Global Mega-Science:
Relationale Qualität und die Zentralität der Universitäten in wissenschaftlichen Kooperationsnetzwerken

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16. September 2021

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

- **Higher education as panacea:** source of learning opportunities, social integration, economic development—and **scientific advance**.
- Growing **global science capacity** relies on **higher education expansion** & investments in research—global **"university-science model"** (Baker & Powell: *Global Mega-Science: Universities Scientize the World*).
- 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-based science** evolve over the "**century of science**"?
  What can we learn from **Germany** about **science production** in an **era of collaboration?**

Global Mega-Science
and "Relational Quality"

1) **Increasingly collaborative** science, esp. in "mega-science" fields, such as Astronomy, Health and Genomics, and Physics (Kahn 2018).
2) **"Collaboration imperative"**—in many disciplines, **innovation depends on collaboration** (Boardman & Bozeman 2014).
3) **Motivations, potentials, and challenges of collaboration need attention.** Yet to measure research "quality" is notoriously difficult, esp. the "relational" dimensions.
4) **Measurement:** usually, co-authored publications, even if this is a conservative and problematic indicator (due to disciplinary diff's & evaluation regimes) (Laudel 2002; Kahn 2018).
5) **Collaborative, relational dimensions** remain largely a **black box** (Dusdal, Oberg & Powell 2019; Dusdal & Powell 2021; Kosmützky & Wöhlert 2021).

Global Mega-Science
Key Arguments

1) **Globalization of science** = worldwide increasing research capacity, due especially to connection between **university & science ("university-science model")**
2) **Most countries** now have **research universities**
3) **Mega-science production is collaborative** (ever-larger teams) and international via universities that are similar everywhere, with **multiple hubs, branches, online offerings**
4) **Greater parity** in research across world regions
5) **Increasing scientific discoveries**—"pure exponential growth"
6) **Global mega-science** creates the conditions for **"scientization"** (Drori et al. 2003)

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 US, the **"university-science model"** has since been emulated **globally**;
  (b) the independent, government funded, highly prestigious **research institute**.
- In an era of collaboration; however, is this **"dual pillar" model** and research policy still appropriate? **Germany offers a valuable 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, regaining a key position. Today, the country's **university *and* institute researchers do collaborate** across organizational boundaries, but to a limited extent. 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

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

- Collaboration of scientists from **Germany** and **Luxembourg**
  (PIs: 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 extensive and **diverse 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 org's worldwide)
- How does collaboration **enhance scientific quality**, via relationships, within nextworks, and at organizational level?

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+** (SCIE 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 lang. 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 Reaching Saturation?

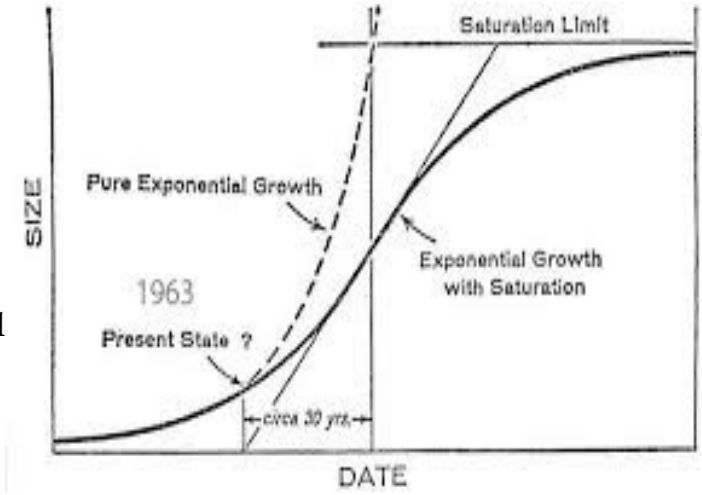
Higher Education & Science Expansion:

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)...
(Derek de Solla Price 1961, 1963)

Were they correct?



