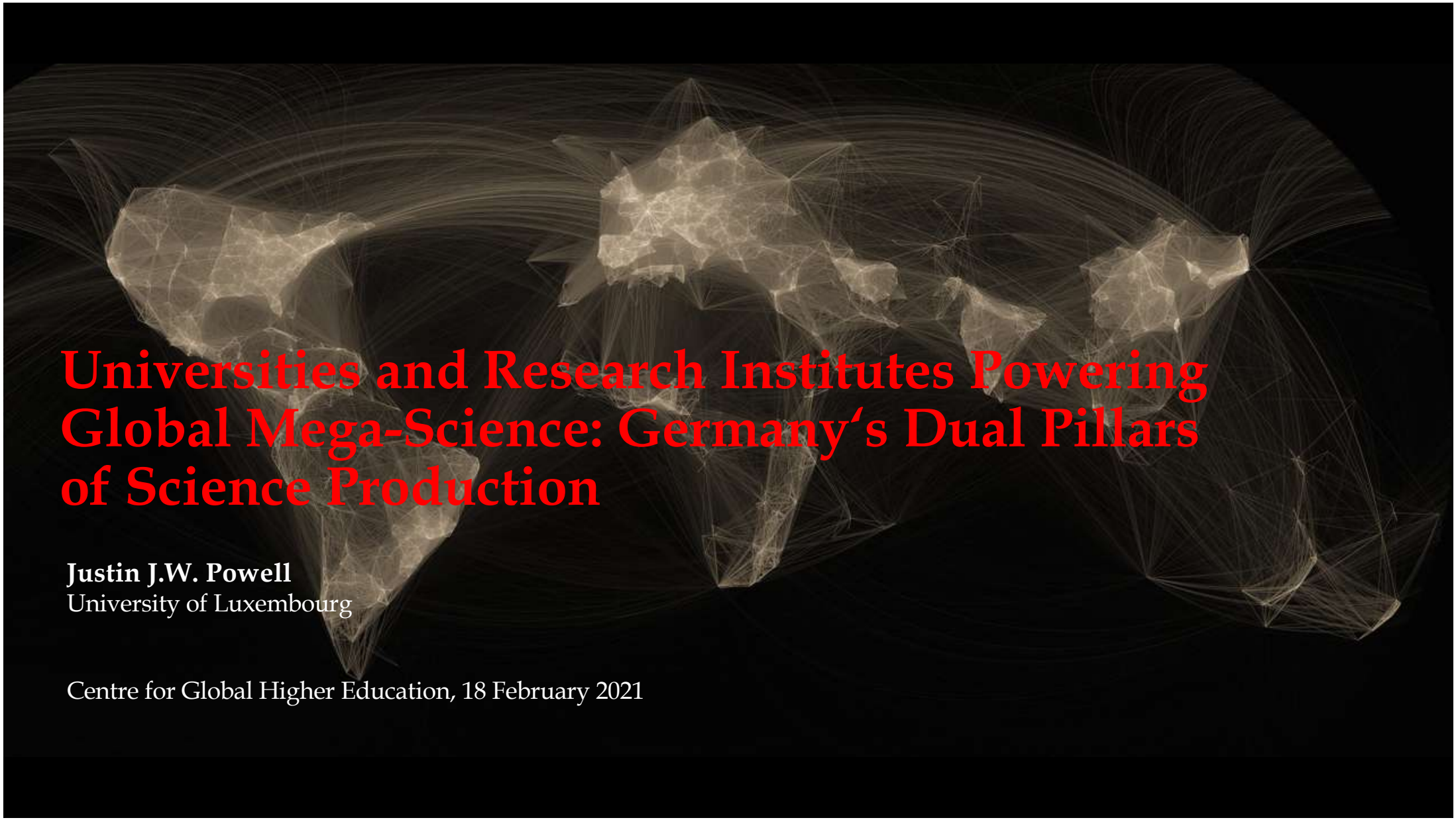

Universities and Research Institutes Powering Global Mega-Science: Germany's Dual Pillars of Science Production

Justin J.W. Powell
University of Luxembourg

Centre for Global Higher Education, 18 February 2021

Higher Education & Global Mega-Science
Setting the Stage & Questions

- **Higher education as panacea:** source of social integration, econ. development & scientific advance. Growing **global science capacity** relies on **higher education expansion** & investments in research — global **"university-science model"** (Baker & Powell, forthcoming).
- Most nations have established **research universities** to educate professionals— and to foster **social & economic innovation**. **All contribute to scientific discovery:** Science is a **global collaborative effort**, esp. "mega-science" projects (vaccine development)!
- Are there **limits to growth in scientific production?** (Continued exponential growth?) How did **university science** evolve over "**the century of science**"? What can we learn from **Germany** about **science production** in an **era of collaboration?**

Sources: Powell, J.J.W., D.P. Baker & F. Fernandez, eds. (2017). *The Century of Science: The Global Triumph of the Research University* (Emerald); Baker, D.P. & J.J.W. Powell (forthcoming). *Global Mega-Science: Universities Scientize the World* (Stanford U Press).

Global Mega-Science & Germany

Context: Why Germany?

- **Germany as provider of models**: (a) the **research university originated there**. Most successfully in the US, the "university-science model" since been **emulated globally**; (b) the independent, government funded, highly prestigious **research institute** was also developed in Germany.
- Ironically, this "dual pillar" model and research policy emphasizing "scientific genius" is now out-of-sync in an era of collaboration **— Germany offers a counterfactual case.**
- **Contributor to Mega-Science:** After the world wars, the *lingua franca* of science shifted from German to English, but **Germany rebuilt** its science infrastructure successfully. Today, the country's **university *and* institute researchers do collaborate** across organizational boundaries, but more often internationally. What conditions support collaboration?

Sources: Powell, J.J.W., D.P. Baker & F. Fernandez, eds. (2017). *The Century of Science: The Global Triumph of the Research University* (Emerald); Baker, D.P. & J.J.W. Powell (forthcoming). *Global Mega-Science: Universities Scientize the World* (Stanford U Press).

Project SPHERE:
Science Productivity, Higher Education, REsearch & the Knowledge Society

- Global, intercultural team of scientists from **China**, **Germany**, **Japan**, **Luxembourg, Qatar**, **Romania**, **South Korea**, **Taiwan** & **U.S.** (Collaborators: **David P. Baker,** John T. Crist, Jennifer Dusdal, Frank Fernandez, Yuan-Chih Fu, Justin Powell, Robert Reisz, Kazunori Shima, Manfred Stock, Liang Zhang, et al.)
- **Project funding**—QNRF; **Project base**—Georgetown U. School of Foreign Service in Qatar
- **International comparison** of the influence of **HE models and HE expansion**—science capacity-building—on scientific **knowledge production from 1900**
- **Focus on Europe, North America, and East Asia** as the three centers of global science
- **Longitudinal analysis on different levels**: Disciplines, org. field, org. forms, org's
- Measuring of science production in science and technology disciplines and health (**STEM+**): **peer-reviewed research articles** = "gold standard" for measurement

Sources: Powell, J.J.W., D.P. Baker & F. Fernandez, eds. (2017). *The Century of Science: The Global Triumph of the Research University* (Emerald); Baker, D.P. & J.J.W. Powell (forthcoming). *Global Mega-Science: Universities Scientize the World* (Stanford U Press).

