Agnieszka Olechnicka
University of Warsaw
The Science of Science Committee, Polish Academy of Science
https://orcid.org/0000-0001-5525-636X
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The geography of scientific collaboration

Summary

DEFINITION OF THE TERM: The geography of scientific collaboration is an interdisciplinary research field concerned with the spatial determinants of scientific collaboration and its implications for the structure and organisation of the science system. It examines knowledge flows across multiple scales, from individual relationships, through institutional and regional links, to national and global connections. The geography of scientific collaboration complements the geography of science, which focuses on knowledge stocks. It investigates relational spaces and the knowledge flows that are manifested in, for example, co-authorship and joint research projects.

HISTORICAL ANALYSIS OF THE TERM: Places and spaces of science have always played a significant role, starting from epistolary exchanges within the Republic of Letters, through Invisible Colleges, to national research systems and transnational research networks. The geography of scientific collaboration emerged in response to changes in the organisation of science, the development of network-based methods, and the growing availability of bibliometric data.

DISCUSSION OF THE TERM: Despite extensive empirical investigation, the field still lacks a coherent theoretical foundation. Key debates focus on the role of spatial proximity. Methodological challenges include data limitations, the choice of analytical scale, and representativeness. Recommended approaches include data triangulation and the integration of quantitative and qualitative methods.

SYSTEMATIC REFLECTION WITH CONCLUSIONS AND RECOMMENDATIONS: The geography of scientific collaboration provides a basis for diagnosing spatial collaboration patterns, identifying barriers, and assessing the effectiveness of support measures. There is an need to develop conceptual frameworks that integrate the mechanisms of collaboration growth, the formation of its spatial patterns, and its impacts on research quality and regional development.

Keywords: geography of scientific collaboration, knowledge flows, research networks, science policy, spatial inequalities

Definition of the term

The geography of scientific collaboration is a dynamically developing interdisciplinary field of research concerned with the places and spaces of science (Livingstone, 2003). Analyses in this field focus on the spatial differentiation of scientific collaboration among individual researchers, research teams, and scientific institutions, as well as on the conditions, mechanisms, processes, and spatial outcomes of such collaboration (Olechnicka, Ploszaj, and Celińska-Janowicz, 2019).

The geography of scientific collaboration draws on research approaches from geography, science of science, science and technology studies (STS), the knowledge economy, and science policy. It places particular emphasis on analysing knowledge flows, information exchange, and interactions between locations where research activity occurs, ranging from the micro scale (relationships between individual scholars), through the institutional level (research teams and units) and the regional scale, to national and global systems. Its key research questions address, on the one hand, the factors influencing the emergence, intensity, and durability of collaboration networks from a spatial perspective, including individual researcher characteristics, geographical distance, various types of proximity, institutional structures, infrastructural resources, and science policy frameworks. On the other hand, the field examines the effects of scientific collaboration on the spatial organisation of the science system, including questions concerning the creation, strengthening, or reconfiguration of connections, the redistribution of resources, and the reproduction or transformation of existing spatial hierarchies in science (Olechnicka et al., 2019).

The geography of scientific collaboration is a research domain distinct from, yet complementary to, the geography of science, characterised by its own research questions, methodological approaches, and theoretical concepts. While the geography of science is primarily concerned with identifying and locating knowledge stocks, i.e., the distribution of scientific institutions, research infrastructure, and human resources, the geography of scientific collaboration shifts the focus toward relational spaces, engaging in both the measurement and qualitative assessment of knowledge flows (Machlup, 1979).

Scientific collaboration is understood broadly and inclusively as an actvity of at least two scholars aimed at achieving shared scientific goals.

This includes both formal modes of collaboration (such as co-authorship of publications and joint implementation of research projects) and informal ones (such as data sharing, consultations, and peer reviewing), provided they contribute to the creation, development, or dissemination of scientific knowledge. The scope of the term may also be extended to intersectoral collaborations, e.g., at the interface between science and the economy, or between science and society (citizen science) (Olechnicka et al., 2019).

