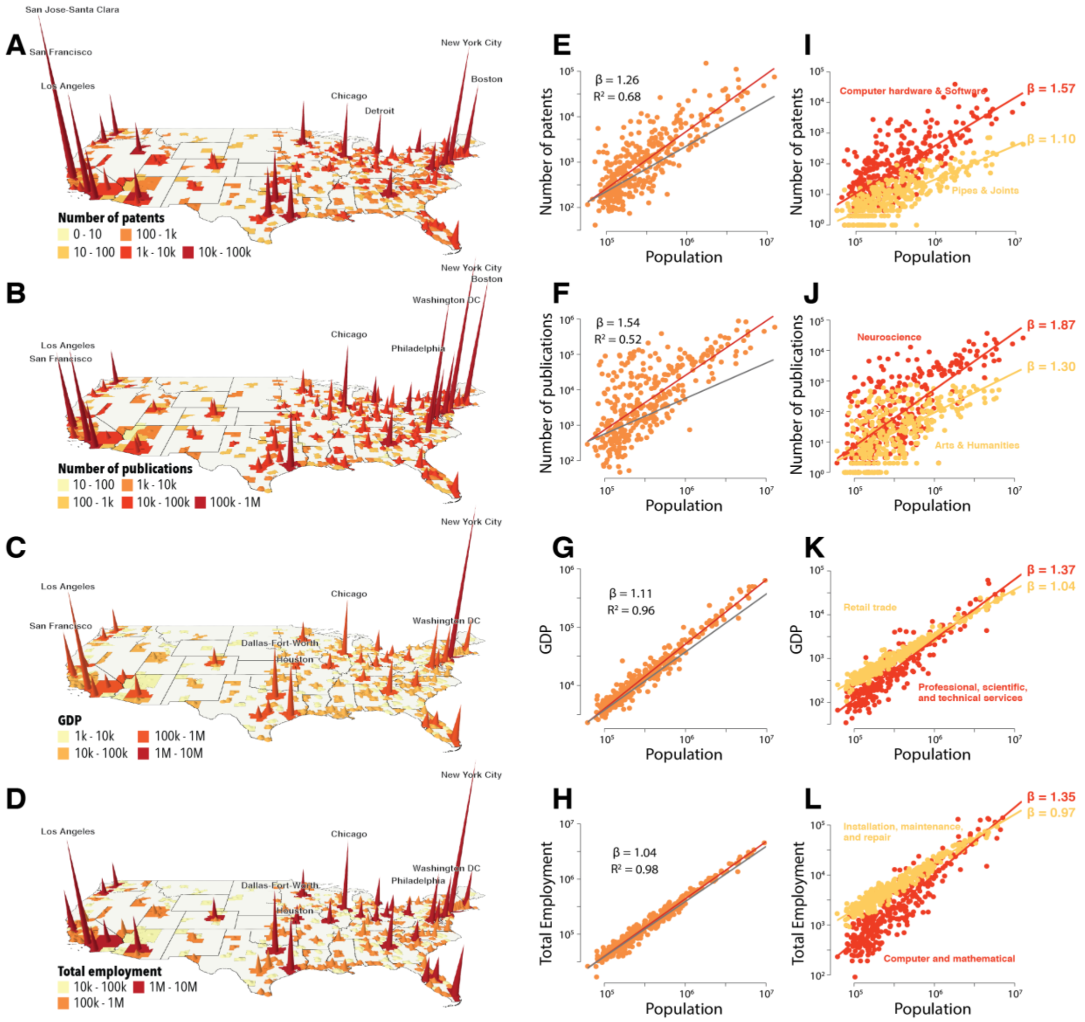
Eagle et al., 2010

Network diversity & development



Eagle et al., 2010

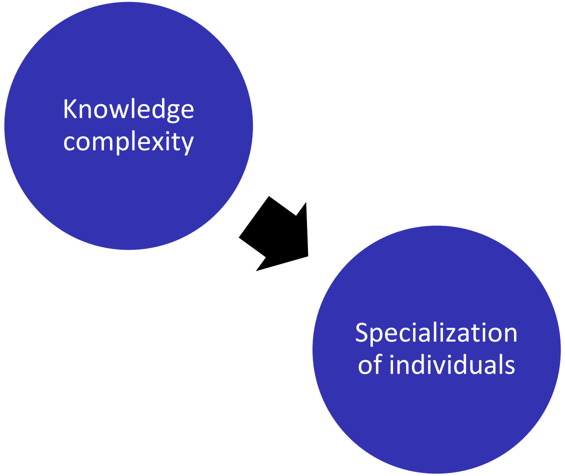
How **complex** economic activities scale in cities