Project Q-KNOW: "Relational Quality" — Developing Quality through Collaborative Networks and Collaboration Portfolios

- Collaboration of scientists from **Germany** and **Luxembourg**
  (Jennifer Dusdal, Anna Kosmützky, Achim Oberg, Justin Powell, et al.)
- **Project funding** — German Federal Ministry of Education and Research (BMBF)
  Project base — Leibniz Center for Science and Society (LCSS), U. of Hannover, Germany
- **Focus on Germany** with its **dual-pillar research system**
- Investigate how **scientific publication patterns** developed, analyzing the **proportion** and **impact of interorganizational collaboration networks**
- Org. output depends on the **collaboration portfolios among German org's** (and partner organizations worldwide)
- How is collaboration leveraged to **enhance scientific quality** at organizational level?

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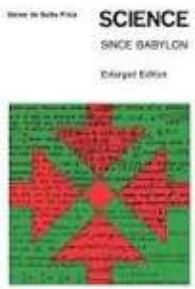
Data & Methods

- **Comparative institutional analyses** of HE and science systems: org. fields & forms; org's
- **Bibliometric analysis of peer-reviewed research articles & citations in STEM+** (raw data, global, 1900–2011) recoded: 1900–1975 (stratified rep. sample, 5-year-steps); 1980–2011 (annual)
- Quantitative & Network Analyses **(1900–2020)**: Clarivate Analytics' WoS (all disciplines, Germany & int'l. partners, 2011–2020)
- **Article information:** title, authors, disciplines, organizational affiliation, journal, JIF, citations
- Limitations: Certain fields, English language dominance, (Western) journals; **focus: counting articles** (not content or citation analysis)
- **Qualitative case studies:** interviews & site visits to investigate **org. conditions** that faciliate durable collaboration networks

Rising Scientific Production:
Pure Exponential Growth or with Saturation?



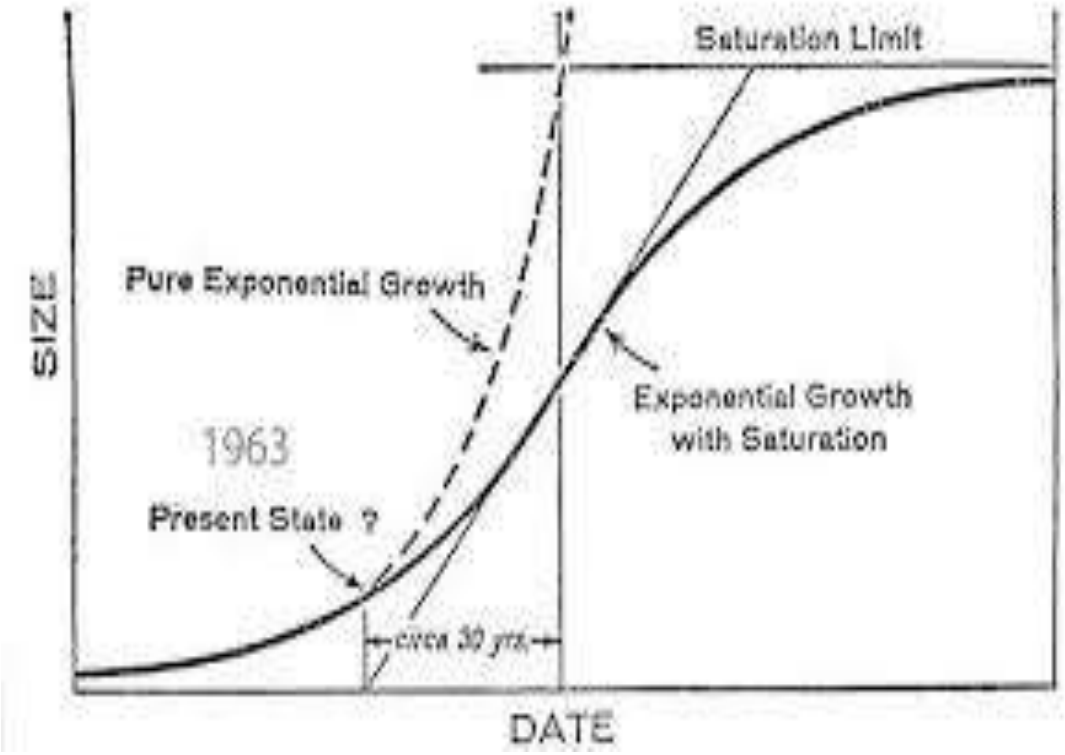
Higher Education & Science Expansion:

Rising numbers of students & scientists; org's & journals

Institutional factors determine scientific growth & development patterns

Early founders of **bibliometrics** hypothesized that scientific growth would slow down (saturation)...

Were they correct?



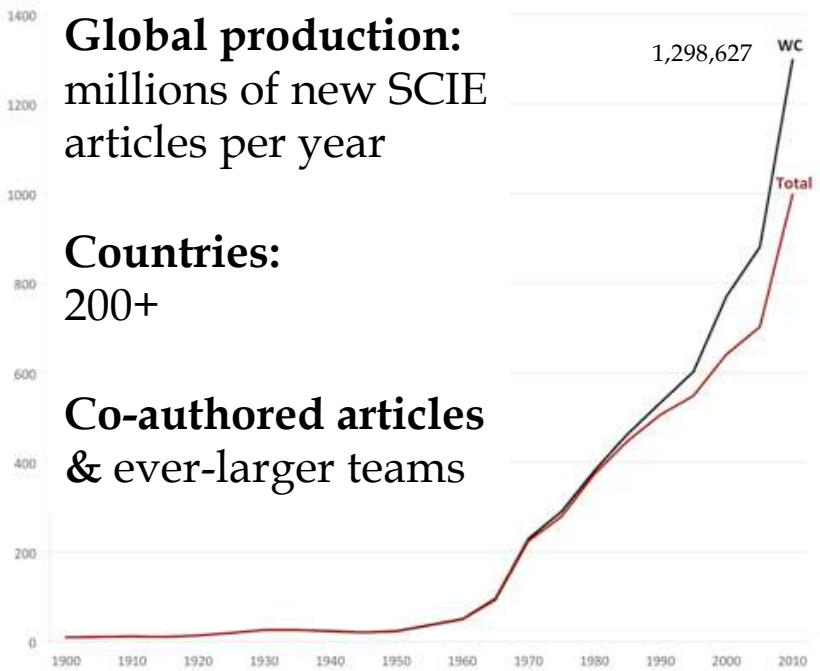
Sources: de Solla Price, D. 1961. *Science Since Babylon*. New Haven: Yale University Press; de Solla Price, D. 1963. *Little Science, Big Science*. New York: Columbia University Press