Historical analysis of the term

The geography of scientific collaboration as a field of research emerged gradually in response to changes in the organisation of science, the growing availability of bibliometric data, and advances in analytical tools, particularly network and spatial methods (Olechnicka et al., pp. 66–72). Reflections on the spatial dimension of collaboration began with the early forms of relationships between scholars, including the epistolary exchanges within the Republic of Letters (in Latin: *Res publica literaria*) in the 17th and 18th centuries, and the informal communication circles known as invisible colleges, whose modern counterparts are today's global research networks (Wagner, 2008). These early forms of collaboration had a distinctly spatial character: they were confined to elite communities concentrated in major academic centres and were heavily dependent on physical and infrastructural accessibility (Olechnicka et al., 2019, pp. 5–6).

In Adams's (2008) framework, this period corresponds to the age of the individual, which lasted until the early 19th century – a time dominated by the solitary scholar and infrequent instances of formalised collaboration. While cooperative exchanges did occur, for example, in the correspondence of Leibniz, Voltaire, or Kircher, they tended to be informal and rarely resulted in co-authored publications. In the first era of scholarly journals (1665–1800), over 97% of texts published in the "Philosophical Transactions" had a single author (Price, 1963). Intermediaries such as Samuel Hartlib, Henry Oldenburg, and Marin Mersenne connected scholars and facilitated the circulation of scientific ideas, thus being crucial to the scholarly communication system of the time (Olechnicka et al., 2019, pp. 5–6).

In the 19th and 20th centuries, with the institutionalisation of science, scientific collaboration became increasingly formalised. The establishment of laboratories, research institutes, and research universities (e.g., in the Humboldtian model) led to enduring hierarchies of research centres and the crystallisation of a core–periphery structure in science (Olechnicka et al., 2019, pp. 6–9, 15–16). Metropolitan centres and state capitals came to dominate the international circulation of knowledge, as confirmed by bibliometric data showing their leading role in both scientific output and international co-authorship (Olechnicka et al., 2019, pp. 14–15). Adams refers to this stage as the age of the institution.

The second half of the 20th century saw the rise of the age of the national research enterprise. This period was defined by the growing role of the state as organiser and patron of scientific activity, expressed in the creation of institutional frameworks for research funding, national strategies for the development of science, and systems for evaluating research performance. These trends had earlier precedents in multinational initiatives such as the 18th-century observations of the transit of Venus and the First International Polar Year (1882–1883), as well as in the institutionalisation of international collaboration, initiated by, among others, the First International Congress of Chemists in Karlsruhe in 1860. They culminated in the establishment of specialised institutions such as the U.S. National Science Foundation and the Max Planck Society in West Germany, which became cornerstones of national research systems (Olechnicka et al., 2019, pp. 31–32).

From the mid-20th century onwards, centralisation and internationalisation processes in science gave rise to new forms of research collaboration. The rising importance of project-based funding, channelled through mechanisms such as the European Union's framework programmes and international ventures like the European Organization for Nuclear Research (CERN), encouraged the consolidation of research around large, multilateral consortia. This transition has been described as a shift from Little Science to Big Science, emphasising the expanding scale of resources, institutions, and infrastructures involved in research (Price, 1963). In this period, scientific collaboration increasingly occurred through extensive institutional networks, with space conceptualised not only in terms of geographical distance but also as a configuration of infrastructural conditions and institutional frameworks. Research infrastructure, which was becoming ever more costly and technologically complex, began to operate within transnational systems of interdependence, profoundly transforming the organisation and dynamics of scientific collaboration (Olechnicka et al., 2019, pp. 9–10, 33–34).

This stage, labelled by Adams (2008) the era of international research networks, is characterised by the consolidation of cross-border multi-institutional and multidisciplinary collaboration as the dominant paradigm in the organisation of science. A key driver of this transformation was the development of digital technologies, together with falling communication costs, which enabled the creation of stable spatially distributed structures of research collaboration (Olechnicka et al., 2019, pp. 33–35). Despite the digitalisation and globalisation of science, spatial factors continue to play a critical role in shaping collaboration patterns, through both physical proximity and access to institutions and resources (Olechnicka et al., 2019, pp. 178–179).