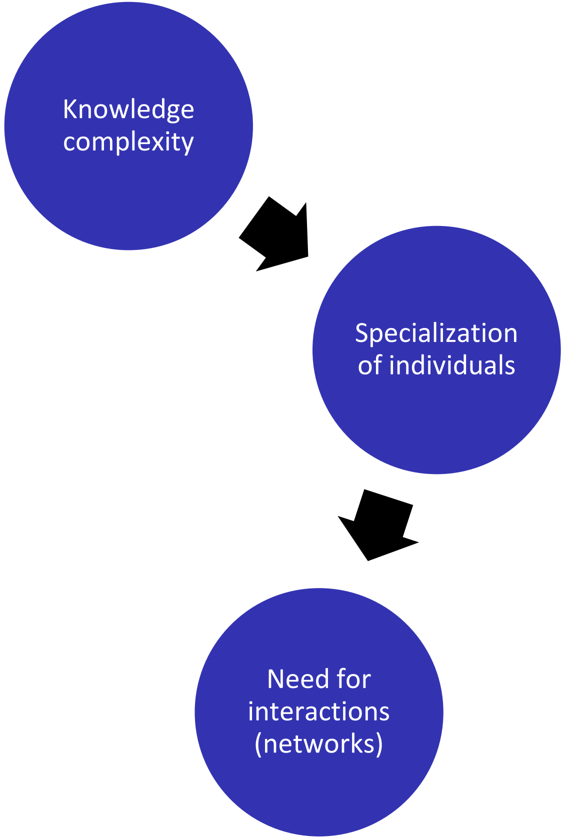
From Complexity to Spatial Inequality

Knowledge complexity

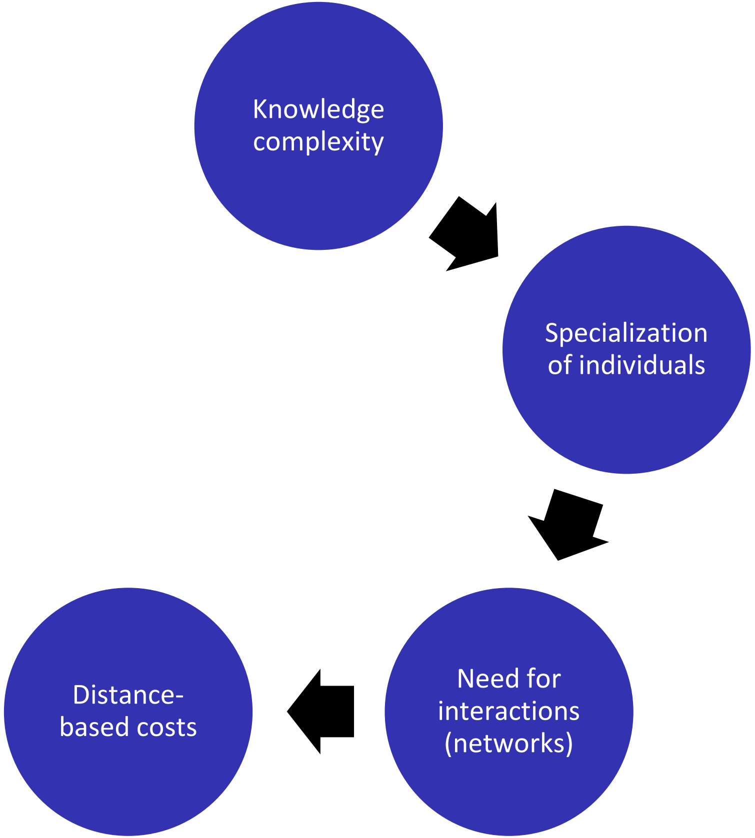
From Complexity to Spatial Inequality



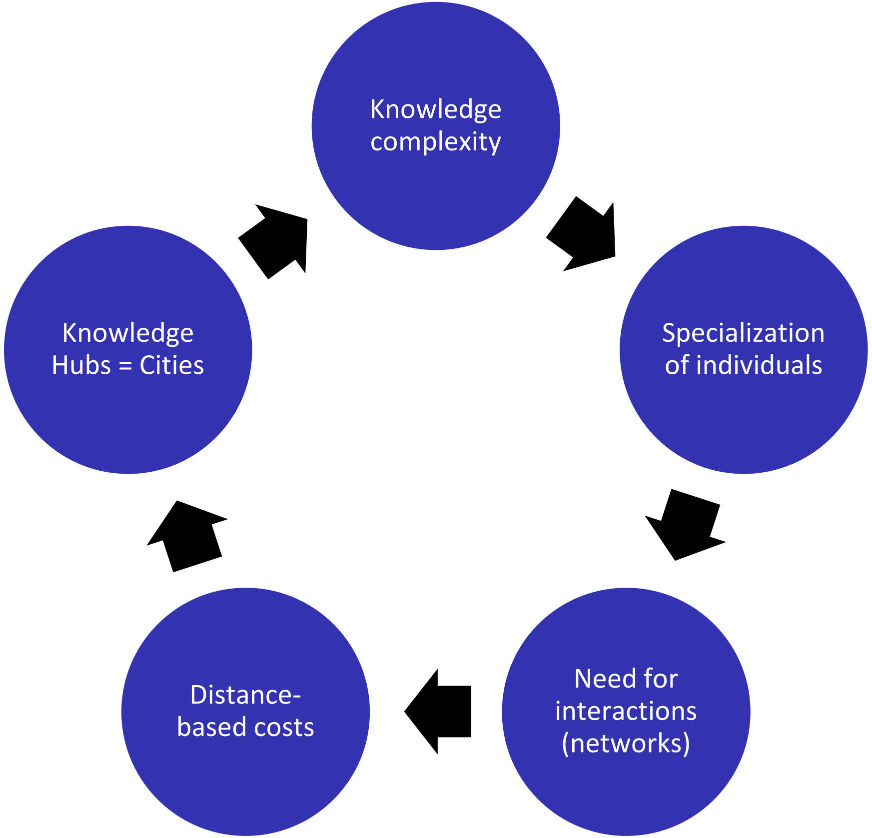
From Complexity to Spatial Inequality

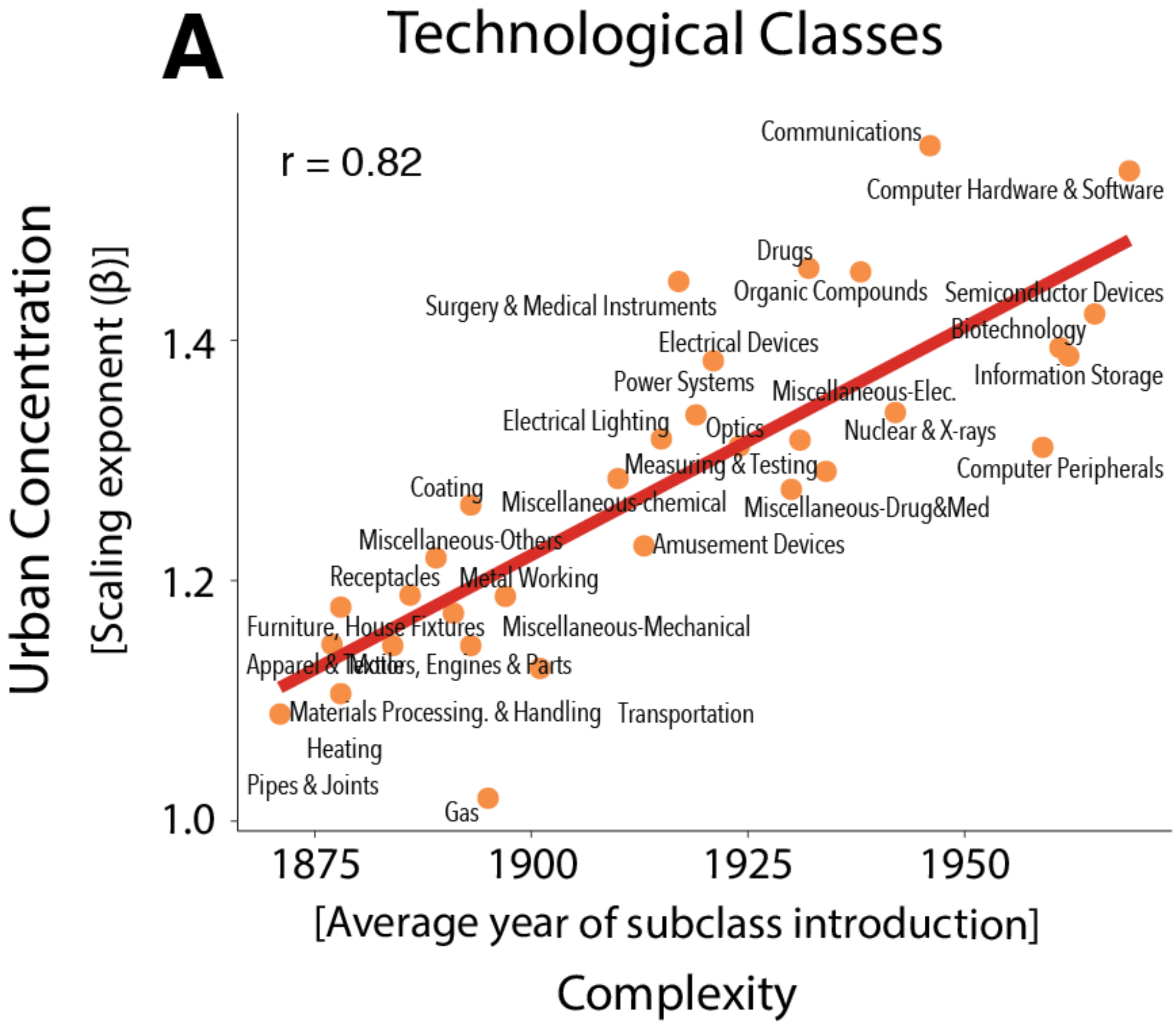