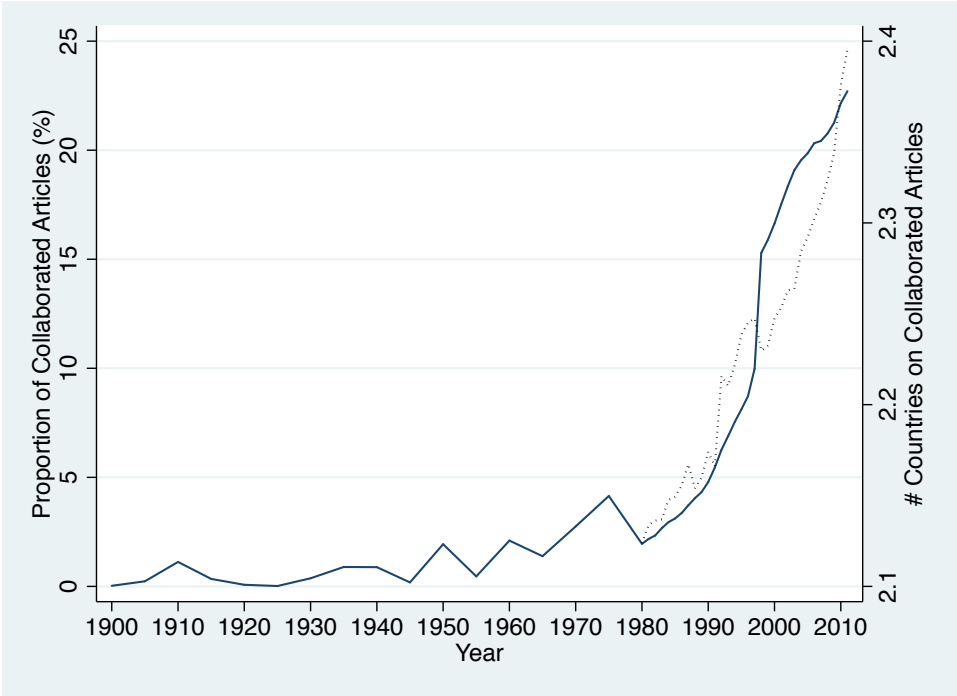
Global Mega-Science: Competition & Collaboration in Global Science

Global production:
millions of new SCIE articles per year

Countries:
200+

Co-authored articles
& ever-larger teams



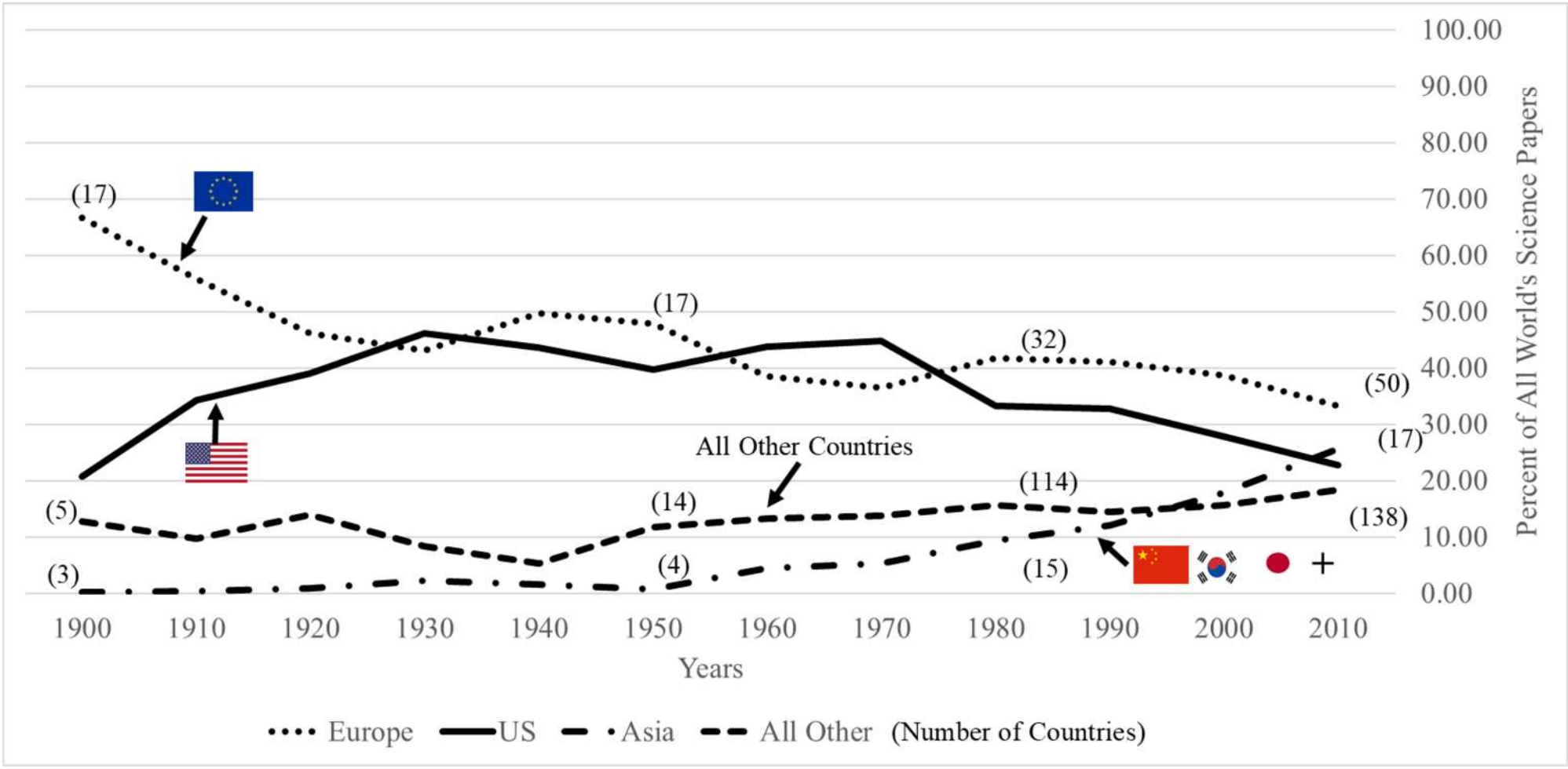


Pure Exponential Growth in SCIE Article Publications, 1960s–
HE Expansion, R&D Investments, Global & Regional Competition, "Knowledge Society"

Pure Exponential Growth in Collaboration, 1990s–
Networks, Collaboration, English, ICT

Sources: Powell, J.J.W., D.P. Baker & F. Fernandez, eds. (2017). *The Century of Science: The Global Triumph of the Research University* (Emerald); Baker, D.P. & J.J.W. Powell (forthcoming). *Global Mega-Science: Universities Scientize the World* (Stanford U Press).