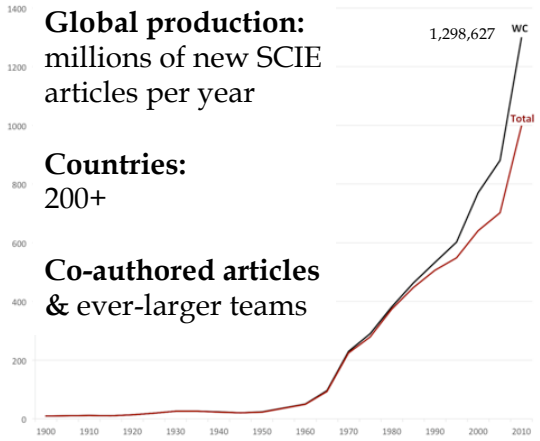
Sources: de Solla Price, D. 1961. *Science Since Babylon*. New Haven: Yale University Press; de Solla Price, D. 1963. *Little Science, Big Science*. New York: Columbia University Press

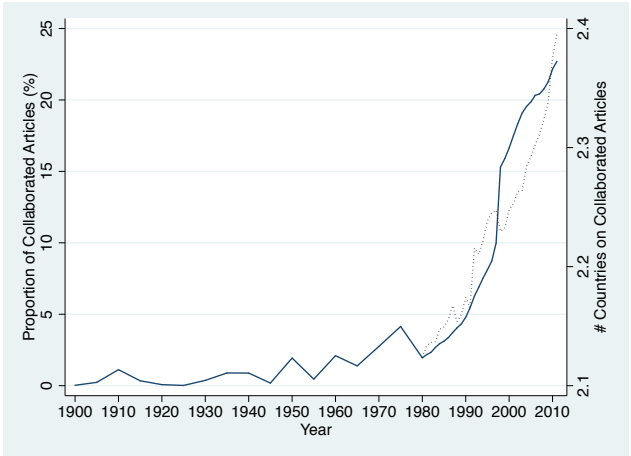
Global Mega-Science: Competition & Collaboration in Global Science

Global production:
millions of new SCIE articles per year

Countries:
200+

Co-authored articles
& ever-larger teams



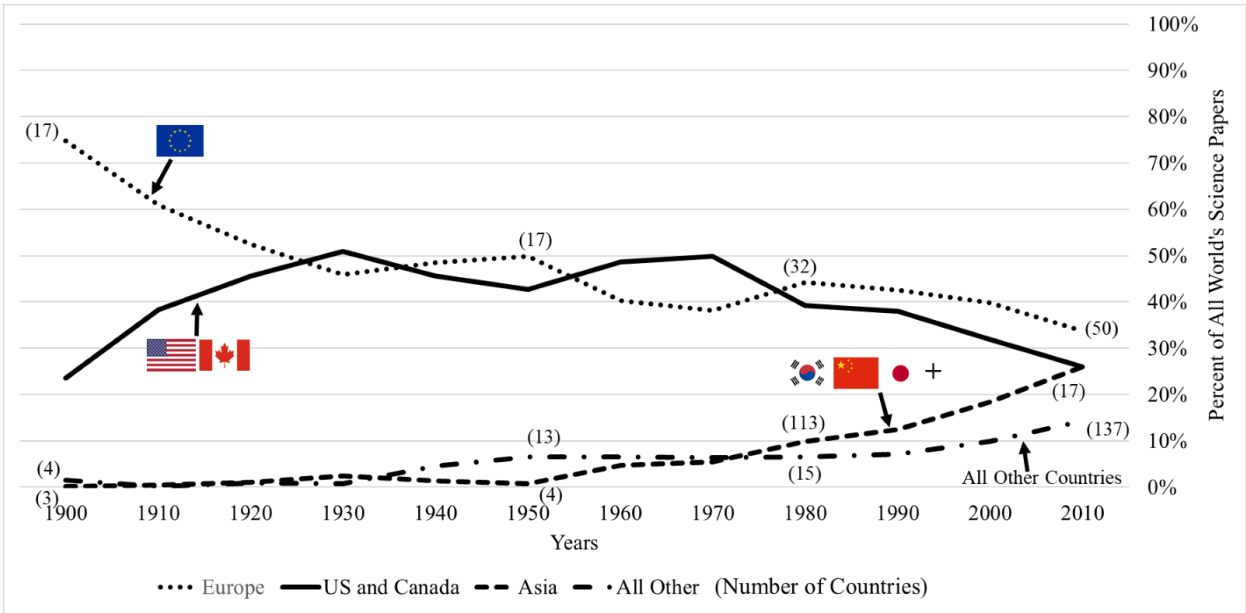


Pure Exponential Growth in SCIE Article Publications, 1960s–
HE Expansion, R&D Investments, Global & Regional Competition, "Knowledge Society"