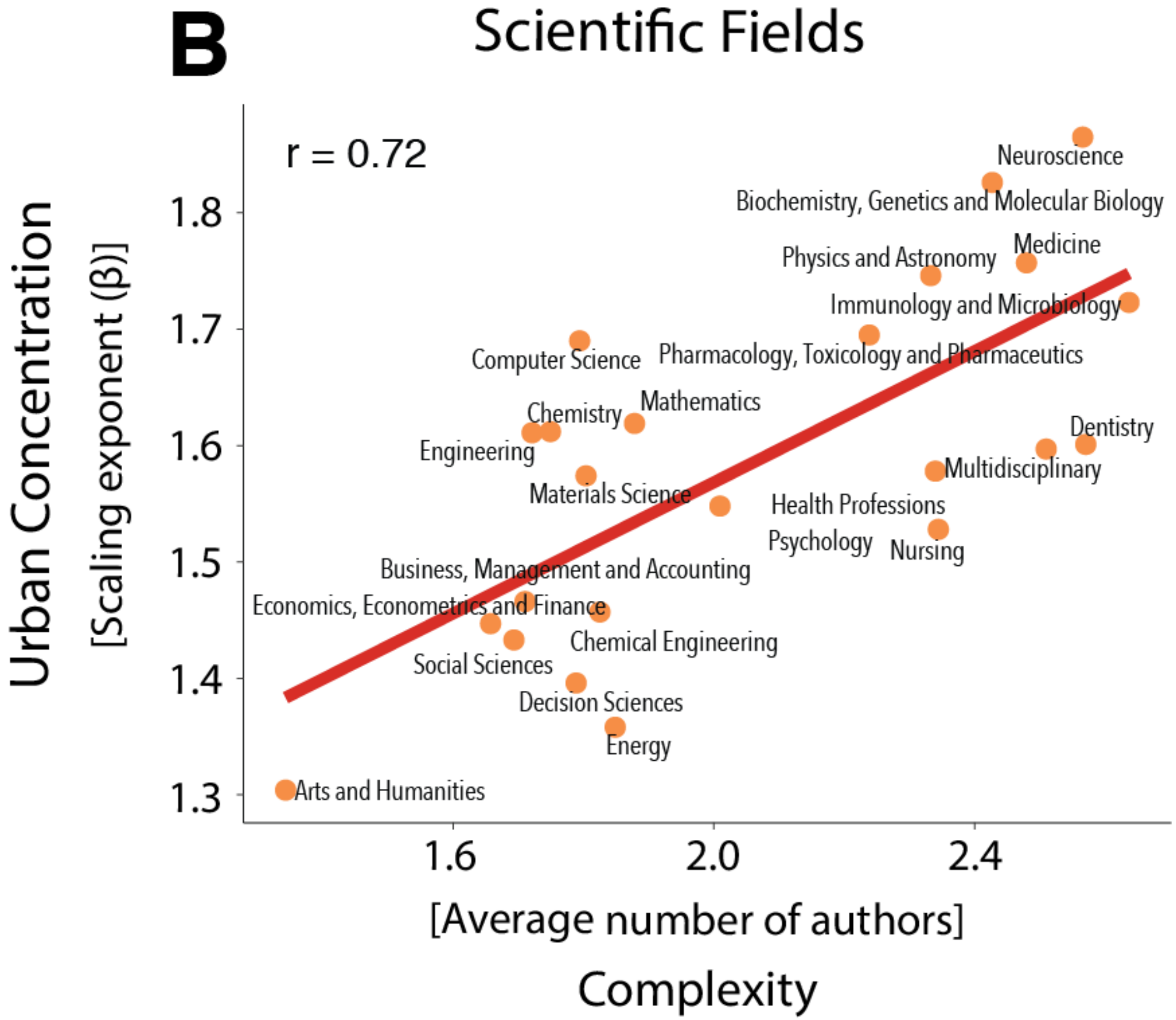
From Complexity to Spatial Inequality

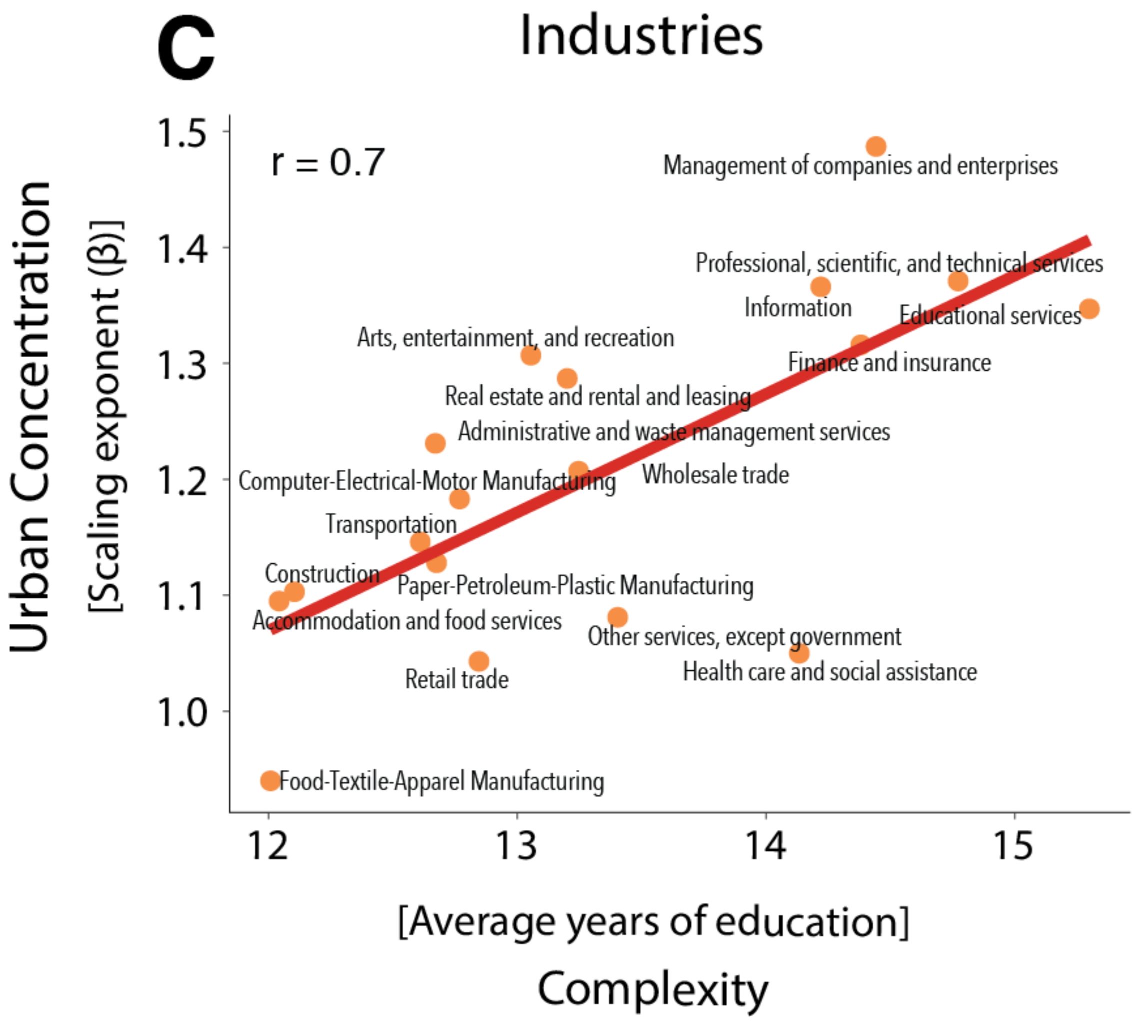


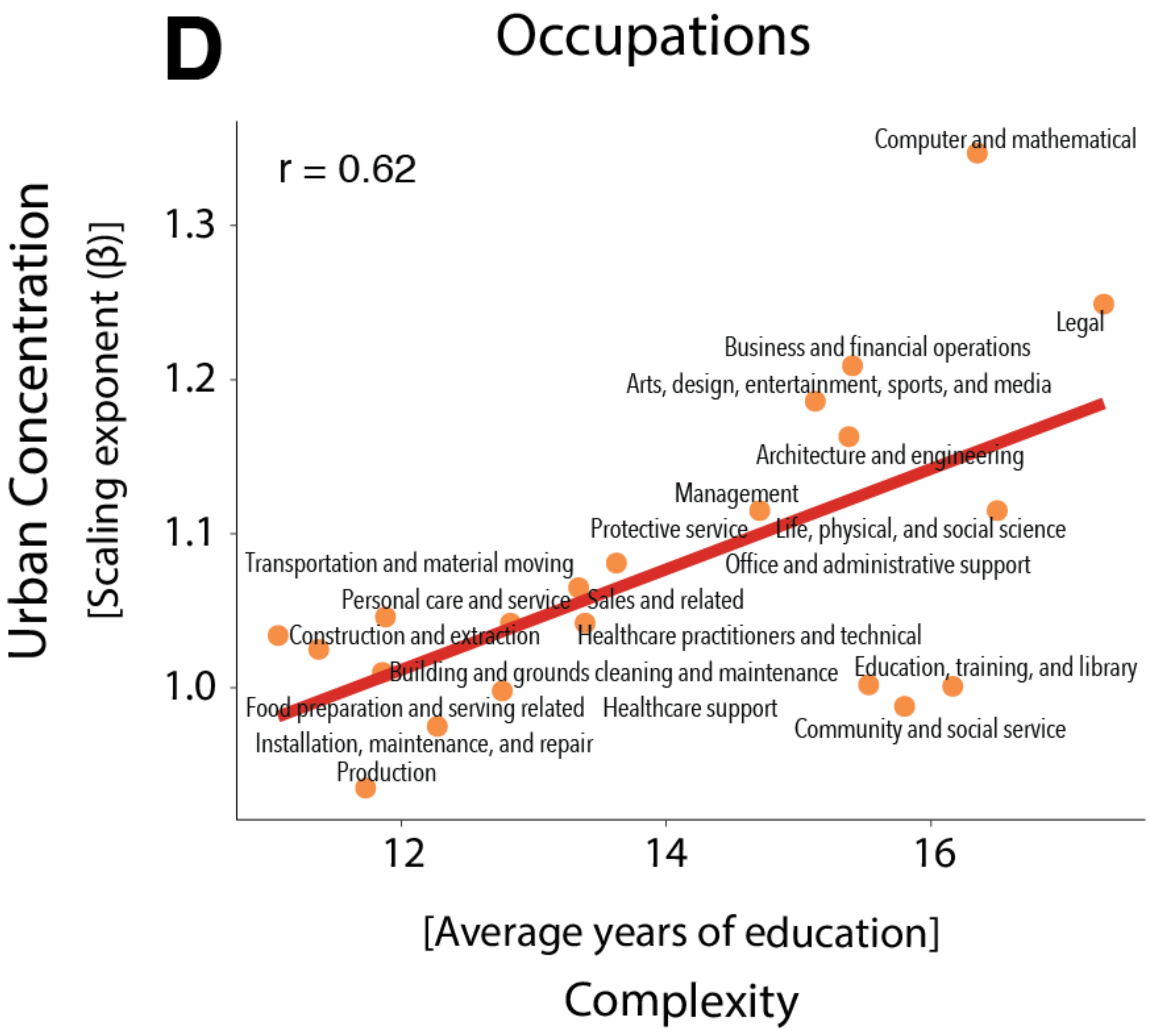
From Complexity to Spatial Inequality




A
Technological Classes
r = 0.82
Communications
Computer Hardware & Software
Drugs
Organic Compounds
Semiconductor Devices
Surgery & Medical Instruments
Biotechnology
Electrical Devices
Information Storage
Power Systems
Miscellaneous-Elec.
Electrical Lighting
Optics
Nuclear & X-rays
Measuring & Testing
Computer Peripherals
Coating
Miscellaneous-chemical
Miscellaneous-Drug&Med
Miscellaneous-Others
Amusement Devices
Receptacles
Metal Working
Furniture, House Fixtures
Miscellaneous-Mechanical
Apparel & Textile
Motors, Engines & Parts
Materials Processing. & Handling
Transportation
Heating
Pipes & Joints
Gas
1.0
1.2
1.4
1875
1900
1925
1950
Urban Concentration
[Scaling exponent (β)]
[Average year of subclass introduction]
Complexity


