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Global knowledge embeddedness

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Global Knowledge Embeddedness

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Global Knowledge Embeddedness

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Abstract

Various forms of interaction during the process of research and innovation constitute a global network of knowledge generation and diffusion. Countries and their research organizations and individual scientists need to be embedded in this network to participate in global knowledge flows and to increase success in idea generation, invention and innovation. In this chapter, we review the literature on two of the most important channels of international knowledge diffusion in the field of science: research collaboration and scientist mobility. We thereby focus on the motives and determinants to collaborate or move internationally, the formation of a global knowledge network and the effects of embeddedness in the network and its influence on aggregate outcomes. From this review, we derive seven stylized facts on global knowledge embeddedness.

Keywords: scientist mobility; research collaboration; global knowledge network; literature review

JEL Classification: O33; F60; O15

1 Introduction

The process of knowledge generation, invention and innovation is cumulative and interactive (Ahuja, 2000; Breschi & Lissoni, 2004; Dosi, 1988; Powell et al., 1996). New ideas are developed based on existing knowledge, and the division of labor leads to specialists in science and research who need to collaborate in increasingly large teams (Fortunato et al., 2018; Jones, 2009; Wuchty et al., 2007). This process of knowledge collaboration and exchange has become increasingly globalized, with a worldwide expansion of mass higher education, growth in the number of international student mobility (Shields, 2013), greater migration of scientists and engineers (Freeman, 2010) and more international co-authorship (Glänzel & Schubert, 2005) and co-patenting (Picci, 2010). All these forms of interaction constitute a global network of knowledge generation and diffusion (Adams, 2012, 2013; Keller, 2004). Embeddedness therein is a necessary asset for any country to be successful in idea generation, invention and innovation.

In this chapter, we review the literature on two of the most widely studied channels of international knowledge diffusion in the field of science: research collaboration and scientist mobility. We thereby focus on the motives to collaborate or move internationally, the effects of

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such actions and how they lead to aggregate outcomes, in particular, global network structures. Based on this, we discuss how embeddedness in such networks influences knowledge generation and performance.

Embeddedness in the global knowledge network is captured by the position of actors, e.g. individuals, organizations or countries, in the network of knowledge related interactions between these actors. In general, higher embeddedness facilitates access to knowledge with positive performance effects (Uzzi, 1996, 1997; Wanzenböck et al., 2014; Wanzenböck et al., 2015). The global network is constituted by knowledge exchange of these actors across territorial borders. Conceptually, such interactions cover a variety of dimensions, such as formality, temporality, intensity, frequency or purpose (Georghiou, 1998), but to observe and measure interaction in all these dimensions is a challenge (Katz & Martin, 1997; Laudel, 2002; Melin & Persson, 1996; Teichler, 2015). Interactions that are most easily observed include joint publications or mobility of individuals between places and/or organizations. Due to their intensity of face-to-face exchange, these interaction channels are also considered particularly effective. Other forms of interaction at meetings or conferences, sharing of data or methods or other means of exchange are harder to track, potentially more frequent but less important for knowledge exchange (e.g. Cronin et al., 2003, 2004; Laudel, 2002).

In the following, we summarize the empirical and conceptual development of the global knowledge network by co-authorship and mobility. In Section 3, we review the literature on drivers of collaboration and mobility on the level of the individual researcher. Aggregate patterns, determinants and consequences of global knowledge embeddedness are discussed in Section 4. We summarize our findings in Section 5 by deriving a set of stylized facts and presenting our ideas on fruitful avenues for future research.

2 Knowledge diffusion through collaboration and mobility

Over the past decades, we observe a continuous increase in interaction and collaboration across all fields of science and research (Wuchty et al., 2007). One of the reasons for this development is an increasing specialization and division of labor because of the cumulative and dispersed nature of knowledge (Jones, 2009). Vast empirical evidence indicates that collaborative research leads to more valuable output than individual research (e.g. Adams et al., 2005; Adams, 2013; Jones, 2021; Wuchty et al., 2007). Research teams and co-authors do not just add their individual expertise to generate joint output, but they also exchange information and learn from each other (Breschi & Lissoni, 2004). The increasing and systematic collaboration and mobility of scientists can be seen as a result of an increasing professionalization of science (deB. Beaver & Rosen, 1978, 1979). Scientific knowledge grows exponentially and the problems researchers address become more complex, requiring higher degrees of interaction and exchange. This process has been referred to as the transition from 'little science' to 'big science' (de Solla Price, 1963). Larivière et al. (2015) show for publication data from 1900 onwards that co-authorship is increasing substantially and is the norm nowadays. Along this development, international research collaboration increases continuously as well.

The development and the structures of interaction among researchers through collaboration and mobility have been subject to several approaches to conceptualize the phenomenon. From

a science of science perspective, the increasing professionalization in science and the transition from little science to big science can be organized in an 'invisible college' (de Solla Price, 1963; Price & Beaver, 1966). The invisible college governs the scientific community and facilitates formal and informal knowledge exchange globally and brings together the members of the community (Crane, 1972). This self-governing process of the researcher community has more recently referred to as the 'fourth age of research' (Adams, 2013) in which international collaboration between research groups form to approach scientific problems. Prominent examples of this tendency are large research facilities, such as CERN, where multiple international teams conduct research together (Carrazza et al., 2016). In these invisible colleges, preferential attachment, i.e. the tendency to form linkages with already highly connected actors, is a key characteristic for international collaboration (Wagner & Leydesdorff, 2005b).

Within the economics of innovation, the concept of (national) innovation systems is extended and integrates international knowledge flows to account for the division of labor in science and the dispersed nature of knowledge (Bathelt et al., 2004; Niosi & Bellon, 1994). Due to the increasing importance of science in technological progress and economic growth, countries need to participate in international knowledge flows (Ribeiro et al., 2018) and integration into these flows can be a starting point for developing countries to catch up. Differentiating between industries and technologies, Binz and Truffer (2017) propose that in multi-locational subsystems resources are acquired and generated and that the different groups of actors are coupled in a global innovation system to exchange knowledge and resources. The functional design of such a subsystem, can influence the embeddedness in the global system and allows countries to access global flows of knowledge via international collaboration (Graf & Kalthaus, 2018).

From a policy perspective, governments influence international collaboration to foster exchange of knowledge or to gain access to foreign knowledge. Already Bush (1945) emphasized that the US government should foster the international flow of knowledge. Governments design programs supporting scientists to engage in international collaboration or to move temporally abroad to establish contacts. The leading example is the European Research Area in which scientific collaboration and mobility are core components to foster knowledge exchange and subsequent technological and economic progress (Defazio et al., 2009; European Union, 2016). This is realized especially via joint research programs (Balland et al., 2019) and mobility grants (Ackers, 2005).

In the growth and development literature, an important stream of research is concerned with the geographical distribution and the direction of migration and mobility flows between countries. These flows have been found to be highly asymmetrical, not least because creative minds have always been attracted to particularly vibrant cities or regions that act as hubs in the global knowledge network (Doehne & Rost, 2021; Florida, 2005). The migration of skilled and educated workers from developing to developed countries was identified as detrimental for economic growth in the sender countries so that the term "brain drain" was used to describe the phenomenon (e.g. Beine et al., 2001, 2008). Historical studies on large migration flows show the large impact on both, sender and receiver countries (e.g. Moser et al., 2014). The opposite, positive effects for the receiving countries are accordingly referred to as 'brain gain'. However, there are also potential positive feedback effects of skilled migration on the sender countries, such as remittances, return migration or scientific and business networks. In addition, migration

prospects might increase the incentives to invest in education and human capital formation in the home countries (Beine et al., 2008).