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:
More Inclusive, with 3 Regional Centers (Europe, N. America, East Asia)



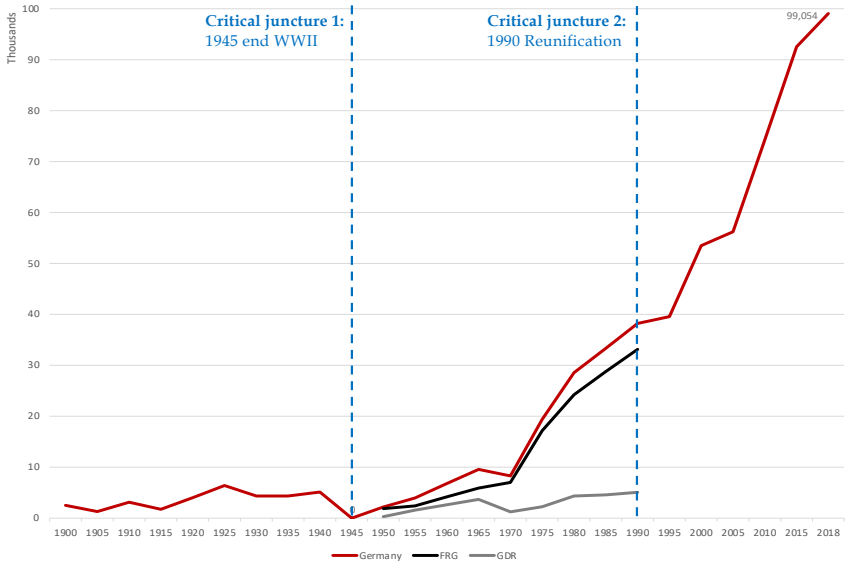
Source: Baker, D.P. & J.J.W. Powell (forthcoming). *Global Mega-Science: Universities Scientize the World.* Stanford: Stanford U. Press.

Contributors to World STEM+ Science % World Papers & by Population

Country	% Total Papers	Papers per 100,000 People
USA	20.6	85.7
China	10.0	9.7
Germany	5.8	90.9
UK	5.4	111.4
Japan	5.0	50.8
France	4.2	85.6
Canada	3.4	128.9
Italy	3.3	71.7
India	3.0	3.3
Spain	2.9	80.1
South Korea	2.8	73.7
Australia	2.4	139.2
Brazil	2.2	14.6
Russia	1.9	17.3
Netherlands	1.9	146.2
Taiwan	1.7	93.3
Turkey	1.5	27.0
Switzerland	1.4	235.2
Sweden	1.3	176.8
Poland	1.3	43.4

Country	% Total Papers	Papers per 100,000 People
Switzerland	1.4	235.2
Denmark	0.8	179.9
Sweden	1.3	176.8
Finland	0.6	156.5
Singapore	0.6	151.6
Netherlands	1.9	146.2
Australia	2.4	139.2
Canada	3.4	128.9
Belgium	1.1	125.9
Israel	0.7	123.7
UK	5.4	111.4
Austria	0.7	115.0
Germany	5.8	90.9
Taiwan	1.7	93.3
US	20.6	85.7
France	4.2	85.6
Greece	0.7	76.9
Spain	2.9	80.1
South Korea	2.8	73.7
Italy	3.3	71.7

Germany: Growth Phases & Critical Junctures (STEM+ Publications) 1900–2018



Source: SPHERE project database (raw data: Thomson Reuters SCIE); extended from Dusdal 2018: 233.