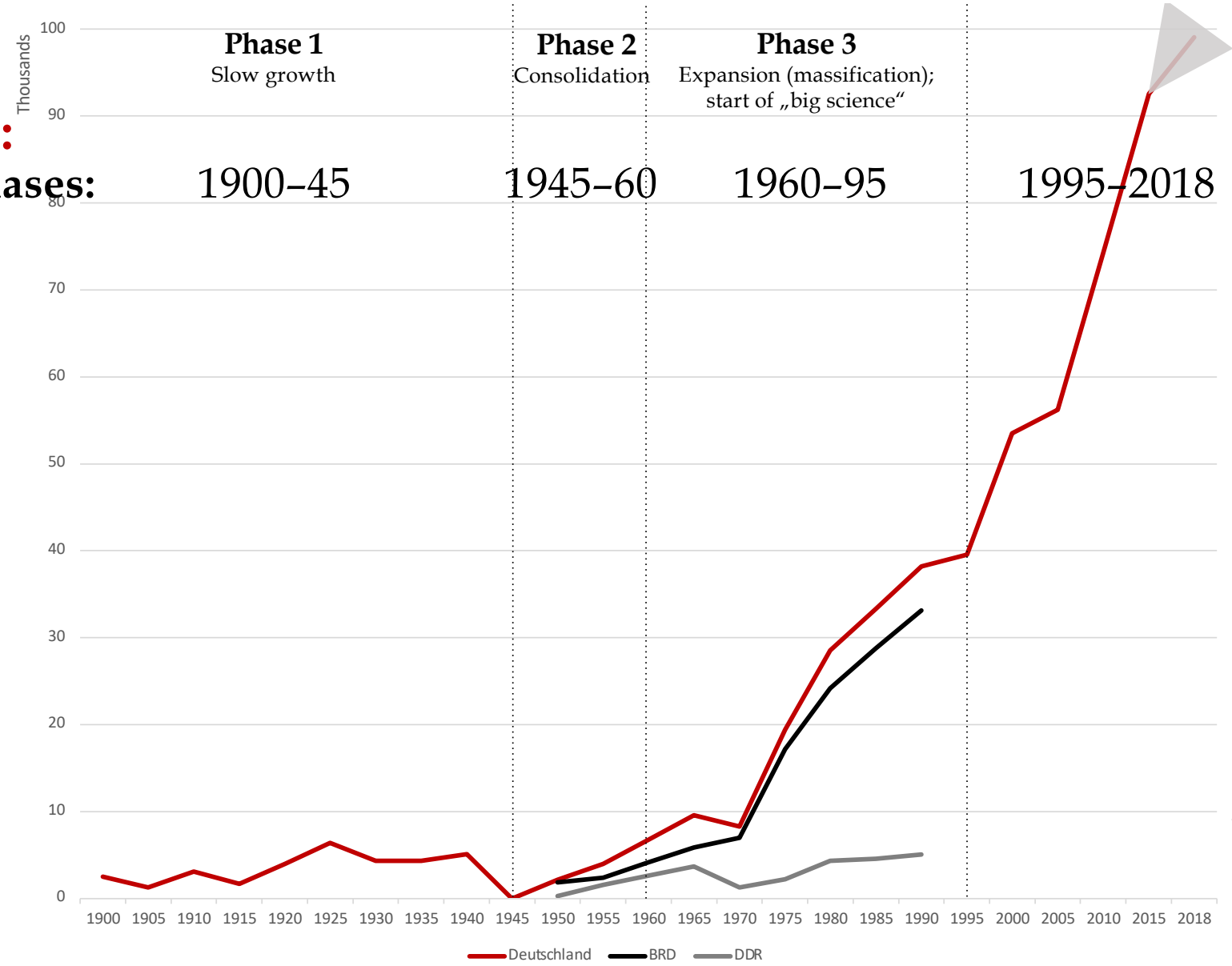
Globalization of Science since 1900:
Inclusive, with 3 Centers (Europe, North America, East Asia)



Source: Baker, D.P. & J.J.W. Powell (forthcoming). *Global Mega-Science: Universities Scientize the World*. Stanford: Stanford U. Press.

Germany:

Growth Phases: 1900–45 1945–60 1960–95 1995–2018



Source: Dusdal, J. (2018). *Welche Organisationsformen produzieren Wissenschaft?* Frankfurt/Main: Campus; SPHERE & Q-KNOW Database

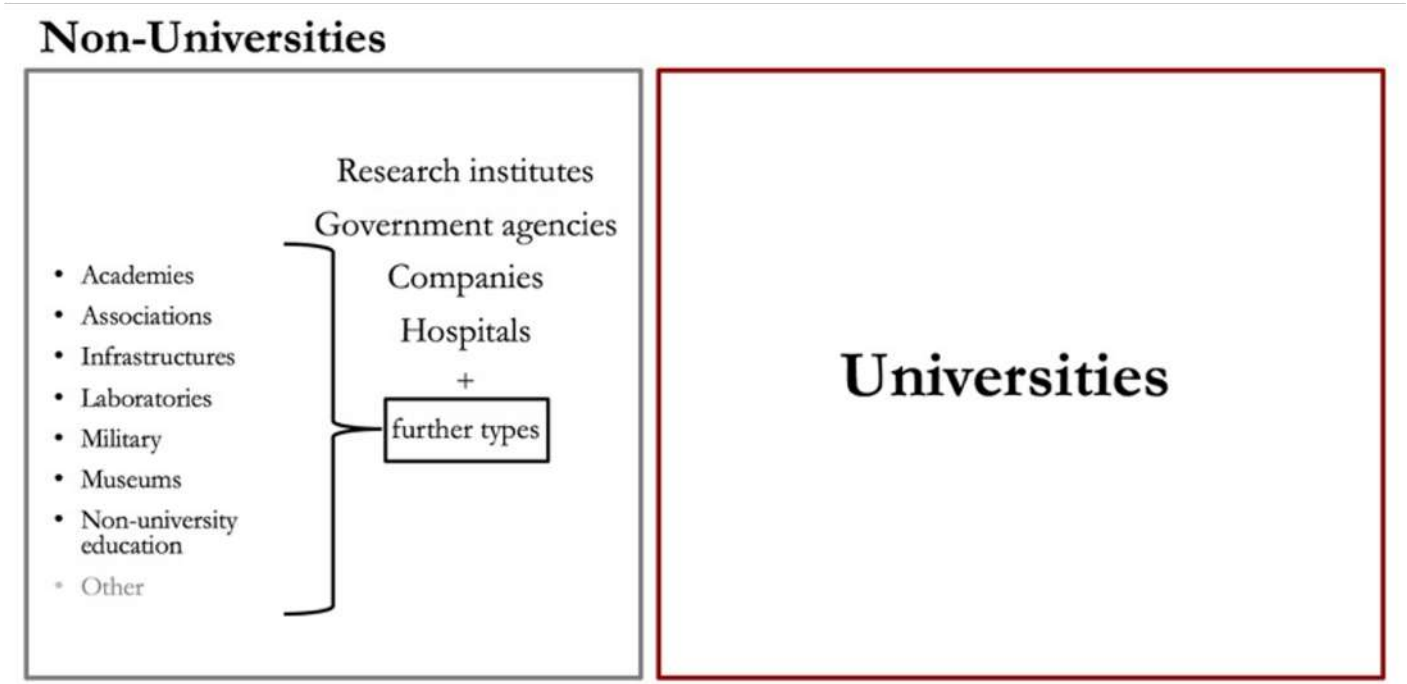
Organizational form	Character, tasks & goals	Research type	Example	Code
Universities	Freedom to teach & to study; orientation towards 2 systems: education & science; support of young researchers; right to award doctorates/habilitations	Basic research	RWTH Aachen, Technische Universität München Universität Heidelberg	12
Research institutes	Focus on research; no teaching; good personell/financial facilities; independence; running of large equipments	Depending on the institute (e.g. basic, applied, „Vorsorgeforschung“)	Institutes of the FhG, HGF, MPG, WGL, o ther independent institutes	11
Companies	Research departments & laboratories; profit; provision of expertise	Applied (industrial) research; development	Bayer, Siemens, Henkel	3
Government agencies	Scientific expertise for government action; expertise & research; political advice & information; regulation & inspection	applied & policy-relevant research	Bundesforschungsanstalt für Geowiss. und Rohstoffe, Bundesanstalt für Material-prüfung, Umweltbundesamt, Robert Koch Institut	4
Hospitals	Care & cure, apprenticeship of nursing staff & doctors, research in cooperation	No or applied research	Deutsche Klinik für Diagnostik, Kerckhoff-Klinik Bad Nauheim, Rehazentrum Bad Brückenau	5
Academies	Policy advice; research funding; distribution of information; publication of research; experimental method; “Wissenschaftspflege”	(Humanities); long-term basic research	Leopoldina Nationale Akademie der Wissenschaften, BBAW, acatech	1
Associations	Allocation & provision of (financial) resources; coordination & organization of dialogue; scientific communication	Limited own research	Deutsches Rotes Kreuz, Gesellschaft Deutscher Chemiker, Verein Deutscher Chemiker, andere Berufsverbände	2
Infrastructure	Instruments, resources or service for research; national importance for the German science landscape; >10 years; open access & usage	Limited own research	Sammlungen, Computer-/Rechenzentren, CERN, Laboratorien, Forschungsschiff SONNE, SOEP, Großgeräte	13
Laboratories	Research & experiments; quality testing; measurments; experiments; autonomy; provision of equipment	Applied & basic research	Europäisches Labor für Molekularbiologie, Münchner Leukämielabor, Institut für Immunologie und Genetik Kaiserslautern	6
Military	State control; authority about the armed forces; development of weapon(systems), communication technologies	Applied research (with a specific goal); „Rüstungsforschung“	Bundeswehr (Universitäten, Institute)	7
Museums	Exhibition; collecting/preserving/exploring knowledge & cultural heritages; conservational research; material research; analysis of origins; age determination	Applied & basic research	Altes und Neues Museum, Hessisches Landesmuseum Darmstadt, Zoologisches Museum Hamburg	8
Non-university education	Teaching; apprenticeship of students; cooperation with companies; convergence to universities; knowledge/ technology transfer to strengthen the regional economy	Applied research; development	Fachhochschule Gießen, Technische Hochschule Mittelhessen, European Management School, DAA Logopädieschule Freiburg	9
Other	Depending on the organization	Depending on the organization	Hybride Organisationen (Charité, KIT, JARA),	10