Return migration and the role of diasporas have been studied, for example, by Agrawal et al. (2011) and Saxenian (2005), who argue that scientist migration establishes long-term connections between migrants and their home countries which might facilitate knowledge flows towards the sender countries. It was also found that emigration of students, academics and other skilled professionals is increasingly temporary (Gaillard & Gaillard, 1997) so that the concept of 'brain circulation' has been suggested as a more complete model (Baruffaldi & Landoni, 2012; Jöns, 2009). China, for example, was able to benefit from international mobility and thereby strengthen its research and innovation system by sending scientists abroad and by being able to attract them back (Verginer & Riccaboni, 2020).

3 Drivers of international mobility and collaboration

3.1 Determinants of scientist mobility

The reasons for migration and mobility are manifold and range from individual choices in search of better opportunities to forced migration due to religious persecution. Historical examples of larger waves of mobility of skilled workers or scientists illustrate their great impact on the global structure of knowledge diffusion and distribution. For example, Hornung (2014) finds long-term productivity effects of religiously persecuted French Huguenots who settled in Brandenburg-Prussia after the revocation of the Edict of Nantes in 1685. Moser et al. (2014) look at Jewish emigrants from Nazi Germany and identify a strong impact on invention in the US.

Besides such unique and often dramatic events, there is a continuous increase in mobility over the last decades, and this trend is particularly pronounced for scientists (Czaika & Orazbayev, 2018). According to their analysis of bibliometric data, the share of mobile scientists who moved internationally at any point in their career has been steadily increasing from about 6% in the 1970s to about 9% by the mid 2010s. So what are the drivers, the individual motivations and determinants of this voluntary mobility of scientists?

A main driver seems to be the aspiration to work in a more professional or better equipped environment, thereby increasing their international professional network (Kato & Ando, 2017). Consequently, the presence of prestigious universities and research organizations of high scientific quality is considered as an important factor for attracting scientists to particular cities, regions, or countries (Bauder, 2015). Several studies show that prolific scientists are particularly mobile and choose their destination carefully by preferentially moving to global cities to continue their career (Azoulay et al., 2017; Verginer & Riccaboni, 2021). There is ample evidence for positive effects of the decision to become mobile on scientists' productivity, scientific impact and occupational situation (Gibson & McKenzie, 2014; Netz et al., 2020; Verginer & Riccaboni, 2021). Scellato et al. (2015) are particularly interested in the relationship between scientist mobility and their collaboration patterns. Their study is based on a very large survey among more than 15000 scientists from 16 countries in selected STEM fields. Their main finding is that migrants and returnees have larger international research networks than their native counterparts without any international background. These mobile scientists often collaborate with researchers

from their country of origin, whether they are in their home country or a third country. The mobility-cooperation nexus is also tackled by Kato and Ando (2017), who conduct a study based on metadata from papers published in Nature and Science between 1989 and 2009. They also find that researchers move to countries with better research environments. However, in line with Wang et al. (2019), they identify international mobility as a driver of collaboration but not as much in the other direction. Additionally, the benefits of mobility for knowledge diffusion are not limited to the academic sphere. Edler et al. (2011) show for a sample of German scientists that temporarily mobile researchers are involved in knowledge and technology transfer activities to industry in both home and host countries. They also find that the duration of research visits has a positive impact on the propensity to transfer knowledge and technology in both countries.

Jöns (2007) studies the motives for temporary research stays in Germany and finds that besides the above-mentioned expectations regarding a better professional environment, scientists are also attracted by existing professional contacts. Other motives that are frequently mentioned in this study are the search for new experiences and ideas and time to do research and to publish academic work and contacts with foreign researchers. Another factor that determines mobility patterns is the career stage. Bauder (2015) provides ample evidence that younger researchers, particularly those in their post doc phase, are more mobile than researchers at later stages of their career. Adding to such life-cycle arguments, Azoulay et al. (2017) find that having adolescent children is a strong barrier for mobility, in particular for mothers.

Besides factors relating to individual life and career planning, governing institutions and mobility support structures by the government or foundations increasingly promote international mobility, especially for young academics (Bauder, 2015; Jacob & Meek, 2013).

One could ask if we still need to meet each other in person to effectively exchange knowledge and ideas. During the COVID-19 pandemic, everybody could experience the possibilities and also the limitations of online meetings, collaborations and conferences. So while technological developments in ICT certainly facilitate long-distance interaction, they are by no means a substitute for face-to-face interaction. Rather, technological developments seem to further reinforce the importance of face-to-face interaction (Czaika & Orazbayev, 2018). From the reviewed literature on the drivers of mobility, we see that the scientific network of collaborative ties is sometimes cause for but mostly the effect of scientific mobility, showing how deeply intertwined these forms of interaction are in the global knowledge network.

3.2 Determinants of international collaboration

The increasing trend in the collaboration in knowledge production in teams (Wuchty et al., 2007), across organizations (Jones et al., 2008) and internationally (Adams, 2013; Wagner et al., 2017) is motivated by different factors and has several consequences. The general increasing trend in collaboration and team formation has many motivations and reasons, as summarized by, e.g. Katz and Martin (1997) and Beaver (2001). Since international collaboration can have higher transaction costs or higher barriers (Ou et al., 2012), researchers pursue international collaborations for specific reasons, or researchers have specific characteristics which make them pursue collaboration across borders (Freeman et al., 2015).

Frame and Carpenter (1979) conduct one of the first empirical assessments of international research collaboration and provide a list of determinants on the collaboration intensity and part-

ner choice for international collaboration. They conclude that "[t]he size of a national research effort, and a number of non-science factors–including geographic locale, and linguistic, cultural, and political factors..." (p. 495) are relevant for the intensity and direction of international collaboration. This list of determinants has been extended with, e.g. the decline in travel cost, improvements in communication technologies, the rise of English as the common language in science, governmental programs, division of labor and specialization, joint research infrastructures, cultural traditions and norms and values (e.g. Luukkonen et al., 1992; Wagner & Leydesdorff, 2005b; Waltman et al., 2011). However, the relevance of these determinants changes over time. For example, geographical proximity and territorial borders have lost relevance over time (Hoekman et al., 2010). Wagner et al. (2015) show that the share of international collaborations and the geographical distance between co-authors increases over time, and Waltman et al. (2011) calculate that the average collaboration distance per publication has increased five-fold from 1980 to 2009. Similarly, Catalini et al. (2020) show that a decline in air-travel costs increases collaboration.

Furthermore, characteristics or motivations of the individual scientists can explain international collaboration. For example, Bozeman and Corley (2004) survey US scientists and show that many collaborations are local or national but that researchers with large grants show a more 'cosmopolitan' collaboration pattern with contacts to industry and international research partners. Based on another US survey, Melkers and Kiopa (2010) analyze the motivations and determinants for international collaboration. They hypothesize that resources and social capital facilitate international collaboration. They find positive relationships between a researcher's international experiences and individual characteristics, such as foreign nationality, and international collaboration, highlighting the role of social capital. The researcher's access to resources, as well as the reputation of the researcher's institute, also correspond with international collaboration. They further show that such international collaboration allows researchers to access specific resources. Similar results are provided by Jeong et al. (2014) for internationally co-authored papers of Korean research projects. In a similar vein, Jöns (2007, 2009) emphasizes the importance of previous personal interaction, publication and (temporal) mobility for international collaboration. However, gender differences and specific barriers for women exist (Fox et al., 2017). Extrinsic incentives, such as R&D subsidies and funding, have also been shown to increase collaboration (Adams et al., 2005; Ebadi & Schiffauerova, 2013).