In the 21st century, scientific collaboration has become the prevailing mode of knowledge production. This is evidenced by the dynamic growth in multi-authored publications and the increasing importance of research consortia, thematic networks, and initiatives such as the EU Framework Programmes and Horizon 2020 (Olechnicka et al., 2019, pp. 35–36). A turning point for the development of the geography of scientific collaboration came in the 1990s with the expanded availability of bibliometric data, which – combined with advances in network theory and spatial analysis methods – made it possible to systematically investigate spatial patterns of collaboration. Of particular importance in this context has been the mapping of co-authorship, treated as an empirical manifestation of collaborative relationships, amenable to both geographical and structural analysis (Olechnicka et al., 2019, pp. 66–72).

The result has been the formation of a stable yet dynamically developing field of research concerned with identifying the spatial patterns of scientific collaboration, analysing the factors that promote or hinder the creation and maintenance of research relationships, and assessing the impact of collaboration on academic mobility, knowledge diffusion, scientific outcomes, and the network of relations between regions with differing research capacities.

Discussion of the term

Fragmentation of the theoretical foundation

Despite significant advances in empirical research on scientific collaboration, there is still no widely accepted coherent theoretical foundation – no unified framework capable of capturing the complex relationships between the structure of collaboration networks and the spatial organisation of science (Olechnicka et al., 2019, p. 107). Developing conceptual frameworks that can serve as a foundation for further theoretical work in this area is therefore an essential task. Three main components are identified as necessary for such an approach: (1) the mechanisms driving the growth of scientific collaboration, (2) the processes shaping and reshaping its spatial patterns, and (3) the impact of collaboration on the quality of scientific outputs and on regional development (Olechnicka et al., 2019, pp. 107–108). The construction of a theory of the geography of scientific collaboration need not involve creating entirely new foundations; it can be rooted in the achievements of multiple research traditions and existing theoretical approaches. These include concepts from economic geography (e.g., proximity theory and gravity models), the sociology of science (e.g., invisible colleges and the Matthew effect; cf. Merton, 1968), network theory (e.g., small-world networks, centrality, and preferential attachment), the economics of innovation (e.g., learning regions and creative milieus), and theories of globalisation (e.g., the space of flows as formulated by M. Castells; cf. Castells, 1996). Some of these approaches are mutually reinforcing, while others yield divergent – or even contradictory – conclusions, complicating the construction of a unified analytical paradigm (Olechnicka et al., 2019, p. 109).

The role of spatial proximity presents a central theoretical tension in the geography of scientific collaboration. On the one hand, approaches grounded in proximity theory and gravity models reveal that geographical closeness facilitates the initiation of collaboration by lowering transaction costs and enabling easier communication. On the other hand, research informed by network theory, including the concepts of preferential attachment and small-world networks, demonstrates that geographically distant collaborations, particularly those involving central network nodes, are often associated with higher-quality research and greater scientific impact (Olechnicka et al., 2019, p. 110). Consequently, there is growing recognition that it is not geographical proximity alone but rather the optimal combination of close (local) and distant (global) ties that creates the most favourable conditions for productive and innovative research collaboration.

Methodological challenges

The measurement of scientific collaboration relies primarily on bibliometric indicators, with co-authorship of scientific publications being the most widely used. The underlying data are drawn mainly from commercial databases such as Web of Science and Scopus, which enable the analysis of co-authorship networks and the identification of links between institutions and geographical locations. Indicators such as the collaboration index, degree of collaboration, and the percentage of international collaboration make it possible to track the intensity and scope of collaboration at different territorial scales. While widely used, these tools have limited analytical value as not all forms of collaboration result in publications, and not every multi-authored publication reflects genuine cooperation (Olechnicka et al., 2019, pp. 66–69; Todeschini and Baccini, 2016). It is also worth accounting for differences in collaboration patterns across scientific fields and disciplines. Notably, even in the humanities, where individual research practices and single-authored publications have traditionally dominated, there is increasing evidence of collaboration, particularly in the context of externally funded projects and the use of shared datasets.