B
Scientific Fields
r = 0.72
Urban Concentration
[Scaling exponent (β)]
1.8
1.7
1.6
1.5
1.4
1.3
Neuroscience
Biochemistry, Genetics and Molecular Biology
Medicine
Physics and Astronomy
Immunology and Microbiology
Computer Science
Pharmacology, Toxicology and Pharmaceutics
Mathematics
Chemistry
Dentistry
Engineering
Multidisciplinary
Materials Science
Health Professions
Psychology
Nursing
Business, Management and Accounting
Economics, Econometrics and Finance
Chemical Engineering
Social Sciences
Decision Sciences
Energy
Arts and Humanities
1.6
2.0
2.4
[Average number of authors]
Complexity


C
Industries
Urban Concentration
[Scaling exponent (β)]
r = 0.7
1.5
1.4
1.3
1.2
1.1
1.0
12
13
14
15
Management of companies and enterprises
Professional, scientific, and technical services
Information
Educational services
Arts, entertainment, and recreation
Finance and insurance
Real estate and rental and leasing
Administrative and waste management services
Computer-Electrical-Motor Manufacturing
Wholesale trade
Transportation
Construction
Paper-Petroleum-Plastic Manufacturing
Accommodation and food services
Other services, except government
Health care and social assistance
Retail trade
Food-Textile-Apparel Manufacturing
[Average years of education]
Complexity


D
Occupations
r = 0.62
Urban Concentration
[Scaling exponent (β)]
1.3
1.2
1.1
1.0
12
14
16
[Average years of education]
Complexity
Computer and mathematical
Legal
Business and financial operations
Arts, design, entertainment, sports, and media
Architecture and engineering
Management
Protective service
Life, physical, and social science
Office and administrative support
Transportation and material moving
Personal care and service
Sales and related
Construction and extraction
Healthcare practitioners and technical
Building and grounds cleaning and maintenance
Education, training, and library
Food preparation and serving related
Healthcare support
Community and social service
Installation, maintenance, and repair
Production

The Historical Gap

There is virtually no historical and systematic analysis on the geography of innovation and technological change prior to 1975.

Biotechnology

1790 **1975** **2010**

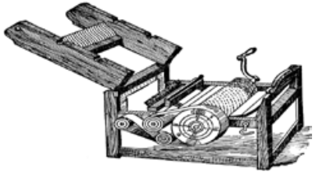
1st U.S. Patent

Information & Communication

The Historical Gap

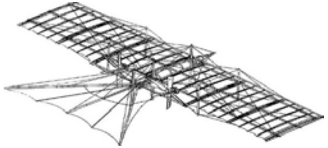
There is virtually no historical and systematic analysis on the geography of innovation and technological change prior to 1975.

Cotton Gin



Telephone

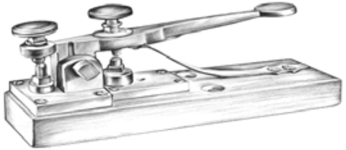
Airplane



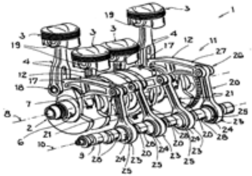
Biotechnology

1790 1820 1850 1880 1910 1940 1975 2010

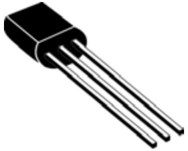
1st U.S. Patent



Telegraph



Internal combustion engine



Semiconductor

Information & Communication

Historical Patent Dataset (HistPat)

www.nature.com/articles/sdata201674 (Petralia, Balland, Rigby; 2016)

United States Patent [19] [11] **4,237,224**

Cohen et al. [45] **Dec. 2, 1980**

[54] **PROCESS FOR PRODUCING BIOLOGICALLY FUNCTIONAL MOLECULAR CHIMERAS**

[75] Inventors: **Stanley N. Cohen,** Portola Valley; **Herbert W. Boyer,** Mill Valley, both of Calif.

[73] Assignee: **Board of Trustees of the Leland Stanford Jr. University,** Stanford, Calif.

[21] Appl. No.: **1,021**

[22] Filed: **Jan. 4, 1979**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 959,288, Nov. 9, 1978, which is a continuation-in-part of Ser. No. 687,430, May 17, 1976, abandoned, which is a continuation-in-part of Ser. No. 520,691, Nov. 4, 1974.