Organizational Forms
Producing Research in Germany

Positioning of organizations in an organizational field

Indicators:
Character, tasks, goals, type(s) of research

Org. form differences
in scientific productivity



Source: Dusdal, J. (2018). *Welche Organisationsformen produzieren Wissenschaft?* Frankfurt/Main: Campus Verlag.

Germany's Second Pillar: Associations of Research Institutes

Max Planck Society	Fraunhofer Society	Leibniz Association	Helmholtz Association
*1948 ~ 22 000 employees **Basic research** (partially emerged from the Kaiser Wilhelm Association)	*1949 ~ 25 000 employees **Applied research**; transfer to companies	*1990 ~ 19 000 employees **Social & natural sciences & humanities** (previously: „blue list" and Academy of Sciences GDR)	*2001 ~ 38 000 employees **Big science** (previously: AG Großforschungs-einrichtungen)

Personnel: ~ 660,000 employees in universities
~ 104,000 employees in extra-university research institutes

Science Production of Germany in Europe:
Small – Big – Mega-Science, 1900–2010

2 Pillars of German Science:
universities & research institutes in global STEM+ science

from 1950:
6x as many universities;
60x as many research institutes

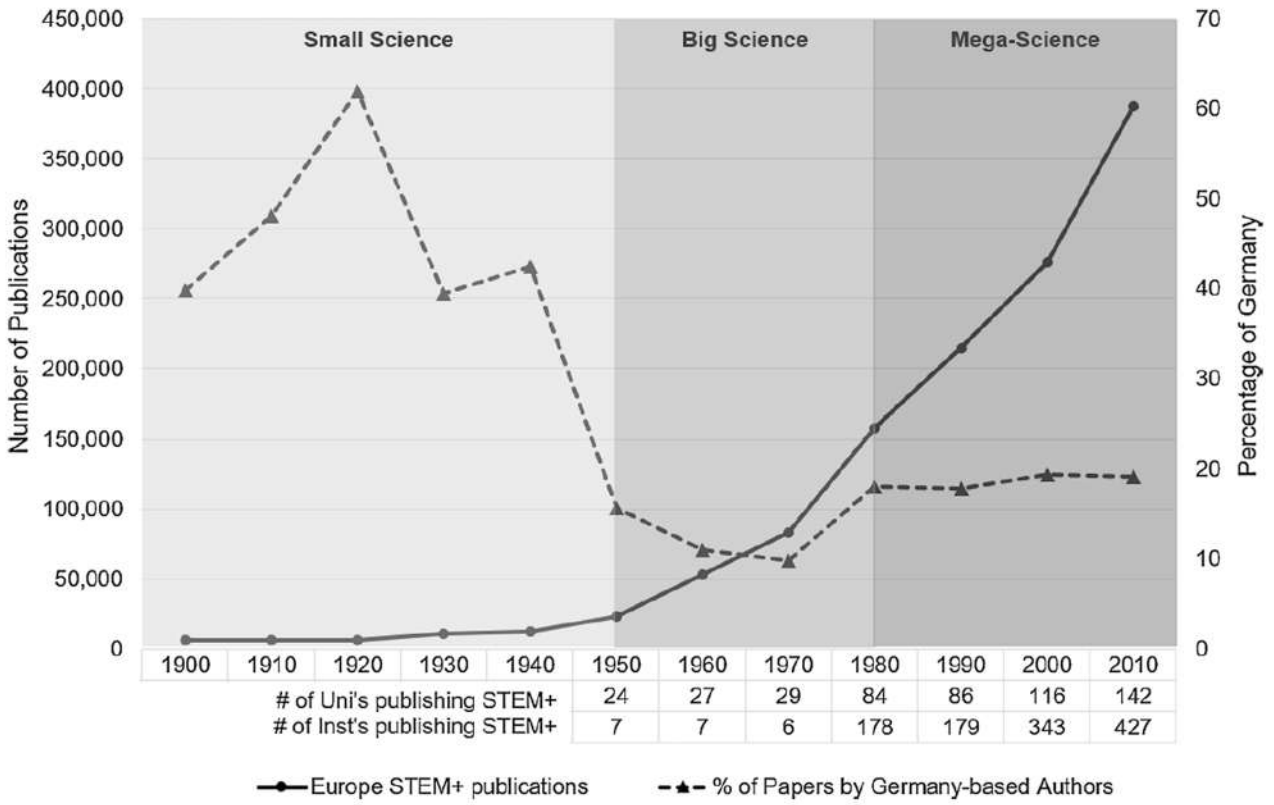


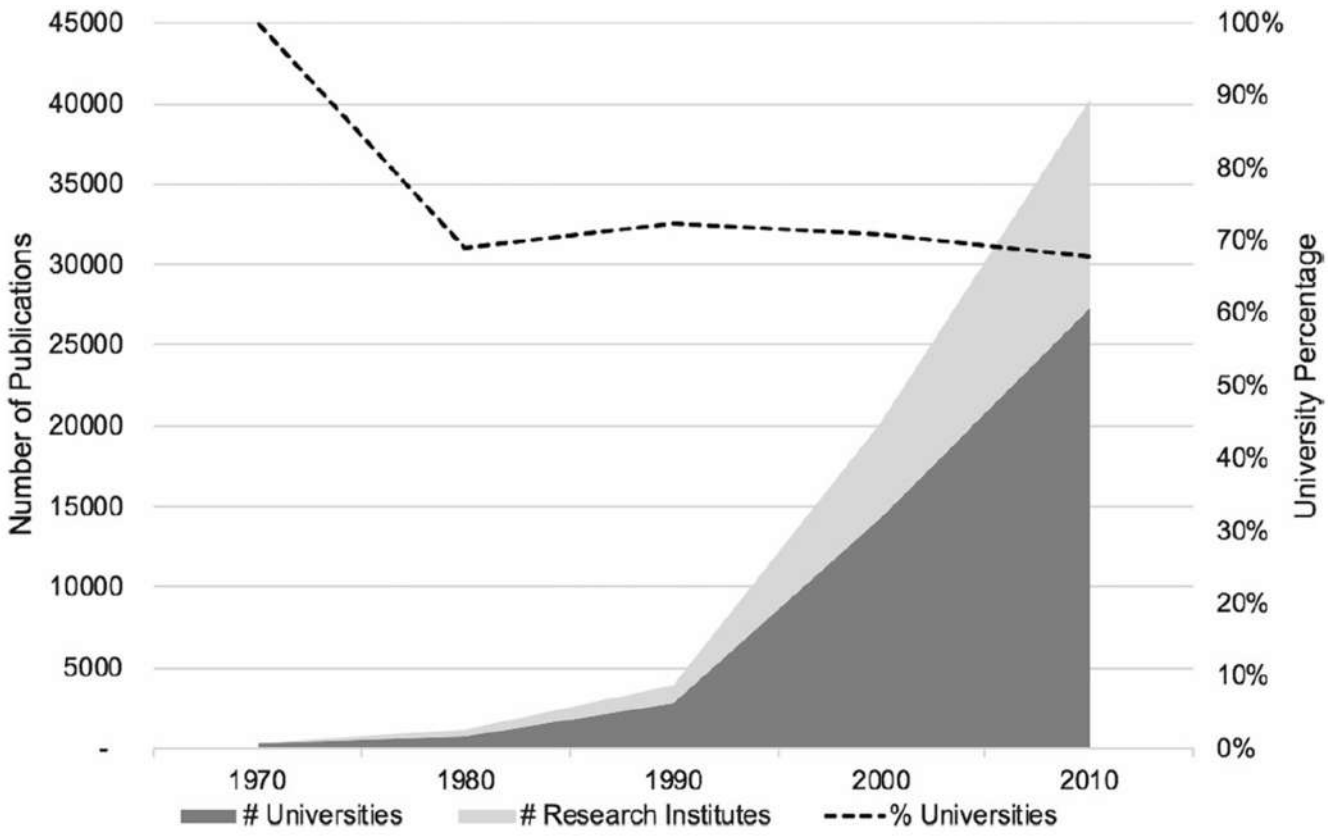