The scientific benefits from international collaboration are an additional strong motivator for researchers to engage in such collaborations. A broadly used measure for the success of scientific articles are received citations. By distinguishing between papers with multiple authors from multiple countries, one can assess the scientific benefits from international collaborations. Narin et al. (1991) were among the first who analyzed the influence of international collaboration on scientific publications. They show that publications with authors from different countries have higher citation rates than publications from authors from the same country. Thereby, there are no differences between international publications from EU-EU and EU-non-EU countries. Glänzel (2001) finds a similar pattern on the aggregate level, but heterogeneous development between disciplines and country pairs, e.g. some country pairs of international collaboration show no observable increase in citations. Besides the increase in citations for international co-authored publications, Persson et al. (2004) show that such papers have about two refer-

ences more than non-international, co-authored papers, indicating a higher rate of knowledge recombination. Larivière et al. (2015) also show, controlling for self-citation, that papers with international co-authorship receive more citations. However, several contributions challenge the higher impact of international co-authored publications. van Leeuwen (2009) find on average a lower impact of internationally co-authored papers than single-authored papers but substantial heterogeneity on the individual country level. Similarly, Freeman et al. (2015) find heterogeneous effects across disciplines. In a different way, Wagner et al. (2019) analyze the novelty of papers written by international teams and show that such papers are less novel and contain more conventional knowledge combinations. They also argue that higher citations for international publications go back to an audience effect, since an increase in authors from different countries increases the potentially citing community. In a different approach, Leung (2013) shows for Chinese researchers in nanomedicine that international collaborations can, besides an increase in resources and reputation, also provide opportunities for learning-by-doing which allow the Chinese researchers to build up absorptive capacity. This suggests that the effects of international collaboration unfold over time.

4 The global network of knowledge embeddedness

4.1 From individual interactions to a global structure

The increasing mobility of individuals and collaboration across national borders can be aggregated to a global network of knowledge exchange (Glänzel & Schubert, 2005). This knowledge network can be considered as a hierarchical construct with three interdependent layers based on the conceptualization of a micro-meso-macro structure (Dopfer et al., 2004; Graf & Kalthaus, 2018). On the micro level, the individual researcher makes a relocation or collaboration decision and selects his or her destination or partner. These individual researchers can thereby establish links across national borders. Individual researchers can be aggregated based on their organizations to a meso level, where the links of individuals establish connections between organizations. The subsequent macro level is the aggregation of organizations in one country, and countries are connected via international collaboration or mobility of researchers belonging to the organizations in a country. Figure 1 shows a graphical representation of the different levels and aggregations of the knowledge network.

For each level of aggregation of the knowledge network, structural properties, such as small world properties, or processes of network formation, such as preferential attachment or homophily, can be analyzed (Barabási et al., 2002; Newman, 2001; Wagner & Leydesdorff, 2005b). Besides the network structure and its dynamics, the position of individual nodes, the individual researcher, the organization or the country and its effects are of interest. Freeman (1979) argues that a central position relates to importance or power in a network, since it allows control of information flows between otherwise unrelated actors. Furthermore, some positions within the knowledge network might give an advantage for accessing novel or diverse knowledge. Understanding the changes in network position and the influence of network positions on performance is highly relevant to access and utilize knowledge flows in the network. Empirical evidence for innovation networks shows that both direct and indirect connections matter for research

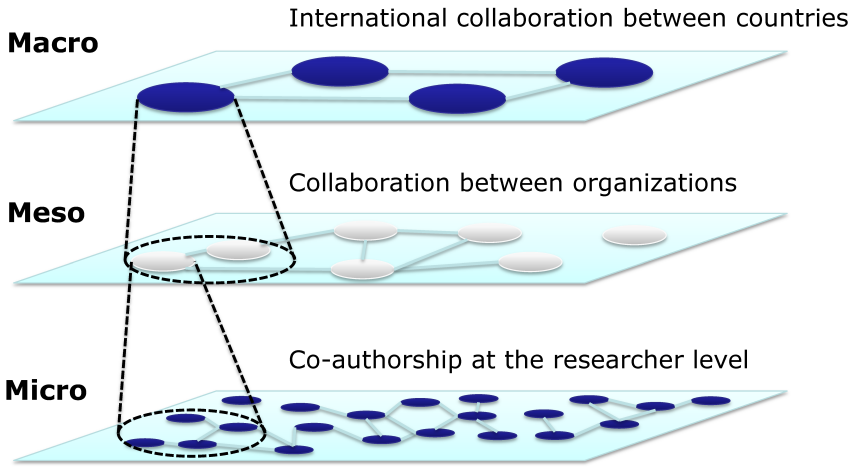

Figure 1: Example of Multimodal structures as in Graf and Kalthaus (2018)

and innovation performance (for reviews, see Cantner & Graf, 2011; Hidalgo, 2016; Ozman, 2009; Phelps et al., 2012). Only recently has the interrelatedness between the different levels of knowledge networks within multimodal structures been tackled in empirical studies (e.g. Graf & Kalthaus, 2018; Guan et al., 2015).

4.2 Patterns and dynamics of the global knowledge network

The pattern and dynamics of country networks have been studied extensively. In such networks, countries are nodes and connected via co-authorship between researchers from different countries or the mobility of researchers across countries. Schubert and Braun (1990) were among the first who use co-authorship information to construct a network of countries. They show for the period 1981-1985 a core of western developed countries and some clusters of countries in the periphery. They argue that besides geographical location, historical or political reasons generate such a pattern. In a comparison of network structures in 1990 and 2000, Wagner and Leydesdorff (2005a) show that the network grew in size and connectedness and that the core of scientifically advanced countries in the network expanded. However, they also observe that the network becomes more decentralized and regional clusters emerge.

Similar findings are obtained by Czaika and Orazbayev (2018) for the global scientific mobility network. They use bibliometric data for the period 1970 to 2014 to calculate annual mobility events for individual authors and aggregate them to the country level. Over time, an increasing number of countries integrates into the global network, and they observe shifts from the periphery to the core for several countries, with average mobility distances increasing and the center of gravity moving eastwards. At a more fine-grained level, Verginer and Riccaboni (2020) look at the global city network based on mobility data for the period 1990 to 2009. They identify a highly connected, relatively stable core of cities, with most of the hubs being located in the US but pronounced catching up by Beijing.

Gui et al. (2019) conduct a detailed analysis of the international collaboration network for the period 2000 until 2015 and show also an increase in the number of countries, with nearly all countries being involved in international collaboration. Most frequent are collaborations between the USA and European countries, Japan and Australia. European countries also col-

laborate frequently among each other. In general, the number of interconnections increases nearly three-fold in this time period. Consequentially, the mean degree and the density in the network increases over time, and nearly 50% of the possible country-connections are established in 2015. The network is highly centralized, but over time, some decentralization takes place, and the scientifically advanced countries lose some of their centrality in the network. Gradually, the general structure changes from a bi-polar core network between Europe and North America to a tri-polar network in which the Asia-Pacific region becomes more prominent. Thereby, collaboration between the USA and China is most prominent. Gui et al. (2019) furthermore analyze the core-periphery structure in the global network and categorize countries in four groups. They observe that over time, countries are moving upwards in the hierarchy and become closer to the core. Most countries in the periphery are lower-income or small countries. Additionally, the authors apply dominant flow analysis and show that the USA is the dominant coordinating actor in the network, only a few sub-dominant actors exist and all other countries are directly affiliated to the USA or the sub-dominated countries. Even though they observe dynamics with several countries changing their relative positions, the dominating role of the USA remains unchallenged.

While these findings show the structure and dynamics for the overall scientific system, field-specific patterns can substantially differ. For example, Gazni et al. (2012) show that in the period 2000-2009, 44% of all space science papers included international collaborations, while in social sciences the rate was only 6%. Wagner et al. (2017) show for six disciplines for the period 1990 to 2013 a substantial growth in field-specific network size and connectivity, however, with high differences in their levels. Mathematics is the smallest and least connected network, with even a decrease in connectedness at the end of the observation period. In contrast, astrophysics has the largest and most densely connected international network, in which countries have on average eight times more connections to other countries than in mathematics. They conclude that over time, the fields converge towards the global development of a highly connected science system. Similar results have been shown by Coccia and Wang (2016) for a period of forty years. They find that there is an increase and convergence between applied and basic sciences in terms of internationalization but that the ranking in international collaboration intensity by field does not change over time. Overall, these findings indicate that despite differences in the intensity of interaction, globalization trends are ubiquitous across science fields. With respect to the partners involved in international collaborations, Pohl (2021) analyses collaboration between academia and corporations. He shows that in relative terms, the share of such collaborations does not increase and accounts for about 2.5% of all publications.