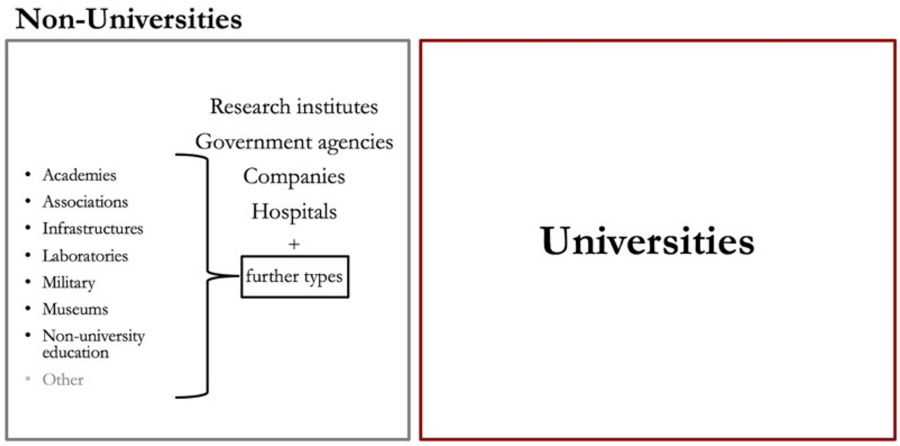
Organizational form	Character, tasks & goals	Research type	Example	Code
Universities	Freedom to teach & to study; orientation towards 2 systems: education & science; support of young researchers; right to award doctorates/habilitations	Basic research	RWTH Aachen, Technische Universität München Universität 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, other 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 Materialprüfung, 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

Dimensions:
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

Institutionalization of Research Universities & Institutes:
France, Germany, UK, Belgium & Luxembourg

		Institutionalization of Research Universities	
		high	*low*
Institutionalization of Research Institutes	*high*	**Germany** Research universities (n=126); Associations of research institutes (n=256 in FhG, HGF, MPG, WGL)	**France** Research universities (n=79); Centre national de la recherche scientifique (n=100 "research structures")
	low	**Belgium** Research universities (n=13) **UK** Research universities (n=152)	**Luxembourg** Research university (n=1); Public research institutes (n=3)

Sources: Powell & Dusdal 2017a; Powell & Dusdal 2017b: Science Production in Germany, France, Belgium, and Luxembourg: Comparing the Contributions of Research Universities and Institutes to Science, Technology, Engineering, and Health. *Minerva*. DOI 10.1007/s11024-017-9327-z .SPHERE project database (raw data from Thomson Reuters' Web of Science SCIE)

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

Europe: „pure exponential growth"

German contribution reflects its history: 60% (1920), <20% (1980-2010)