Fig. 1 Estimated Volume of STEM+ Journal Articles Authored by European Scientists; Percentage of Papers by Germany-based Authors; and Number of Universities and Research Institutes Contributing to Publications in Germany, 1900–2010. *Source* SPHERE project database of SCIE publications (Clarivate Analytics' Web of Science). *Note* Number of universities and institutes with at least one STEM+ publication approximates but does not necessarily match official totals of all universities and institutes as a small number may not have contributed articles in the database's journals in selected years

Source: Dusdal, J., Powell, J.J.W., Baker, D.P. et al. (2020). University vs. Research Institute? The Dual Pillars of German Science Production, 1950–2010. *Minerva* 58, 319–342.

International Co-authorships: Germany's Connected Universities

Publications of researchers at universities and research institutes (% unis of all international co-authorships, 1970–2010).

- **Universities as the driving force of science production:** continuous contribution (70%)
- **Growth despite stagnant funding** – highly collaborative
- **Mode 1 remains dominant form** of science production

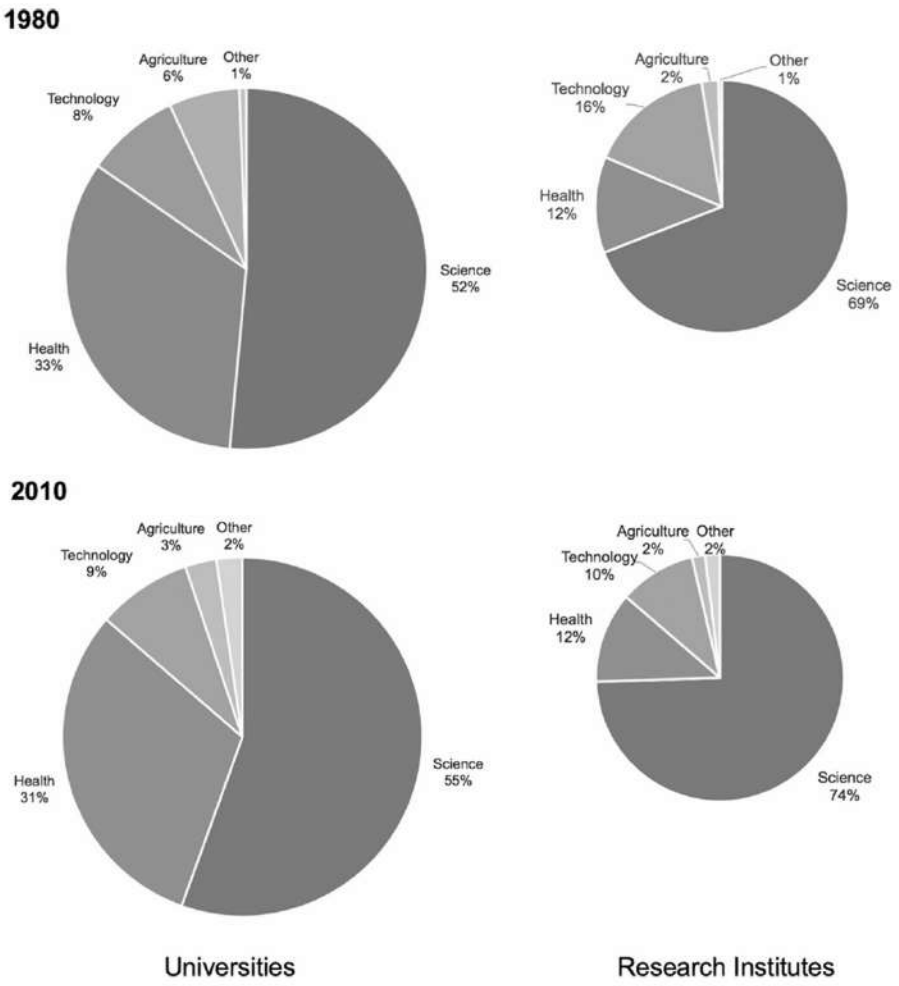


Source: Dusdal, J., Powell, J.J.W., Baker, D.P. et al. (2020). University vs. Research Institute? The Dual Pillars of German Science Production, 1950–2010. *Minerva* 58, 319–342.