4.3 Determinants of country embeddedness

Several arguments have been put forward to explain why countries form linkages in research. Zitt et al. (2000) show for five core countries that their likelihood to form an international collaboration is influenced by political and cultural, linguistic, economic and geographical factors. Gui et al. (2019) empirically test ten different factors on the likelihood that a connection is established between two countries. They find no influence of geographic distance, but having English as an official language and a colonial relationship in the past increase the likelihood to establish a connection. Furthermore, international student mobility is highly relevant, as is the

difference in the number of publications and the difference in the research expenditure per country. Lastly, scientific, social and economic proximity are relevant to establish a collaboration. Similar results are reported by Hou et al. (2021) who subsume factors under scientific, economic, geopolitical and cultural factors. Using a relative measure of closeness in collaboration, they show for six disciplines that the more similar countries are in these factors, the closer they are collaborating, while the larger are the differences in scientific and economic capabilities as well as geographic distance, the lower is the closeness. They also report detailed, heterogeneous influences of different languages, religions and geopolitical factors across disciplines on collaboration closeness.

In a different methodological approach, Plotnikova and Rake (2014) consider pharmaceutical research and test in a gravity model for the influence of geographical, cognitive, institutional, social and cultural proximity on formation of international collaboration. They show that geographical proximity has a negative effect but social proximity a positive one. Wagner and Leydesdorff (2005b) provide a different perspective and argue that international collaboration is governed by preferential attachment and that the science system is self-organizing. Their results point towards scale-free network properties, consistent with Barabási et al. (2002) or Ribeiro et al. (2018) for collaboration in scientific fields. Furthermore, universities use internationalization as a strategic element to increase embeddeddness and to facilitate knowledge flows. Youtie et al. (2017) and Kolesnikov et al. (2019) show how universities strategically set up research or teaching locations in foreign countries to institutionalize international research collaborations.

Similar factors are also relevant for the international mobility of scientists. Appelt et al. (2015) use changes in the affiliation of researchers' publications over the period 1996–2011 to track mobility and explain aggregate mobility between origin and destination countries by economic, cultural and scientific factors. They show that scientific and economic distance between two countries reduces mobility, indicating that a convergence of countries in these dimensions increases mobility between the countries. Furthermore, they show that geographic distance and visa restrictions have a negative influence on mobility, while resources dedicated to R&D increase mobility. Besides these factors, research collaboration is a major factor for scientists' mobility, indicating the co-determination between collaboration and mobility. They conclude that mobility forms a complex international network and that there is ample evidence for brain circulation. However, Arrieta et al. (2017) use the case of the European integration to show that access to the Western European labor market for Eastern European scientists increases their mobility westwards and subsequently reduces international collaboration rates for Eastern European countries.

From a network position perspective, Cantner and Rake (2014) analyze endogenous network dynamics that establish or reinforce international collaboration between countries in pharmaceutical research. They show that tie formation and tie break-up are related to countries' relative connectedness, i.e. countries that have a larger difference in their relative positions in the network are more likely to connect. Furthermore, they demonstrate that the number of past collaborations of a country increases the likelihood that a connection is established, indicating that collaborative activity is self-reinforcing and cumulative. Country similarity in terms of scientific output increases collaboration, but economic differences between countries are not relevant. Sharing the same language shows ambiguous results in their analysis. Lastly, they argue

that multi-connectivity is relevant for tie formation. Empirically, they show that knowledge flows matter by demonstrating that countries which indirectly connect two countries increase their connections. For photovoltaics research, Graf and Kalthaus (2018) show for the period 1980–2015 that the embeddeddness of countries in the global network is influenced by the structure and functionality of the underlying national research system and by policy intervention. The embeddeddness into the global knowledge network is measured by countries' degree, flow betweenness and coreness. In that paper, we showed that cohesion and connectedness of the national research system positively affect international embeddedness, whereas centralized national research systems are detrimental to international embeddedness. This indicates that a diffusion-oriented research system allows better access to international knowledge flows. We also show that demand-inducing innovation policy can increase international embeddedness. Related research shows that on the national level, research universities play a central role in facilitating access to and embeddedness in the global knowledge network, in particular for low- and middle-income countries (Altbach, 2013). By taking the example of South Korea, Ahn et al. (2019) show that universities are key for accessing global knowledge flows and that they can bridge knowledge flows to other domestic universities, which are subsequently able to increase their performance.

4.4 Embeddedness and performance

A country's level of international collaboration and its position in the global knowledge network – be it by mobility or by collaboration linkages – improves access to knowledge flows with positive effects on scientific activity and performance. Cimini et al. (2016) as well as Wagner et al. (2017) show that there is a strong correlation between internationalization of science in a country and its success in terms of citations. In a methodologically different approach, Wagner et al. (2018) construct an openness index based on international collaborations and scientist mobility and show that the openness of countries correlates with its scientific impact. Such openness and connection to the global knowledge network is also documented for individual countries. Nguyen et al. (2017) show for Vietnam that research increased substantially after it opened up to the world in 1986, and after the USA revoked a trade embargo against Vietnam in 1995, most research output was conducted in international collaborations, esp. with scientifically advanced countries. They argue that such international collaborations were essential to develop research capacity. Over time, the share of internationally co-authored papers declined as national capacity was built. Furthermore, papers with international collaboration receive more citations and are published in higher ranked journals than domestic ones.

In a detailed analysis of the country level benefits from international scientist mobility, Verginer and Riccaboni (2020) show that not all countries benefit from international exchange. The authors decompose growth in scientific publications into growth effects attributed to stationary, domestically mobile and internationally mobile scientists. Interestingly, for most countries, international mobility has a higher weight than domestic mobility. Regarding the age structure, they find that for most countries, leaving scientists are younger than the incoming, typically more prolific ones. China, for example, benefits from international mobility by sending scientists abroad and attracting them back. India, on the other hand, does not benefit from international mobility in terms of direct research output, neither do Israel or Japan. Apparently,

the particular settings of the respective national innovation systems play not only a big role in determining the level of international embeddedness but also in how countries can benefit from it. When looking at the beneficiaries of international embeddedness from a micro perspective, there are some indications that knowledge diffusion is highly uneven. It is mostly direct collaborators who benefit from connections with mobile inventors (Zacchia, 2018), and in low income countries, such links are established by few individuals (Vanni et al., 2014). Findings on the city level also point to uneven distributions of knowledge flows within countries (Verginer & Riccaboni, 2021).

There are also indications that such performance effects are not limited to academia, but the evidence here is still limited. Bathelt and Li (2020) analyze how Canadian firms tap into local knowledge in China and show that cross-border knowledge generation is possible, especially if the local knowledge in China is systematically integrated with corporate knowledge pools. Tsouri et al. (2021) take the case of offshore wind and show that embeddedness in international knowledge networks can also facilitate access to market resources in a Global Innovation System.

5 Conclusion

The world is moving closer together across all kinds of activities. Just as trade flows increase along ever more complex Global Value Chains, sources of knowledge become more dispersed so that keeping up with scientific and technological developments requires integration within the global research and innovation system. Taking a network perspective, in this chapter, we reviewed the literature connected to the phenomenon of global knowledge embeddedness, with a particular focus on two of the main channels of international knowledge diffusion: mobility of and collaboration among scientists. A common trend in the literature is that increasingly sophisticated methods are employed to analyze large databases of scientific publications and patents to identify mobility and collaboration patterns over long time spans. From this review, we derive stylized facts on the structure and dynamics of the global knowledge network.