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

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

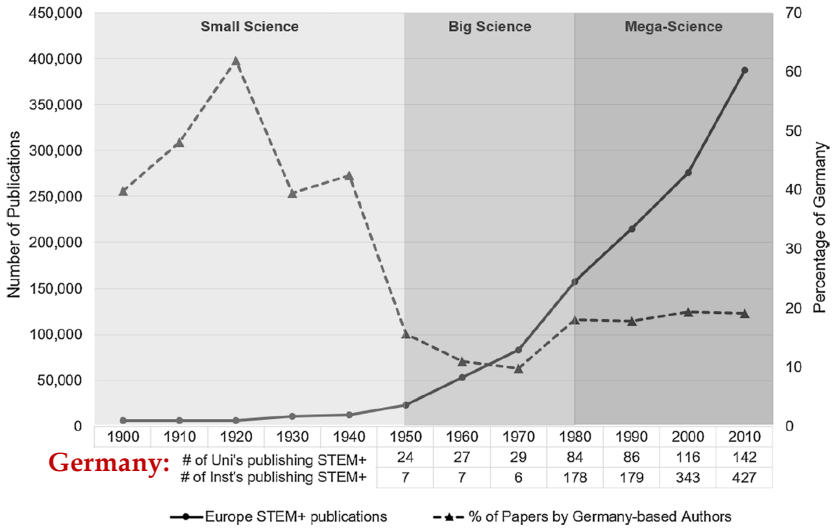


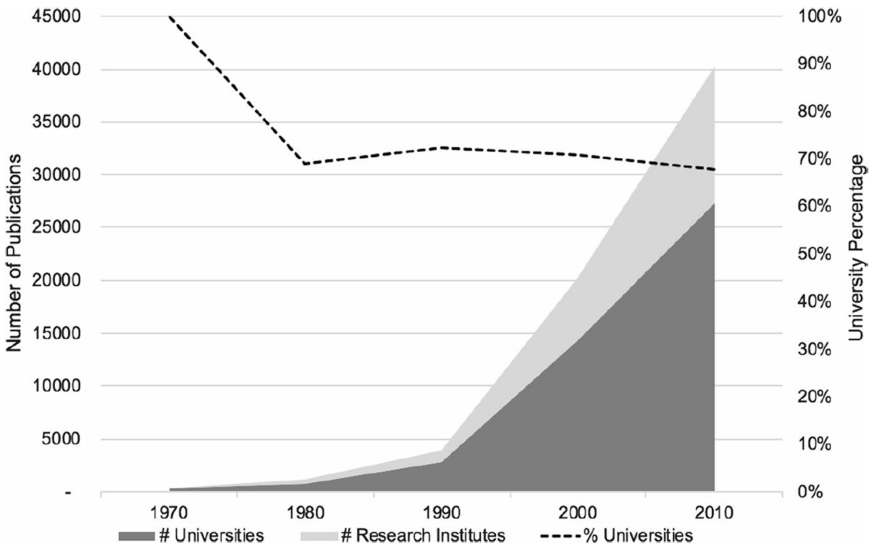
Fig. 1 Estimated Volume of STEM+ Journal Articles Authored by European Scientists; Percentage of Papers by Germany-based Authors; and Number of Universities and Research Institutes Contributing to Publications in Germany, 1900–2010. *Source* SPHERE project database of SCIE publications (Clarivate Analytics' 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 from 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 org. form
- **Mode 1 remains dominant form** of science production

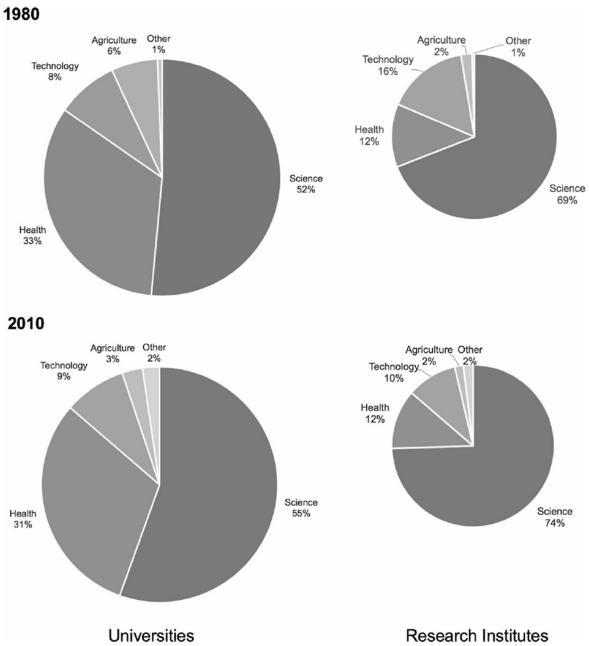


Source: Dusdal, J., Powell, J.J.W., Baker, D.P. et al. (2020). University vs. Research Institute? The Dual Pillars of German Science Production, 1950–2010. *Minerva* 58, 319–342.

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

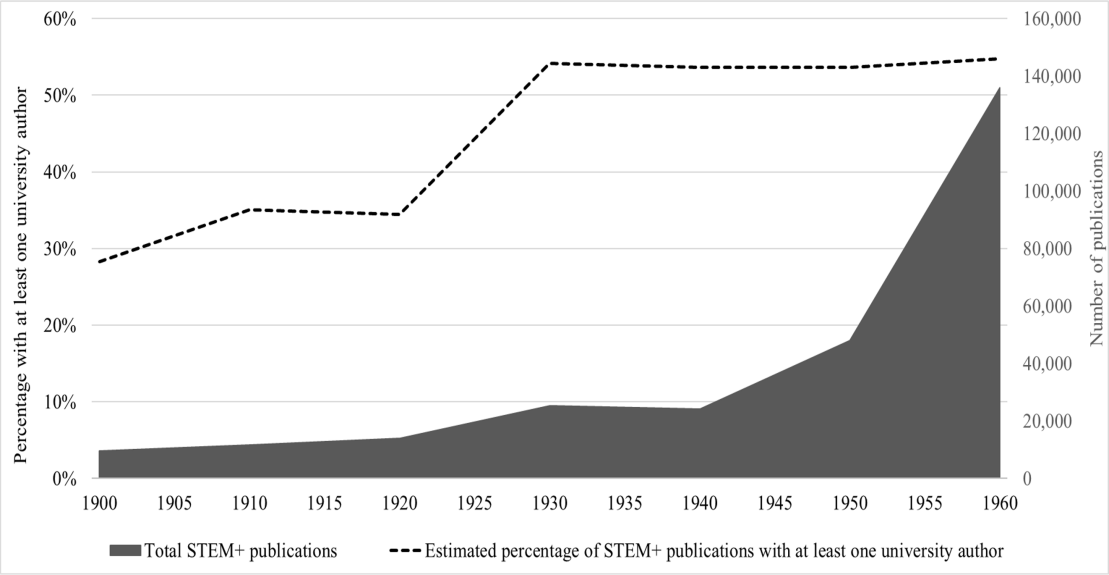
Stable proportions despite redistribution of resources: rising funds for research institutes; stagnation for universities.