German Universities' & Institutes' Contributions to Disciplines (Science, Technology, Agriculture, Health, Other):
1980 and 2010 per Sector

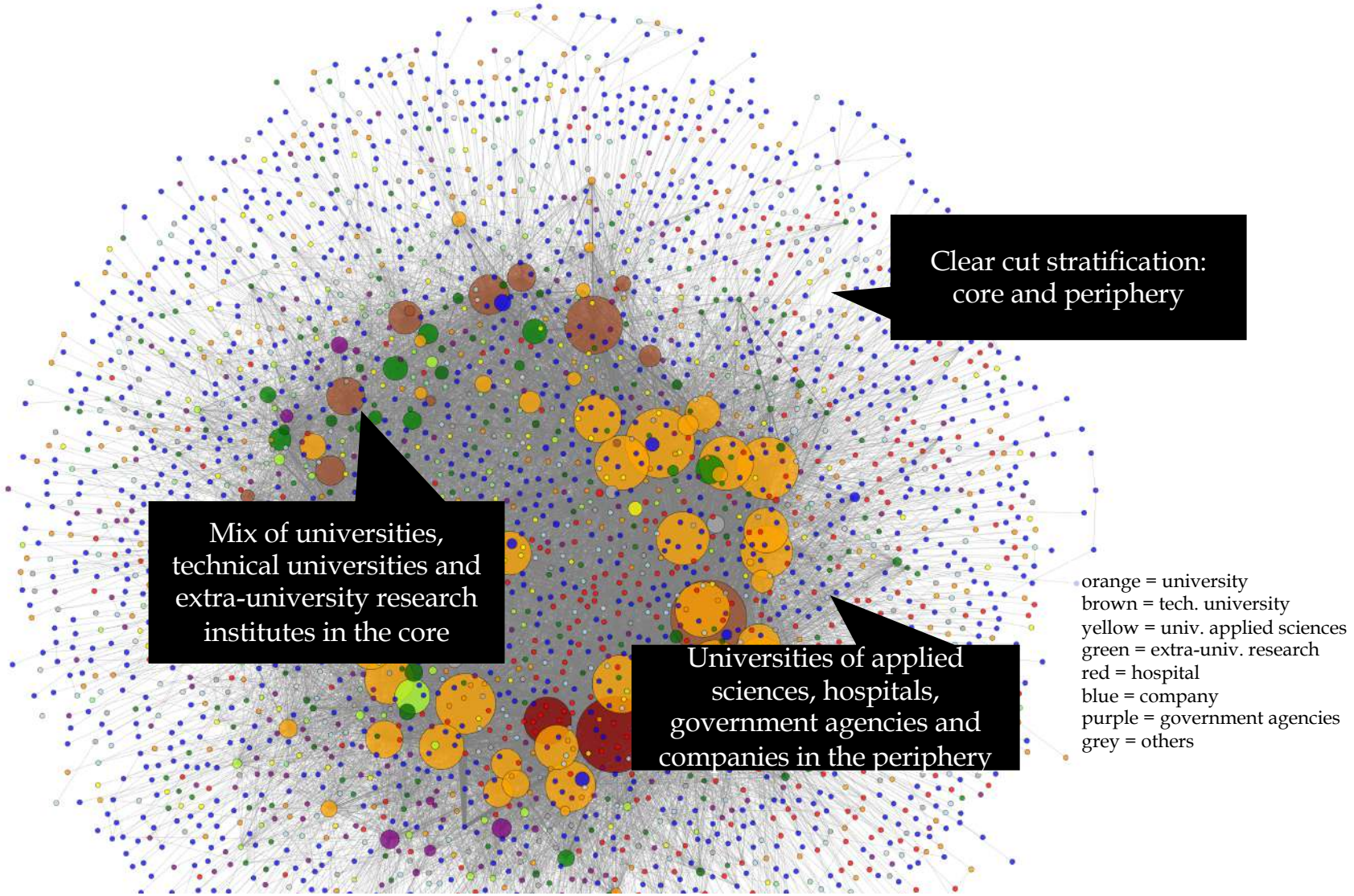
Stable proportions despite redistribution of resources:
rising funds for research institutes; stagnation for universities.

Cross-sectoral co-authorships
(2000–10): increase from 3% to 12%



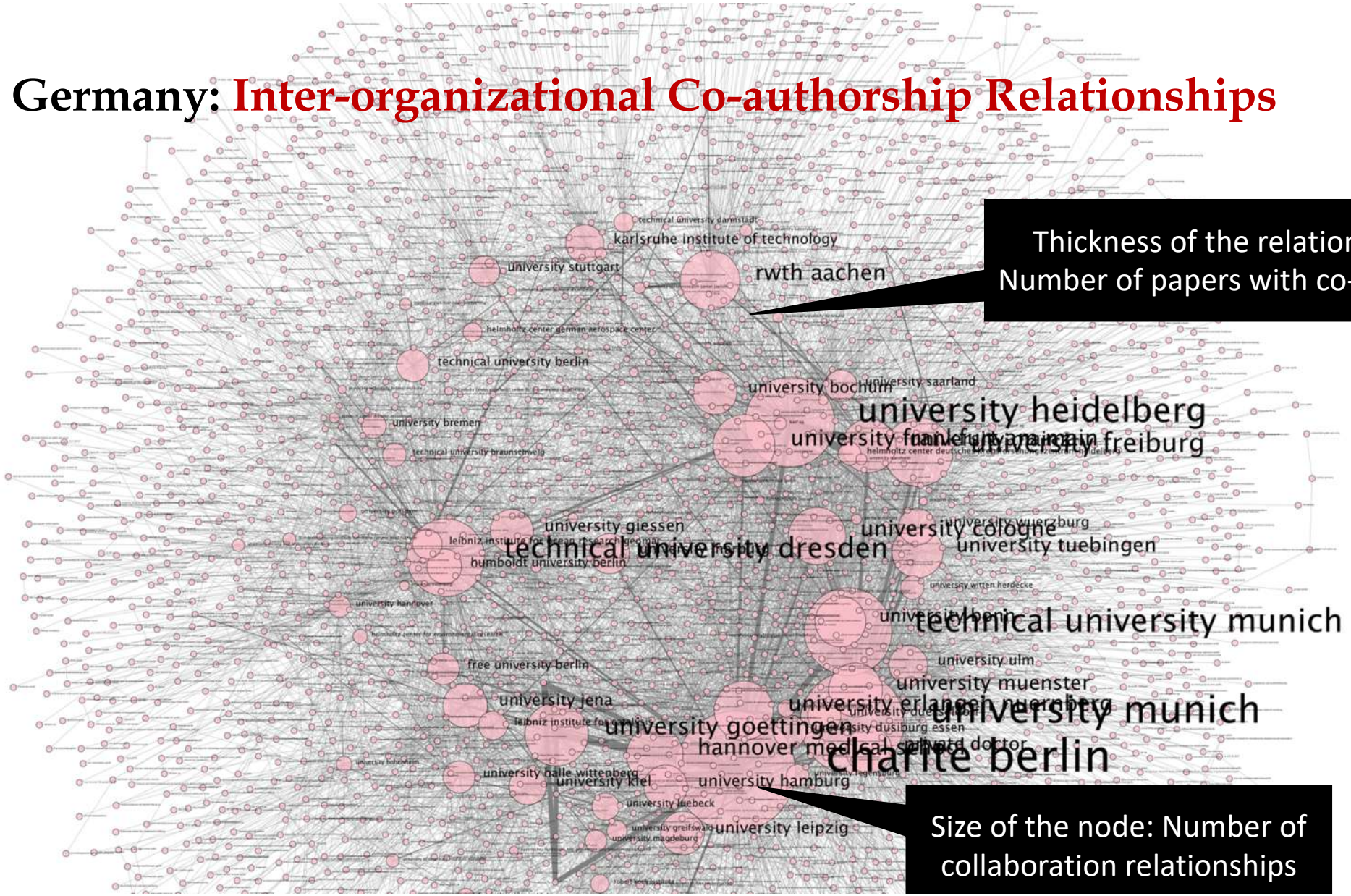
Source: Dusdal, J., Powell, J.J.W., Baker, D.P. et al. (2020). University vs. Research Institute? The Dual Pillars of German Science Production, 1950–2010. *Minerva* 58, 319–342.