[51] **Int. Cl.**[3] **C12P 21/00**
[52] **U.S. Cl.** .... **435/68;** 435/172; 435/231; 435/183; 435/317; 435/849; 435/820; 435/91; 435/207; 260/112.5 S; 260/27R; 435/212
[58] **Field of Search** .... 195/1, 28 N, 28 R, 112, 195/78, 79; 435/68, 172, 231, 183

[56] **References Cited**

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Chemical and Engineering News, p. 4, May 30, 1977.
Chemical and Engineering News, p. 6, Sep. 11, 1978.

Primary Examiner—Alvin E. Tanenholtz
Attorney, Agent, or Firm—Bertram I. Rowland

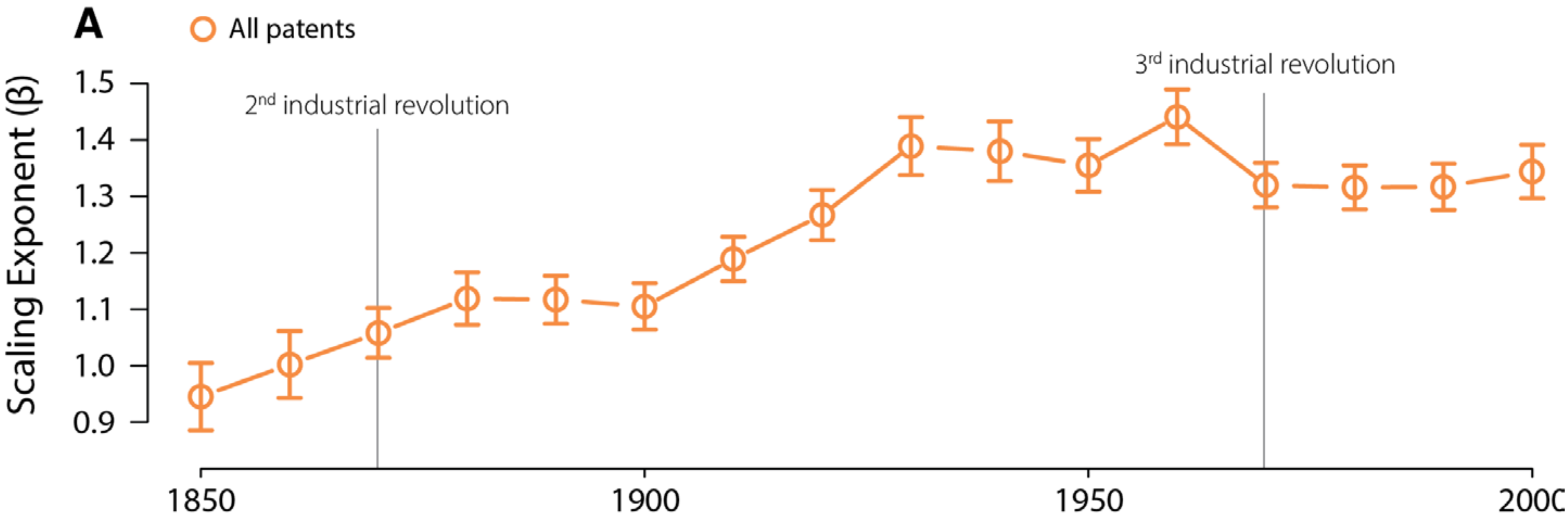
[57] **ABSTRACT**

Method and compositions are provided for replication and expression of exogenous genes in microorganisms. Plasmids or virus DNA are cleaved to provide linear DNA having ligatable termini to which is inserted a gene having complementary termini, to provide a biologically functional replicon with a desired phenotypical property. The replicon is inserted into a microorganism cell by transformation. Isolation of the transformants provides cells for replication and expression of the DNA molecules present in the modified plasmid. The method provides a convenient and efficient way to introduce genetic capability into microorganisms for the production of nucleic acids and proteins, such as medically or commercially useful enzymes, which may have direct usefulness, or may find expression in the production of drugs, such as hormones, antibiotics, or the like, fixation of nitrogen, fermentation, utilization of specific feedstocks, or the like.