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



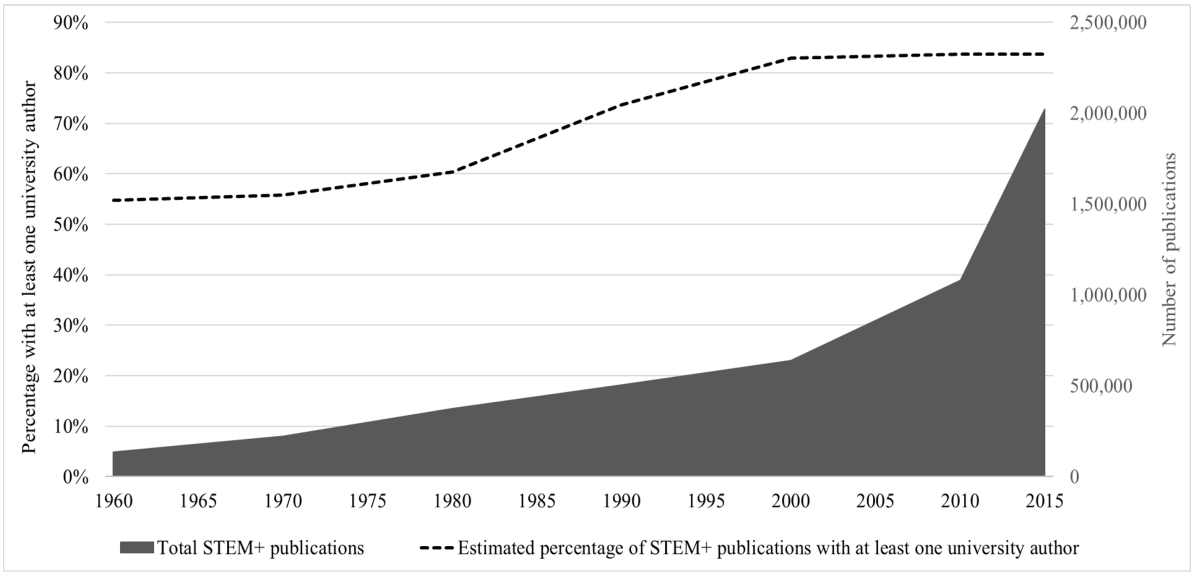
Source: Dusdal, J., Powell, J.J.W., Baker, D.P. et al. (2020). University vs. Research Institute? The Dual Pillars of German Science Production, 1950–2010. *Minerva* 58, 319–342.

World Growth in New Scientific Knowledge:
Increasing Role of University-based Scientists, 1900–60