Germany's Organizational Forms: Scientific Networks



Source: SPHERE & Q-KNOW project database (raw data from Clarivate Analytics' Web of Science SCIE); Dusdal, Oberg & Powell 2019

Germany: Inter-organizational Co-authorship Relationships



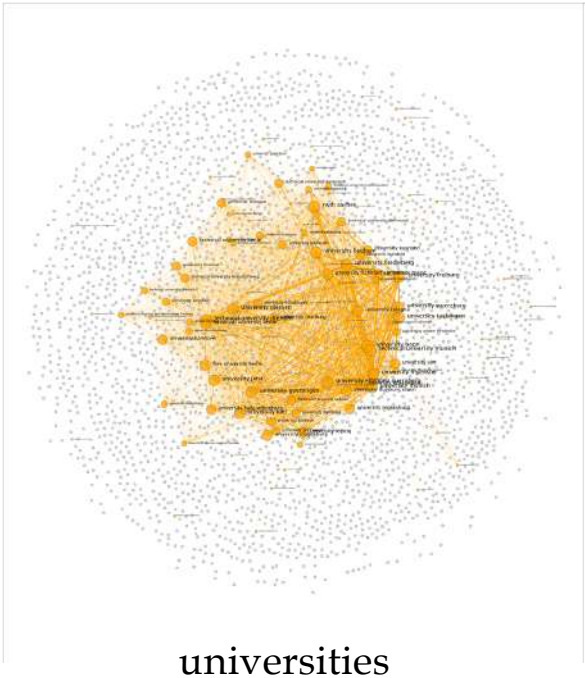
Thickness of the relationship: Number of papers with co-authors

Size of the node: Number of collaboration relationships

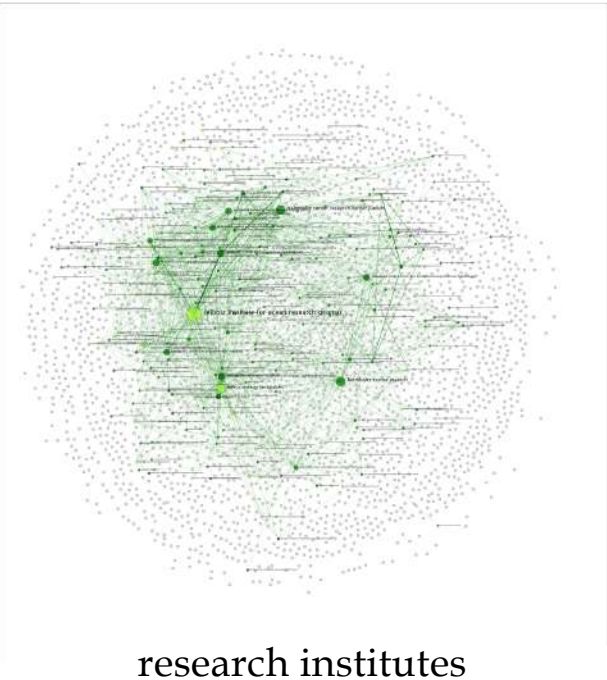
Source: SPHERE & Q-KNOW project database (raw data from Clarivate Analytics' Web of Science SCIE); Dusdal, Oberg & Powell 2019

Germany Collaborates:

Research Between Universities and Institutes



universities



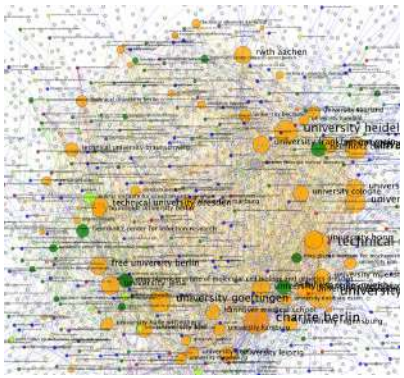
research institutes

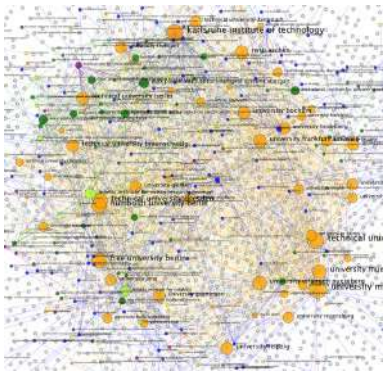
universities &
research institutes

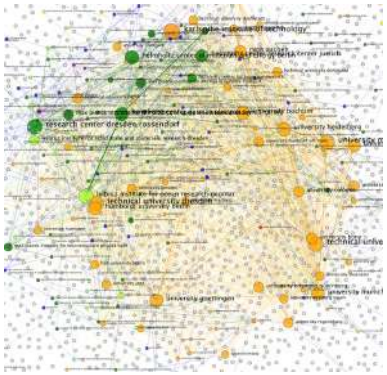
Universities remain the central organizational form for science;
Research institutes act as catalysts for universities and technical universities

Source: SPHERE & Q-KNOW project database (raw data from Clarivate Analytics' Web of Science SCIE); Dusdal, Oberg & Powell 2019

Disciplinary Relevance of Organizational Forms







	biology	chemistry	physics
universities	(old) universities	univ. & technical universities	technical universities
extra-university institutes	some	variety	central resource
companies	partly connected	central actors	largely irrelevant

Relevance of organizational forms & types of relationships vary by discipline

Source: SPHERE & Q-KNOW project database (raw data from Clarivate Analytics' Web of Science SCIE); Dusdal, Oberg & Powell 2019

Conclusions

- Remarkable **pure exponential growth of science**, due to expanded research capacity
- **"Inclusive" globalization of science since 1900**, but Europe, North America & East Asia dominant
- **Rising global, regional, and national competition**, but also **massively increasing collaboration:** worldwide, across Europe & in Germany—majority of world's STEM+ publications **co-authored**
- **Shifting modes of science production:** Small science — big science — mega-science
- **German science's two pillars:**
  Long-term institutionalization of **research universities & research institutes**
- Both organizational forms contribute to science production, yet **different foci, network structures,** and **types of collaborations:** Disciplines | Organizational forms | Basic vs. applied
- **Universities** remain the **driving force of science**:
  the **key platform for collaboration** in Germany—and globally
- Among organizational forms, **collaboration with varying intensity** and diverse characteristics