1. The global knowledge network changes continuously with an increasing participation (globalization) and connectivity.

2. The global knowledge network is characterized by a core-periphery structure, with a growing core and countries changing relative positions.

3. Over time, there is a global shift from a bi-polar (Europe - North America) to a tri-polar world (Europe - North America - Asia). Consequently, the global network is becoming less centralized with larger spatial distances covered by mobility and collaboration linkages.

4. Networks across scientific fields differ substantially in their interaction intensity, but the observed globalization trends are ubiquitous.

5. The determinants for international collaboration change over time, with geographical and political factors (e.g. a common colonial history) becoming less relevant over time. International mobility is a main driver of international collaboration in science.

6. Network structures and innovation systems on different levels are interrelated. A functioning national system influences not only embeddeddness but also how countries benefit from being embedded.

7. Being embedded in the global knowledge network and openness towards global knowledge flows is positively correlated with scientific impact and performance.

While our understanding of global patterns and dynamics of interaction has increased substantially, much is still to understand, especially on the determinants, consequences and effects of international knowledge embeddedness. First, we need a better understanding of why a collaboration or mobility decision is made and what the individual and contextual determinants are. In particular on the contextual level, the inter-relatedness between networks on different levels of aggregation is a fruitful avenue for future research. The organization of research systems as well as national strategies towards international knowledge exchange can significantly affect the access and flow of knowledge. Understanding such relationships is also highly relevant from a policy perspective in the context of the brain-drain – brain circulation debate. Second, we need to learn more about the effects of embeddedness in the global knowledge network. While first results show that research performance increases due to international collaboration and mobility, direct effects on economic performance have not been analyzed yet. In this context, it would be of great importance to understand the mediating role of (national) preconditions, such as the absorptive capacity of nations, to benefit from growing international embeddedness. Improved access to and use of global knowledge flows for countries far from the scientific frontier could reduce knowledge inequality and help increase innovation and economic prosperity.

A limitation of the literature is a lack of causal evidence on the determinants and effects of global knowledge embeddedness. Most of the insights presented in this chapter are based on correlations. Conditions that allow for a causal identification of knowledge flows, international embeddedness and the effects of such embeddedness are hard to identify. There are a few exceptions. Agrawal et al. (2016), for example, use the collapse of the Soviet Union and the sudden inflow of mathematical knowledge into the US as a natural experiment. The COVID-19 pandemic can provide cases to analyze how global networks are formed or disintegrated, as, for example, by Wagner et al. (2021). As a final methodological remark, the realization of knowledge flows is only implicit in studies of the global network. The underlying assumption is that through relationships among individuals, knowledge is exchanged between countries so that subsequently, knowledge is diffused within the country and then exchanged again with other countries. A more explicit analysis of actual knowledge flows can support or invalidate the underlying assumptions, which would have significant implications for the relevance of global knowledge networks.

References

Ackers, L. (2005). Promoting scientific mobility and balanced growth in the European Research Area. *Innovation: The European Journal of Social Science Research*, *18*(3), 301–317. https://doi.org/10.1080/13511610500186680

Adams, J. D., Black, G. C., Clemmons, J. R., & Stephan, P. E. (2005). Scientific teams and institutional collaborations: Evidence from U.S. universities, 1981-1999. *Research Policy*, *34*(3), 259–285. https://doi.org/10.1016/j.respol.2005.01.014

Adams, J. (2012). The rise of research networks. *Nature*, *490*(7420), 335–336. https://doi.org/10.1038/490335a

Adams, J. (2013). The fourth age of research. *Nature*, *497*(7451), 557–560. https://doi.org/10.1038/497557a

Agrawal, A., Goldfarb, A., & Teodoridis, F. (2016). Understanding the changing structure of scientific inquiry. *American Economic Journal: Applied Economics*, *8*(1), 100–128. https://doi.org/10.1257/app.20140135

Agrawal, A., Kapur, D., McHale, J., & Oettl, A. (2011). Brain drain or brain bank? the impact of skilled emigration on poor-country innovation. *Journal of Urban Economics*, *69*(1), 43–55. https://doi.org/10.1016/j.jue.2010.06.003

Ahn, J., Choi, H., & Oh, D.-h. (2019). Leveraging bridging universities to access international knowledge: Korean universities' r&d internationalization. *Scientometrics*, *120*(2), 519–537. https://doi.org/10.1007/s11192-019-03138-4

Ahuja, G. (2000). Collaboration networks, structural holes, and innovation: A longitudinal study. *Administrative Science Quarterly*, *45*(3), 425–455. https://doi.org/10.2307/2667105

Altbach, P. G. (2013). Advancing the national and global knowledge economy: The role of research universities in developing countries. *Studies in Higher Education*, *38*(3), 316–330. https://doi.org/10.1080/03075079.2013.773222

Appelt, S., van Beuzekom, B., Galindo-Rueda, F., & de Pinho, R. (2015). Which factors influence the international mobility of research scientists? (A. Geuna, Ed.). In A. Geuna (Ed.), *Global mobility of research scientists*. Elsevier. https://doi.org/10.1016/b978-0-12-801396-0.00007-7

Arrieta, O. A. D., Pammolli, F., & Petersen, A. M. (2017). Quantifying the negative impact of brain drain on the integration of European science. *Science Advances*, *3*(4). https://doi.org/10.1126/sciadv.1602232

Azoulay, P., Ganguli, I., & Zivin, J. G. (2017). The mobility of elite life scientists: Professional and personal determinants. *Research Policy*, *46*(3), 573–590. https://doi.org/10.1016/j.respol.2017.01.002

Balland, P.-A., Boschma, R., & Ravet, J. (2019). Network dynamics in collaborative research in the EU, 2003–2017. *European Planning Studies*, *27*(9), 1811–1837. https://doi.org/10.1080/09654313.2019.1641187

Barabási, A. L., Jeong, H., Néda, Z., Ravasz, E., Schubert, A., & Vicsek, T. (2002). Evolution of the social network of scientific collaborations. *Physica A: Statistical Mechanics and its Applications*, *311*(3-4), 590–614. https://doi.org/10.1016/s0378-4371(02)00736-7

Baruffaldi, S. H., & Landoni, P. (2012). Return mobility and scientific productivity of researchers working abroad: The role of home country linkages. *Research Policy*, *41*(9), 1655–1665. https://doi.org/10.1016/j.respol.2012.04.005

Bathelt, H., & Li, P. (2020). Processes of building cross-border knowledge pipelines. *Research Policy*, *49*(3), 103928. https://doi.org/10.1016/j.respol.2020.103928

Bathelt, H., Malmberg, A., & Maskell, P. (2004). Clusters and knowledge: Local buzz, global pipelines and the process of knowledge creation. *Progress in Human Geography*, *28*(1), 31–56. https://doi.org/10.1191/0309132504ph469oa

Bauder, H. (2015). The international mobility of academics: A labour market perspective. *International Migration*, *53*(1), 83–96. https://doi.org/10.1111/j.1468-2435.2012.00783.x

Beaver, D. D. (2001). Reflections on scientific collaboration (and its study): Past, present, and future. *Scientometrics*, *52*(3), 365–377. https://doi.org/10.1023/A:1014254214337

Beine, M., Docquier, F., & Rapoport, H. (2001). Brain drain and economic growth: Theory and evidence. *Journal of Development Economics*, *64*(1), 275–289. https://doi.org/10.1016/s0304-3878(00)00133-4

Beine, M., Docquier, F., & Rapoport, H. (2008). Brain drain and human capital formation in developing countries: Winners and losers. *The Economic Journal*, *118*(528), 631–652. https://doi.org/10.1111/j.1468-0297.2008.02135.x

Binz, C., & Truffer, B. (2017). Global innovation systems–a conceptual framework for innovation dynamics in transnational contexts. *Research Policy*, *46*(7), 1284–1298. https://doi.org/10.1016/j.respol.2017.05.012

Bozeman, B., & Corley, E. (2004). Scientists' collaboration strategies: Implications for scientific and technical human capital. *Research Policy*, *33*(4), 599–616. https://doi.org/10.1016/j.respol.2004.01.008

Breschi, S., & Lissoni, F. (2004). Knowledge networks from patent data: Methodological issues and research targets (H. Moed, W. Glänzel, & U. Schmoch, Eds.). In H. Moed, W. Glänzel, & U. Schmoch (Eds.), *Handbook of quantitative science and technology research: The use of publication and patent statistics in studies on s&t systems*. Berlin, Springer.