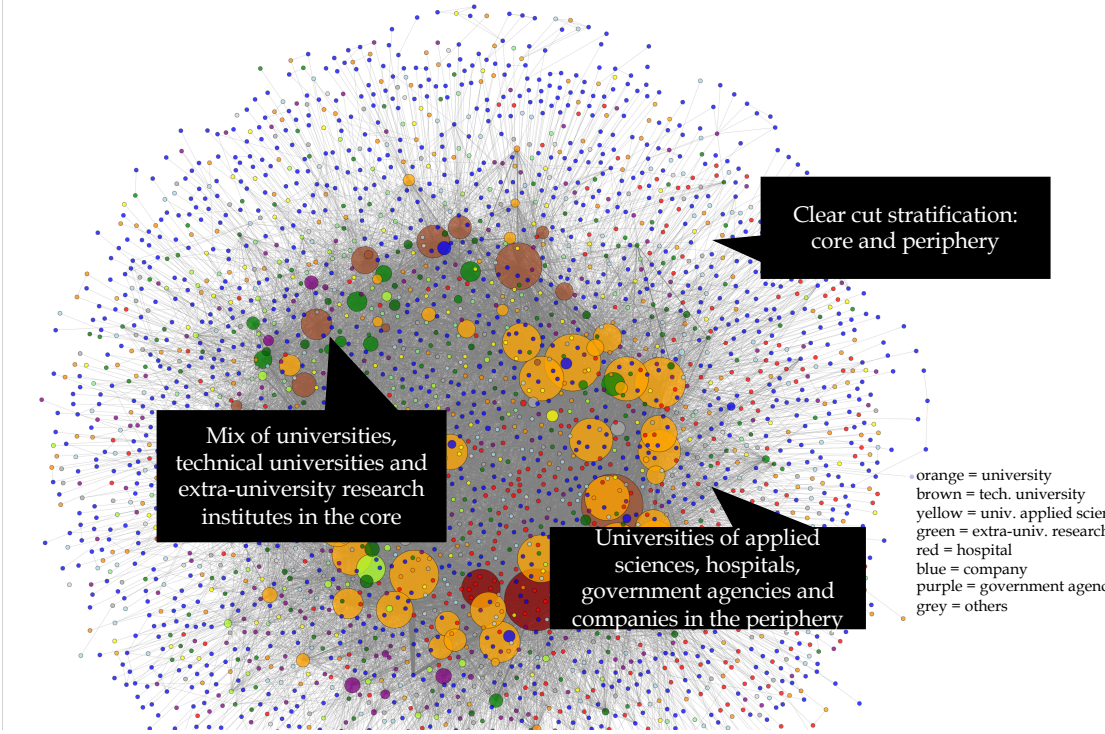
Source: Baker, D.P. & J.J.W. Powell (forthcoming). *Global Mega-Science: Universities Scientize the World* (Stanford U Press).

World Growth in New Scientific Knowledge:
Increasing Role of University-based Scientists, 1960–2015



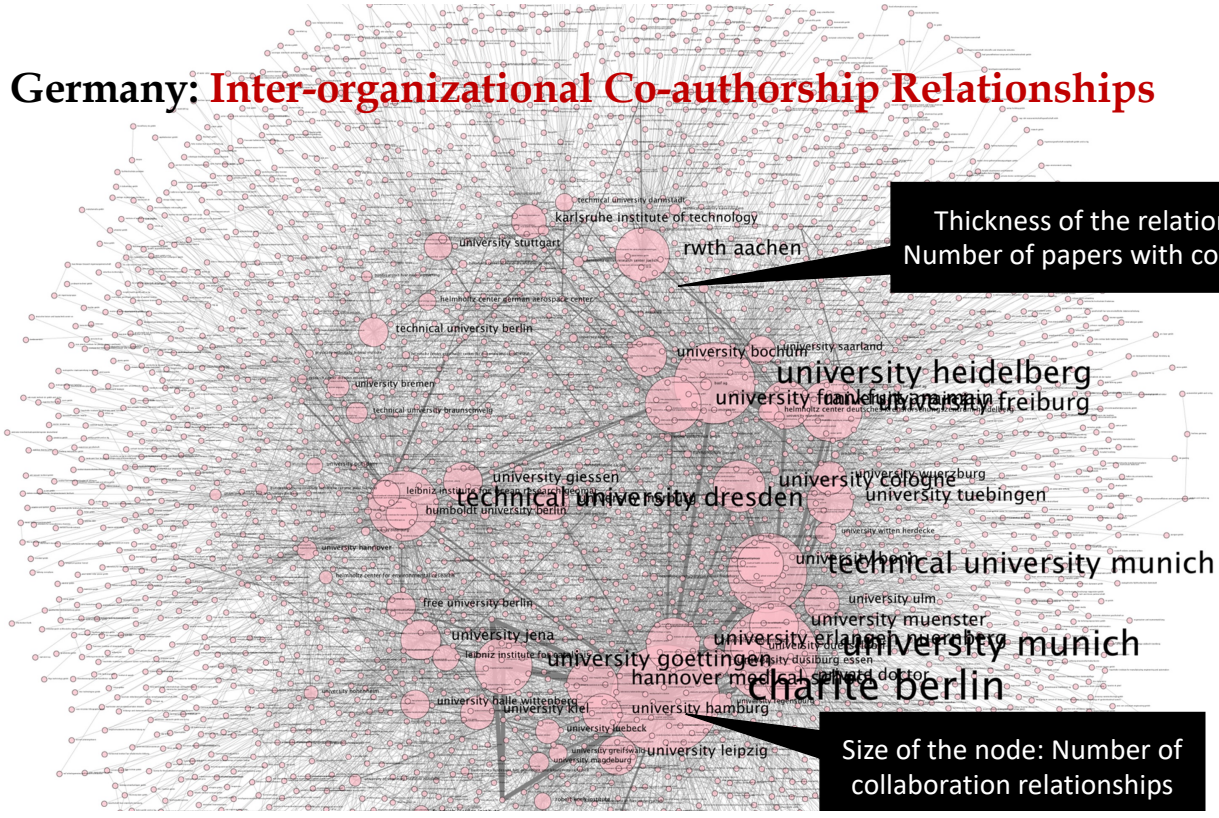
Source: Baker, D.P. & J.J.W. Powell (forthcoming). *Global Mega-Science: Universities Scientize the World* (Stanford U Press).