The methodological challenges of the geography of scientific collaboration extend beyond source data limitations to issues of selecting an appropriate scale of analysis and managing spatial aggregation. Collaboration can be analysed at the micro level (university, institute), the meso level (region, country), and the macro level (international networks). However, results often depend on the chosen spatial unit: national-level aggregation can mask regional variation, and high internationalisation rates may simply reflect the activity of a few elite centres (Olechnicka et al., 2019, pp. 73–75).

To address these challenges, scholars advocate integrating analyses based on diverse data sources, such as project registries (e.g., CORDIS), patent databases (e.g., PATSTAT), researcher profiles in identification and communication systems (e.g., ORCID, ResearchGate, and Google Scholar), altmetric data (e.g., Altmetric.com, and PlumX), as well as local institutional registries and national research evaluation systems. A fuller understanding of the spatial dimension of scientific collaboration requires combining quantitative approaches with qualitative methods, including in-depth interviews, case studies, and the analysis of policy and institutional strategy documents.

The uneven geographical and disciplinary coverage of bibliometric data remains a significant analytical challenge. Major databases such as Web of Science and Scopus do not cover all countries or all fields of knowledge equally, leading to systematic biases in comparative analyses. The under-representation of certain regions and research areas distorts results, particularly in studies of global collaboration patterns and knowledge diffusion. Scholars also stress that research on collaboration should encompass less formal and harder-to-measure forms of scholarly interaction, such as data sharing, joint use of infrastructure, and researcher mobility (Olechnicka et al., 2019, p. 74). Future developments of the field should aim for data triangulation, the creation of complementary indicators, and the advancement of tools capable of capturing the qualitative and currently unavailable aspects of collaboration (Olechnicka et al., 2019, p. 100).

Selected findings from empirical research: concentration, hierarchies, and spatial inequalities

Empirical studies of scientific collaboration confirm pronounced spatial disparities in the structure of both global and national co-authorship networks. Bibliometric analyses indicate that although scientific collaboration is increasingly international in scope, its intensity and quality remain highly concentrated within a limited number of research centres. Metropolitan areas, countries with high research intensity, and institutions with established scientific reputations dominate these networks. Such centres not only produce a greater volume of publications but also participate more frequently in international collaborations, occupying central hub positions in the global science system. By contrast, peripheral and scientifically weaker institutions, while increasingly included in research projects, tend to play subordinate or auxiliary roles (Olechnicka et al., 2019, pp. 77–107).

The entrenched core–periphery structure, evident both globally (e.g., the dominance of the USA, Western Europe, and China) and regionally (e.g., the higher degree of internationalisation in metropolitan areas compared with regions with less developed scientific institutions) is one of the most persistent patterns identified in empirical studies. Although scientific collaboration is nominally open and inclusive, it frequently reinforces existing hierarchies as leading actors attract partners through their reputation, research infrastructure, and ability to secure funding. This dynamic aligns with the Matthew effect and the theory of preferential attachment: actors with more research partnerships and greater scientific visibility are more likely to expand further and attract additional collaborators. In this way, scientific collaboration often operates as a mechanism that reproduces existing advantages rather than equalising them (Olechnicka et al., 2019, pp. 77–107).

Empirical evidence also reveals substantial variation in the scale and forms of collaboration. Local and national networks remain important, particularly in large countries with extensive science systems, while international collaboration is crucial for enhancing the visibility and/or impact of scientific output (measured, for example, by citation rates). The benefits of collaboration are often asymmetrical: partners from core countries and institutions more frequently lead consortia and shape research agendas, whereas peripheral partners tend to be involved primarily in implementation or support tasks. While collaboration promotes knowledge diffusion, it can also create dependency and limit the research autonomy of weaker partners (Olechnicka et al., 2019, pp. 77–107).