Bush, V. (1945). *Science - the endless frontier* (tech. rep.). A Report to the President by Vannevar Bush, Director of the Office of Scientific Research and Development, July 1945. http://www.nsf.gov/about/history/vbush1945.htm

Cantner, U., & Graf, H. (2011). Innovation networks: Formation, performance and dynamics (C. Antonelli, Ed.). In C. Antonelli (Ed.), *Handbook on the economic complexity of technological change*. Cheltenham, UK, Edward Elgar. http://www.e-elgar.com/bookentry_main.lasso?id=13391

Cantner, U., & Rake, B. (2014). International research networks in pharmaceuticals: Structure and dynamics. *Research Policy*, *43*(2), 333–348. https://doi.org/10.1016/j.respol.2013.10.016

Carrazza, S., Ferrara, A., & Salini, S. (2016). Research infrastructures in the LHC era: A scientometric approach. *Technological Forecasting and Social Change*, *112*, 121–133. https://doi.org/10.1016/j.techfore.2016.02.005

Catalini, C., Fons-Rosen, C., & Gaulé, P. (2020). How do travel costs shape collaboration? *Management Science*, *66*(8), 3340–3360. https://doi.org/10.1287/mnsc.2019.3381

Cimini, G., Zaccaria, A., & Gabrielli, A. (2016). Investigating the interplay between fundamentals of national research systems: Performance, investments and international collaborations. *Journal of Informetrics*, *10*(1), 200–211. https://doi.org/10.1016/j.joi.2016.01.002

Coccia, M., & Wang, L. (2016). Evolution and convergence of the patterns of international scientific collaboration. *Proceedings of the National Academy of Sciences*, *113*(8), 2057–2061. https://doi.org/10.1073/pnas.1510820113

Crane, D. (1972). *Invisible colleges; diffusion of knowledge in scientific communities*. Chicago, University of Chicago Press.

Cronin, B., Shaw, D., & Barre, K. L. (2003). A cast of thousands: Coauthorship and subauthorship collaboration in the 20th century as manifested in the scholarly journal literature of psychology and philosophy. *Journal of the American Society for Information Science and Technology*, *54*(9), 855–871. https://doi.org/10.1002/asi.10278

Cronin, B., Shaw, D., & Barre, K. L. (2004). Visible, less visible, and invisible work: Patterns of collaboration in 20th century chemistry. *Journal of the American Society for Information Science and Technology*, *55*(2), 160–168. https://doi.org/10.1002/asi.10353

Czaika, M., & Orazbayev, S. (2018). The globalisation of scientific mobility, 1970–2014. *Applied Geography*, *96*, 1–10. https://doi.org/10.1016/j.apgeog.2018.04.017

de Solla Price, D. J. (1963). *Little science, big science*. New York, Columbia Univ. Press.

deB. Beaver, D., & Rosen, R. (1978). Studies in scientific collaboration. *Scientometrics*, *1*(1), 65–84. https://doi.org/10.1007/bf02016840

deB Beaver, D., & Rosen, R. (1979). Studies in scientific collaboration part III. professionalization and the natural history of modern scientific co-authorship. *Scientometrics*, *1*(3), 231–245. https://doi.org/10.1007/bf02016308

Defazio, D., Lockett, A., & Wright, M. (2009). Funding incentives, collaborative dynamics and scientific productivity: Evidence from the eu framework program. *Research Policy*, *38*(2), 293–305. https://doi.org/10.1016/j.respol.2008.11.008

Doehne, M., & Rost, K. (2021). Long waves in the geography of innovation: The rise and decline of regional clusters of creativity over time. *Research Policy*, *50*(9), 104298. https://doi.org/10.1016/j.respol.2021.104298

Dopfer, K., Foster, J., & Potts, J. (2004). Micro-meso-macro. *Journal of Evolutionary Economics*, *14*(3), 263–279. https://doi.org/10.1007/s00191-004-0193-0

Dosi, G. (1988). The nature of the innovative process (G. Dosi, C. Freeman, R. Nelson, G. Silverberg, & L. Soete, Eds.). In G. Dosi, C. Freeman, R. Nelson, G. Silverberg, & L. Soete (Eds.), *Technical change and economic theory*. London, Pinter.

Ebadi, A., & Schiffauerova, A. (2013). Impact of funding on scientific output and collaboration: A survey of literature. *Journal of Information & Knowledge Management*, *12*(04), 1350037. https://doi.org/10.1142/s0219649213500378

Edler, J., Fier, H., & Grimpe, C. (2011). International scientist mobility and the locus of knowledge and technology transfer. *Research Policy*, *40*(6), 791–805. https://doi.org/10.1016/j.respol.2011.03.003

European Union. (2016). *The European Research Area – evolving concept, implementation challenges* (tech. rep.). European Union. https://www.europarl.europa.eu/thinktank/en/document/EPRS_IDA(2016)579097

Florida, R. (2005). The world is spiky. *The Atlantic Monthly*, 48–51.

Fortunato, S., Bergstrom, C. T., Börner, K., Evans, J. A., Helbing, D., Milojević, S., Petersen, A. M., Radicchi, F., Sinatra, R., Uzzi, B., Vespignani, A., Waltman, L., Wang, D., &

Barabási, A.-L. (2018). Science of science. *Science*, *359*(6379), eaao0185. https://doi.org/10.1126/science.aao0185

Fox, M. F., Realff, M. L., Rueda, D. R., & Morn, J. (2017). International research collaboration among women engineers: Frequency and perceived barriers, by regions. *The Journal of Technology Transfer*, *42*(6), 1292–1306. https://doi.org/10.1007/s10961-016-9512-5

Frame, J. D., & Carpenter, M. P. (1979). International research collaboration. *Social Studies of Science*, *9*(4), 481–497. https://doi.org/10.1177/030631277900900405

Freeman, L. C. (1979). Centrality in social networks conceptual clarification. *Social Networks*, *1*(3), 215–239. https://doi.org/10.1016/0378-8733(78)90021-7

Freeman, R. B. (2010). Globalization of scientific and engineering talent: International mobility of students, workers, and ideas and the world economy. *Economics of Innovation and New Technology*, *19*(5), 393–406. https://doi.org/10.1080/10438590903432871

Freeman, R. B., Ganguli, I., & Murciano-Goroff, R. (2015). Why and wherefore of increased scientific collaboration. In A. B. Jaffe & B. F. Jones (Eds.), *The changing frontier* (pp. 17–48). Chicago, University of Chicago Press. https://doi.org/10.7208/9780226286860-003

Gaillard, J., & Gaillard, A. M. (1997). Introduction: The international mobility of brains: Exodus or circulation? *Science, Technology and Society*, *2*(2), 195–228. https://doi.org/10.1177/097172189700200202

Gazni, A., Sugimoto, C. R., & Didegah, F. (2012). Mapping world scientific collaboration: Authors, institutions, and countries. *Journal of the American Society for Information Science and Technology*, *63*(2), 323–335. https://doi.org/10.1002/asi.21688

Georghiou, L. (1998). Global cooperation in research. *Research Policy*, *27*(6), 611–626. https://doi.org/10.1016/s0048-7333(98)00054-7