Germany's Organizational Forms: Scientific Networks



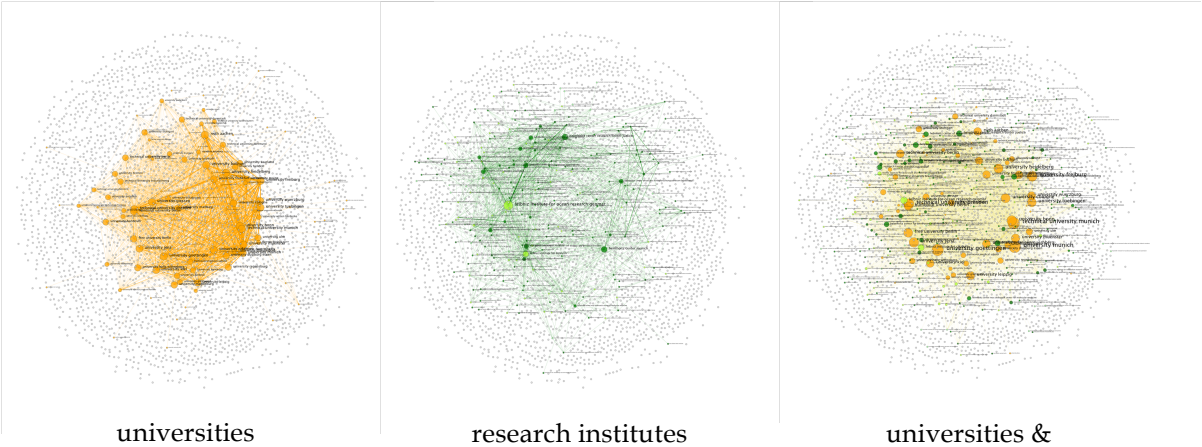
Source: SPHERE & Q-KNOW project database (raw data from Clarivate Analytics' Web of Science SCIE); Dusdal, Oberg & Powell 2019

Germany: Inter-organizational Co-authorship Relationships



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

Germany Collaborates:
Research Between Universities & Institutes

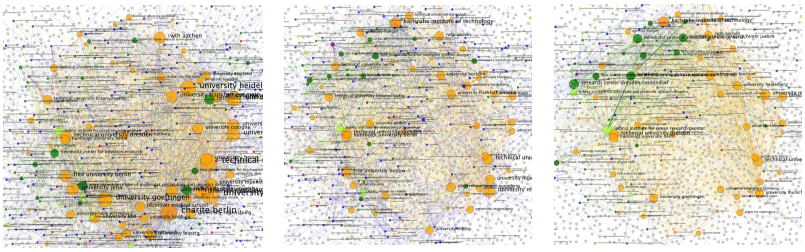


universities | research institutes | universities & research institutes

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

Organizational Forms'
Disciplinary Relevance



	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** of research universities and research institutes were institutionalized over the "century of science" in contrast to the global "university-science model"
- Both organizational forms contribute to science production, yet **different foci** in **science** and **types of collaborations:** Disciplines | Organizational forms | Basic vs. applied
- Among organizational forms (and organizations), **collaboration with varying intensity** and diverse characteristics
- **Universities** remain the **driving force of science**: the **key platform for collaboration** in Germany—and globally

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).