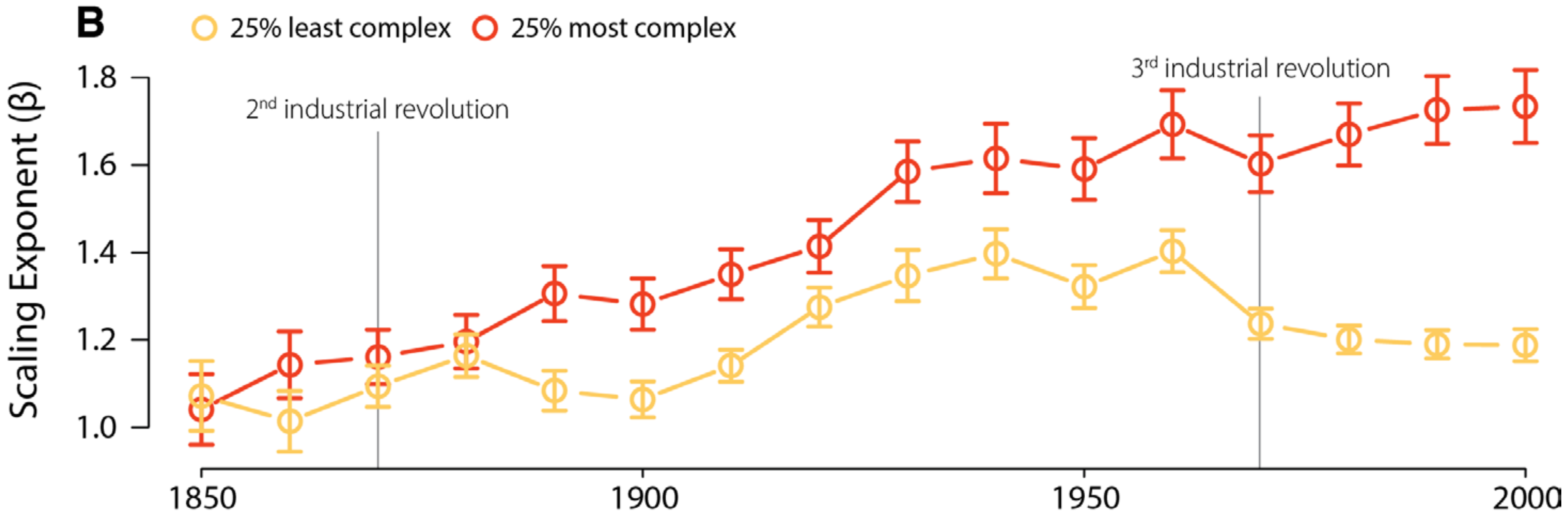
14 Claims, No Drawings

- ~ 7,000,000 US patents
- 1790 to 2016
- Geography of patents (county level – 4,000)
- And their tech classes (436 classes; 150,000 sub-classes)

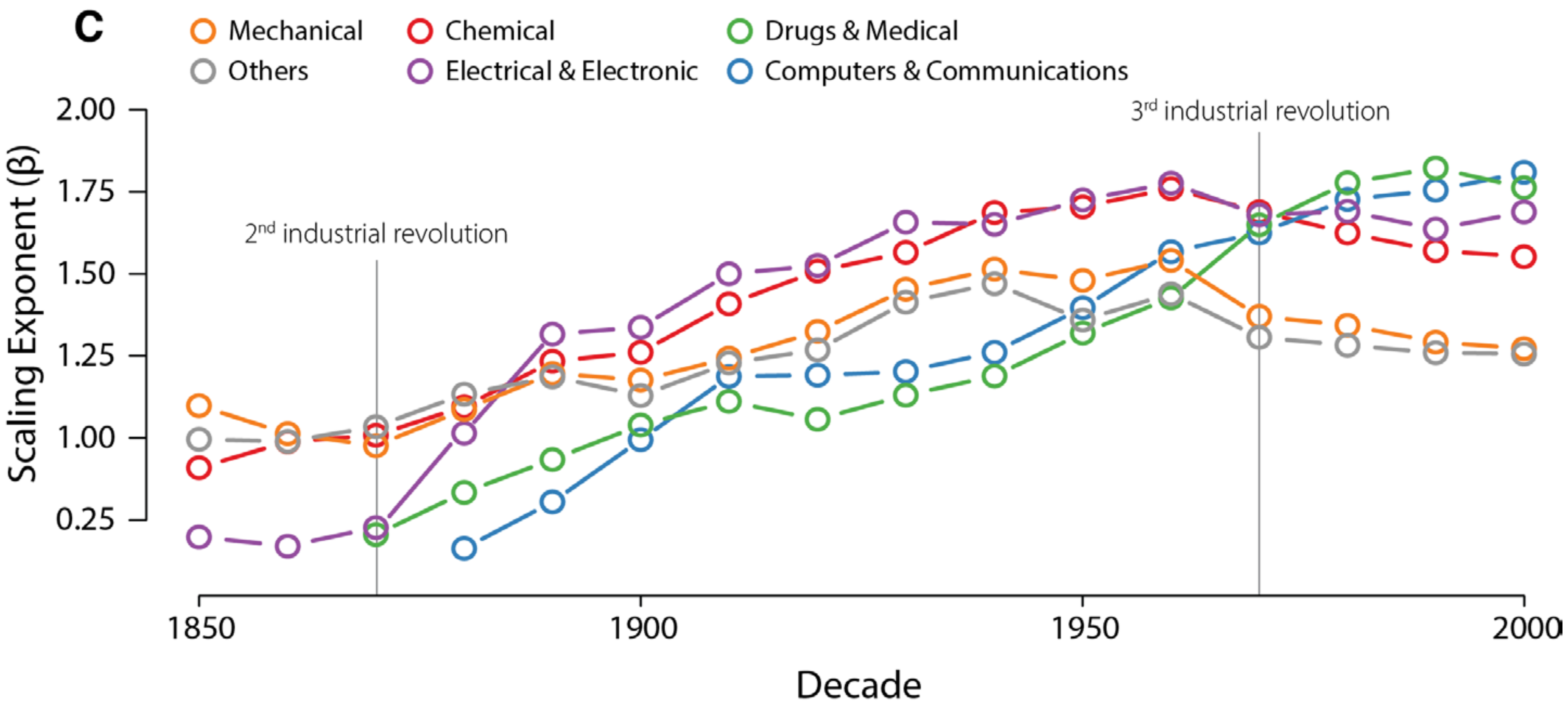
Complexity and scaling (1850-2000)



Complexity and scaling (1850-2000)



Complexity and scaling (1850-2000)



Thanks!

paballand.com

github.com/PABalland/EconGeo