Gibson, J., & McKenzie, D. (2014). Scientific mobility and knowledge networks in high emigration countries: Evidence from the pacific. *Research Policy*, *43*(9), 1486–1495. https://doi.org/10.1016/j.respol.2014.04.005

Glänzel, W. (2001). National characteristics in international scientific co-authorship relations. *Scientometrics*, *51*(1), 69–115. https://doi.org/10.1023/a:1010512628145

Glänzel, W., & Schubert, A. (2005). Analysing scientific networks through co-authorship. In H. F. Moed, W. Glänzel, & U. Schmoch (Eds.), *Handbook of quantitative science and technology research: The use of publication and patent statistics in studies of s&t systems* (pp. 257–276). Dordrecht, Springer Netherlands. https://doi.org/10.1007/1-4020-2755-9_12

Graf, H., & Kalthaus, M. (2018). International research networks: Determinants of country embeddedness. *Research Policy*, *47*(7), 1198–1214. https://doi.org/10.1016/j.respol.2018.04.001

Guan, J., Zhang, J., & Yan, Y. (2015). The impact of multilevel networks on innovation. *Research Policy*, *44*(3), 545–559. https://doi.org/10.1016/j.respol.2014.12.007

Gui, Q., Liu, C., & Du, D. (2019). Globalization of science and international scientific collaboration: A network perspective. *Geoforum*, *105*, 1–12. https://doi.org/10.1016/j.geoforum.2019.06.017

Hidalgo, C. A. (2016). Disconnected, fragmented, or united? a trans-disciplinary review of network science. *Applied Network Science*, *1*(6), 1–19. https://doi.org/10.1007/s41109-016-0010-3

Hoekman, J., Frenken, K., & Tijssen, R. J. W. (2010). Research collaboration at a distance: Changing spatial patterns of scientific collaboration within Europe. *Research Policy*, *39*(5), 662–673. https://doi.org/10.1016/j.respol.2010.01.012

Hornung, E. (2014). Immigration and the diffusion of technology: The huguenot diaspora in prussia. *American Economic Review*, *104*(1), 84–122. https://doi.org/10.1257/aer.104.1.84

Hou, L., Pan, Y., & Zhu, J. J. (2021). Impact of scientific, economic, geopolitical, and cultural factors on international research collaboration. *Journal of Informetrics*, *15*(3), 101194. https://doi.org/10.1016/j.joi.2021.101194

Jacob, M., & Meek, V. L. (2013). Scientific mobility and international research networks: Trends and policy tools for promoting research excellence and capacity building. *Studies in Higher Education*, *38*(3), 331–344. https://doi.org/10.1080/03075079.2013.773789

Jeong, S., Choi, J. Y., & Kim, J.-Y. (2014). On the drivers of international collaboration: The impact of informal communication, motivation, and research resources. *Science and Public Policy*, *41*(4), 520–531. https://doi.org/10.1093/scipol/sct079

Jones, B. F. (2009). The burden of knowledge and the "death of the renaissance man": Is innovation getting harder? *Review of Economic Studies*, *76*(1), 283–317. https://doi.org/10.1111/j.1467-937x.2008.00531.x

Jones, B. F. (2021). The rise of research teams: Benefits and costs in economics. *Journal of Economic Perspectives*, *35*(2), 191–216. https://doi.org/10.1257/jep.35.2.191

Jones, B. F., Wuchty, S., & Uzzi, B. (2008). Multi-university research teams: Shifting impact, geography, and stratification in science. *Science*, *322*(5905), 1259–1262. https://doi.org/10.1126/science.1158357

Jöns, H. (2007). Transnational mobility and the spaces of knowledge production: A comparison of global patterns, motivations and collaborations in different academic fields. *Social Geography*, *2*(2), 97–114. https://doi.org/10.5194/sg-2-97-2007

Jöns, H. (2009). 'Brain circulation' and transnational knowledge networks: Studying long-term effects of academic mobility to Germany, 1954-2000. *Global Networks*, *9*(3), 315–338. https://doi.org/10.1111/j.1471-0374.2009.00256.x

Kato, M., & Ando, A. (2017). National ties of international scientific collaboration and researcher mobility found in nature and science. *Scientometrics*, *110*(2), 673–694. https://doi.org/10.1007/s11192-016-2183-z

Katz, J. S., & Martin, B. R. (1997). What is research collaboration? *Research Policy*, *26*(1), 1–18. https://doi.org/10.1016/s0048-7333(96)00917-1

Keller, W. (2004). International technology diffusion. *Journal of Economic Literature*, *42*, 752–782.

Kolesnikov, S., Woo, S., Li, Y., Shapira, P., & Youtie, J. (2019). Mapping the emergence of international university research ventures. *The Journal of Technology Transfer*, *44*(4), 1134–1162. https://doi.org/10.1007/s10961-017-9640-6

Larivière, V., Gingras, Y., Sugimoto, C. R., & Tsou, A. (2015). Team size matters: Collaboration and scientific impact since 1900. *Journal of the Association for Information Science and Technology*, *66*(7), 1323–1332. https://doi.org/10.1002/asi.23266

Laudel, G. (2002). What do we measure by co-authorships? *Research Evaluation*, *11*(1), 3–15. https://doi.org/10.3152/147154402781776961

Leung, R. C. (2013). Networks as sponges: International collaboration for developing nanomedicine in china. *Research Policy*, *42*(1), 211–219. https://doi.org/10.1016/j.respol.2012.05.001

Luukkonen, T., Persson, O., & Sivertsen, G. (1992). Understanding patterns of international scientific collaboration. *Science, Technology, & Human Values*, *17*(1), 101–126. https://doi.org/10.1177/016224399201700106

Melin, G., & Persson, O. (1996). Studying research collaboration using co-authorships. *Scientometrics*, *36*(3), 363–377. https://doi.org/10.1007/BF02129600

Melkers, J., & Kiopa, A. (2010). The social capital of global ties in science: The added value of international collaboration. *Review of Policy Research*, *27*(4), 389–414. https://doi.org/10.1111/j.1541-1338.2010.00448.x

Moser, P., Voena, A., & Waldinger, F. (2014). German Jewish émigrés and US invention. *American Economic Review*, *104*(10), 3222–3255. https://doi.org/10.1257/aer.104.10.3222

Narin, F., Stevens, K., & Whitlow, E. S. (1991). Scientific co-operation in Europe and the citation of multinationally authored papers. *Scientometrics*, *21*(3), 313–323. https://doi.org/10.1007/BF02093973

Netz, N., Hampel, S., & Aman, V. (2020). What effects does international mobility have on scientists' careers? a systematic review. *Research Evaluation*, *29*(3), 327–351. https://doi.org/10.1093/reseval/rvaa007

Newman, M. E. J. (2001). The structure of scientific collaboration networks. *Proceedings of the National Academy of Sciences*, *98*(2), 404–409. https://doi.org/10.1073/pnas.98.2.404

Nguyen, T. V., Ho-Le, T. P., & Le, U. V. (2017). International collaboration in scientific research in vietnam: An analysis of patterns and impact. *Scientometrics*, *110*(2), 1035–1051. https://doi.org/10.1007/s11192-016-2201-1

Niosi, J., & Bellon, B. (1994). The global interdependence of national innovation systems: Evidence, limits, and implications. *Technology in Society*, *16*(2), 173–197. https://doi.org/10.1016/0160-791x(94)90028-0

Ou, A. Y., Varriale, L., & Tsui, A. S. (2012). International collaboration for academic publication: Implications from the resource-based view and transaction cost theory. *Group & Organization Management*, *37*(4), 407–451. https://doi.org/10.1177/1059601112448422

Ozman, M. (2009). Inter-firm networks and innovation: A survey of literature. *Economics of Innovation and New Technology*, *18*(1), 39–67. https://doi.org/10.1080/10438590701660095