Analyses conducted during the COVID-19 pandemic revealed an additional layer of inequality in the structure of scientific collaboration. Although certain disciplines – particularly biomedical sciences and public health – saw an increase in the number of international publications, collaboration became more concentrated around already strong centres (Celińska-Janowicz et al., 2023). Rather than opening up to new participants, the dominant pattern was the deepening of existing ties as research teams relied more heavily on existing contacts, reinforcing central networks. In parallel, digital tools enabling remote collaboration became widespread, but their adoption did not eliminate infrastructural barriers or asymmetries in access to technological resources. Teams in regions with weaker digital infrastructure had limited opportunities for active participation in international projects, while institutions with strong technological capabilities further strengthened their competitive advantage. The pandemic thus acted as a catalyst for knowledge concentration while reducing the inclusiveness of the global science system, both institutionally and technologically (Celińska-Janowicz et al., 2020).

Policy and governance of scientific collaboration

Contemporary forms of scientific collaboration are increasingly shaped not only by the bottom-up initiatives of researchers but also by public policy and science governance structures. Many current research initiatives are developed in response to funding agencies' requirements, which promote or mandate international, cross-sectoral, or interdisciplinary collaboration. The European Union's Framework Programmes (e.g., Horizon 2020 and Horizon Europe) require the creation of consortia involving partners from multiple countries, and similar approaches are applied by agencies in the USA, China, and other countries (Olechnicka et al., 2019, pp. 110–112).

In this context, collaboration becomes not only a means of achieving science and innovation policy objectives but also the focus of a diverse catalogue of policy instruments. Four main categories of policy tools supporting scientific collaboration can be identified: (1) financial instruments (e.g., team grants, joint research programmes), (2) regulatory instruments (e.g., requirements for consortium composition, eligibility criteria), (3) coordination instruments (e.g., thematic platforms, research missions, strategic agendas), and (4) symbolic and motivational instruments (e.g., awards, rankings, reputational excellence indicators) (Olechnicka et al., 2019, pp. 113–114).

Science policy exerts a mixed influence on the geographical patterns of collaboration. On the one hand, support mechanisms and incentives promote internationalisation and openness, enabling participation by smaller or peripheral centres. On the other hand, dominant research institutions are more likely to assume leadership roles, draw on greater resources, and leverage extensive experience in securing grants, thereby reproducing existing inequalities. As a result, policies designed to foster collaboration can also reinforce the advantage of the core over the periphery (Olechnicka et al., 2019, p. 117).

The governance of scientific collaboration also encompasses issues of authorship recognition, career trajectories, and the evaluation of scientific output. As multi-authored publications have become the dominant format in many disciplines, challenges in attributing credit and accurately assessing individual contributions within team-based projects have intensified. Yet evaluation systems often continue to prioritise individual achievements, discouraging participation in collaborative work, particularly in competitive contexts such as academic promotion or funding. In response, some scientific institutions have adopted 'conscious collaboration' criteria that explicitly recognise the value of teamwork and the specific roles of individual project participants. Science policy therefore shapes not only the spatial configuration of research collaboration, but also its organisation, quality, and sustainability (Olechnicka et al., 2019, p. 119).

Systematic reflection with conclusions and recommendations

The geography of scientific collaboration is an emerging interdisciplinary research field that examines knowledge flows and interactions among researchers and scientific institutions from a multiscalar perspective, as well as the reciprocal effects of such collaboration on the research landscape. Empirical studies reveal that collaboration is unevenly distributed, with established core–periphery patterns reinforced by science policy instruments and natural processes of knowledge and resource concentration. At the same time, certain trends indicate a rising visibility of scientific centres in peripheral regions.

Despite intensive research activity, the geography of scientific collaboration still lacks a coherent theoretical framework. Drawing on diverse research traditions – including proximity theory, network models, and the economics of innovation – the field requires conceptual frameworks that integrate the mechanisms driving the growth of collaboration, the processes shaping its spatial patterns, and the effects of collaboration on research quality and regional development.

The geography of scientific collaboration has significant practical value for shaping effective science policy. It enables the diagnosis of spatial collaboration patterns, the identification of barriers and inequalities in access to research networks, and the assessment of the effectiveness of support instruments. Research findings in this area can inform the design of policy tools, guide the allocation of public resources, monitor the impacts of internationalisation, and align science development strategies with actual needs and capacities.

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