Persson, O., Glänzel, W., & Danell, R. (2004). Inflationary bibliometric values: The role of scientific collaboration and the need for relative indicators in evaluative studies. *Scientometrics*, *60*(3), 421–432. https://doi.org/10.1023/B:SCIE.0000034384.35498.7d

Phelps, C., Heidl, R., & Wadhwa, A. (2012). Knowledge, networks, and knowledge networks: A review and research agenda. *Journal of Management*, *38*(4), 1115–1166. https://doi.org/10.1177/0149206311432640

Picci, L. (2010). The internationalization of inventive activity: A gravity model using patent data. *Research Policy*, *39*(8), 1070–1081. https://doi.org/10.1016/j.respol.2010.05.007

Plotnikova, T., & Rake, B. (2014). Collaboration in pharmaceutical research: Exploration of country-level determinants. *Scientometrics*, *98*(2), 1173–1202. https://doi.org/10.1007/s11192-013-1182-6

Pohl, H. (2021). Internationalisation, innovation, and academic–corporate co-publications. *Scientometrics*, *126*(2), 1329–1358. https://doi.org/10.1007/s11192-020-03799-6

Powell, W. W., Koput, K. W., & Smith-Doerr, L. (1996). Interorganizational collaboration and the locus of innovation: Networks of learning in biotechnology. *Administrative Science Quarterly*, *41*(1), 116–145. https://doi.org/10.2307/2393988

Price, D. J. D. S., & Beaver, D. (1966). Collaboration in an invisible college. *American Psychologist*, *21*(11), 1011–1018. https://doi.org/10.1037/h0024051

Ribeiro, L. C., Rapini, M. S., Silva, L. A., & Albuquerque, E. M. (2018). Growth patterns of the network of international collaboration in science. *Scientometrics*, *114*(1), 159–179. https://doi.org/10.1007/s11192-017-2573-x

Saxenian, A. (2005). From brain drain to brain circulation: Transnational communities and regional upgrading in india and china. *Studies in Comparative International Development*, *40*(2), 35–61. https://doi.org/10.1007/bf02686293

Scellato, G., Franzoni, C., & Stephan, P. (2015). Migrant scientists and international networks. *Research Policy*, *44*(1), 108–120. https://doi.org/10.1016/j.respol.2014.07.014

Schubert, A., & Braun, T. (1990). International collaboration in the sciences 1981—1985. *Scientometrics*, *19*(1-2), 3–10. https://doi.org/10.1007/bf02130461

Shields, R. (2013). Globalization and international student mobility: A network analysis. *Comparative Education Review*, *57*(4), 609–636. https://doi.org/10.1086/671752

Teichler, U. (2015). Academic mobility and migration: What we know and what we do not know. *European Review*, *23*(S1), S6–S37. https://doi.org/10.1017/S1062798714000787

Tsouri, M., Hanson, J., & Normann, H. E. (2021). Does participation in knowledge networks facilitate market access in global innovation systems? the case of offshore wind. *Research Policy*, *50*(5), 104227. https://doi.org/10.1016/j.respol.2021.104227

Uzzi, B. (1996). The sources and consequences of embeddedness for the economic performance of organizations: The network effect. *American Sociological Review*, *61*(August), 674–698. https://doi.org/10.2307/2096399

Uzzi, B. (1997). Social structure and competition in interfirm networks: The paradox of embeddedness. *Administrative Science Quarterly*, *42*(1), 35–67. https://doi.org/10.2307/2393808

van Leeuwen, T. N. (2009). Strength and weakness of national science systems: A bibliometric analysis through cooperation patterns. *Scientometrics*, *79*(2), 389–408. https://doi.org/10.1007/s11192-009-0426-y

Vanni, T., Mesa-Frias, M., Sanchez-Garcia, R., Roesler, R., Schwartsmann, G., Goldani, M. Z., & Foss, A. M. (2014). International scientific collaboration in HIV and HPV: A network analysis. *PLoS ONE*, *9*(3), e93376. https://doi.org/10.1371/journal.pone.0093376

Verginer, L., & Riccaboni, M. (2020). Cities and countries in the global scientist mobility network. *Applied Network Science*, *5*(1). https://doi.org/10.1007/s41109-020-00276-0

Verginer, L., & Riccaboni, M. (2021). Talent goes to global cities: The world network of scientists' mobility. *Research Policy*, *50*(1), 104127. https://doi.org/10.1016/j.respol.2020.104127

Wagner, C. S., Cai, X., Zhang, Y., & Fry, C. V. (2021). One-year in: COVID-19 research at the international level in CORD-19 data. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3874974

Wagner, C. S., & Leydesdorff, L. (2005a). Mapping the network of global science: Comparing international co-authorships from 1990 to 2000. *International Journal of Technology and Globalisation*, *1*(2), 185–208.

Wagner, C. S., & Leydesdorff, L. (2005b). Network structure, self-organization, and the growth of international collaboration in science. *Research Policy*, *34*(10), 1608–1618. https://doi.org/10.1016/j.respol.2005.08.002

Wagner, C. S., Park, H. W., & Leydesdorff, L. (2015). The continuing growth of global cooperation networks in research: A conundrum for national governments. *PLOS ONE*, *10*(7), e0131816. https://doi.org/10.1371/journal.pone.0131816

Wagner, C. S., Whetsell, T. A., & Leydesdorff, L. (2017). Growth of international collaboration in science: Revisiting six specialties. *Scientometrics*, *110*(3), 1633–1652. https://doi.org/10.1007/s11192-016-2230-9

Wagner, C. S., Whetsell, T. A., & Mukherjee, S. (2019). International research collaboration: Novelty, conventionality, and atypicality in knowledge recombination. *Research Policy*, *48*(5), 1260–1270. https://doi.org/10.1016/j.respol.2019.01.002

Wagner, C. S., Whetsell, T., Baas, J., & Jonkers, K. (2018). Openness and impact of leading scientific countries. *Frontiers in Research Metrics and Analytics*, *3*(10). https://doi.org/10.3389/frma.2018.00010

Waltman, L., Tijssen, R. J., & van Eck, N. J. (2011). Globalisation of science in kilometres. *Journal of Informetrics*, *5*(4), 574–582. https://doi.org/10.1016/j.joi.2011.05.003

Wang, J., Hooi, R., Li, A. X., & Chou, M.-h. (2019). Collaboration patterns of mobile academics: The impact of international mobility. *Science and Public Policy*, *46*(3), 450–462. https://doi.org/10.1093/scipol/scy073

Wanzenböck, I., Scherngell, T., & Brenner, T. (2014). Embeddedness of regions in European knowledge networks: A comparative analysis of inter-regional R&D collaborations, co-patents and co-publications. *The Annals of Regional Science*, *53*(2), 337–368. https://doi.org/10.1007/s00168-013-0588-7

Wanzenböck, I., Scherngell, T., & Lata, R. (2015). Embeddedness of European regions in european union-funded research and development (R&D) networks: A spatial econometric perspective. *Regional Studies*, *49*(10), 1685–1705. https://doi.org/10.1080/00343404.2013.873119

Wuchty, S., Jones, B. F., & Uzzi, B. (2007). The increasing dominance of teams in production of knowledge. *Science*, *316*(5827), 1036–1039. https://doi.org/10.1126/science.1136099

Youtie, J., Li, Y., Rogers, J., & Shapira, P. (2017). Institutionalization of international university research ventures. *Research Policy*, *46*(9), 1692–1705. https://doi.org/10.1016/j.respol.2017.08.006

Zacchia, P. (2018). Benefiting colleagues but not the city: Localized effects from the relocation of superstar inventors. *Research Policy*, *47*(5), 992–1005. https://doi.org/10.1016/j.respol.2018.03.004

Zitt, M., Bassecoulard, E., & Okubo, Y. (2000). Shadows of the past in international cooperation: Collaboration profiles of the top five producers of science. *Scientometrics*, *47*(3), 627–657. https://doi.org/10.1023/A:1005632319799

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