an open access journal

RESEARCH ARTICLE

Geography of scientific knowledge: A proximity approach

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Keywords: citation, controversy, diffusion, mobility, replication, tacit knowledge

Citation: Frenken, K. (2020). Geography of scientific knowledge: A proximity approach. *Quantitative Science Studies*, *1*(3), 1007–1016. https://doi.org/10.1162/qss_a_00058

DOI:
https://doi.org/10.1162/qss_a_00058

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Handling Editors:
Loet Leydesdorff, Ismael Rafols, and Staša Milojević

ABSTRACT

Proximity among scientists in social, cognitive, and physical dimensions promotes the sharing of tacit knowledge. Tacit knowledge helps scientists to understand the credibility of papers they read and to use the results in subsequent research. Hence, given the proximity among scientists in social, cognitive, and physical dimensions, one can predict patterns of diffusion in science. However, for controversial knowledge claims to become replicated, one expects the proximity between scientists itself to change as like-minded scientists relocate and create new coalitions. Proximity can thus be used as a unifying concept for the study of scientific knowledge diffusion as well as for the analysis of mobility of scientists.

1. INTRODUCTION

It is quite common to view scientific knowledge as essentially “placeless” (Livingstone, 2003). The principle of replication in science holds that a knowledge claim can be said to be true if this claim is repeatedly confirmed by independent replication studies. This view was challenged by many cases showing that replication is very difficult in practice (Begley & Ioannidis, 2015; Collins, 1985). In particular, for scientists it is hard to establish whether two studies yield the exact same results or not. Furthermore, many studies are never replicated at all, but their results nevertheless can become widely accepted as truths in the scientific community. This shows that what is being “replicated” in many instances is not the research as such, but only the knowledge *claim* based on the initial research (Latour, 1987).

One can formulate, as the central research question for a geography of scientific knowledge, under what conditions a knowledge claim originating from one place becomes accepted as scientific in other places (Shapin, 1998). This formulation allows one to shed a new light on scientific knowledge production by bringing in concepts and methodologies from geography. Since research, by nature, is geographically localized in specific places–be they offices, labs, or field sites—the question of how knowledge claims become widely accepted outside the places of origin can be understood as a question of spatial diffusion and the role of distance herein. In developing a theoretical framework, I will make use of proximity (Bellet, Colletis, et al., 1993; Boschma, 2005), as the mirror concept of distance, to disentangle the various types of relationships between scientists—cognitive, social, and physical—that support the diffusion of knowledge claims.

2. GEOGRAPHY, SCIENCE, AND SCIENTIFIC KNOWLEDGE

Rather than posing the philosophical question of which empirical knowledge can be said to be scientifically true or untrue, sociologists of scientific knowledge analyze the conditions under

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which a knowledge claim becomes established as scientific among scientists (Collins, 1985; Gilbert, 1976; Latour, 1987; Shapin, 1984). The sociology of scientific knowledge is not only different from the philosophy of science, but also departs from the Mertonian program in the sociology of science (Merton, 1973). This latter tradition investigates the institutions governing scientific activity rather than the conditions under which a knowledge claim becomes accepted within science.

Analogous to the distinction between sociology of scientific knowledge and the classic sociology of science, I use the phrase *geography of scientific knowledge* for the study of how knowledge claims become replicated across different places, while *geography of science* covers the larger set of questions regarding the local conditions and shaping of scientific knowledge and spatial diffusion of scientific practices and institutions (Barnes, 2001; Finnegan, 2008; Livingstone, 2003; Meusburger, Livingstone, & Jöns, 2010; Naylor, 2005; Powell, 2007). Thus, like the sociology of scientific knowledge, the geography of scientific knowledge focuses on the process rendering knowledge claims scientific.

To put forward a coherent framework for the study of the geography of scientific knowledge, the scope of the present paper is deliberately limited. First, I focus only on how claims are being replicated among scientists. Thus, I am not concerned here with how knowledge claims become replicated in society at large (Latour, 1987; Porter, 1995), nor do I go into the question of why certain knowledge claims originate in some places rather than others (Heimeriks & Boschma, 2014; Nomaler, Frenken, & Heimeriks, 2014; Whatmore, 2009). Second, the framework is an analytical one, which aims to serve as a framework for science studies.

3. ON REPLICATION IN SCIENCE

In the early stages of what is generally associated with modern experimental science, fellow scientists were often invited to witness an experiment in person (Shapin, 1994). The copresence of individuals was of importance in their role as witnesses to establish a consensus about what exactly was being observed and how these observations were to be interpreted. Progressively, copresence became less common (though it still plays a role in team research or in contact with the media). Witnessing has instead become organized through codification in written reports that are evaluated by peers before and after publication. Empirical knowledge is abstracted from the context of discovery by codifying the knowledge claim in written form so that it can travel (Latour, 1987; Shapin, 1984, p. 491). Without codification of a knowledge claim in a written report, the production of knowledge claims would be severely constrained by space and time due to the need for physical copresence. The credibility of a knowledge claim would then depend solely on the testimonies of those who have witnessed the experiment.

Empirical knowledge becomes established as scientific knowledge once the empirical results of a study are accepted as credible by others who were not copresent at the research site. To establish credibility, a written report should describe not only the actual event but also the laboratory conditions (objects, physical conditions, equipment, protocols, methodologies, etc.). Careful reporting of laboratory conditions should allow fellow scientists to replicate the experiment independently at different sites. Subsequent replications of an experiment by fellow scientists, if successful, lead to the accumulation of confirmations of the original claim. It is common to view the process of successful replications of experiments at different sites as evidence that the original knowledge claim is universally true. Accordingly, scientific knowledge is commonly considered as “placeless” (Livingstone, 2003) in the sense that claims that have been proven replicable in different places hold independently of the private observations of scientists who have been involved in the process of successive replications.

However, the set of instructions as codified in a scientific paper are generally insufficient for fellow scientists to be able to replicate an experiment. The codified instructions have to be complemented with the relevant tacit knowledge and information on contextual conditions for scientists to be able to replicate the underlying experiment (Balconi, Pozzali, & Viale, 2007; Collins, 1985; Van Bavel, Mende-Siedlecki, et al., 2016). Codified information cannot be exchanged in a fully unambiguous manner, as the receiver of codified information still requires complementary tacit knowledge as "interpretative skills" to interpret the information content as meaningful in a particular material context (Balconi et al., 2007, p. 836 and p. 842; cf. Nelson, 2003, p. 911).

Given that replication studies involve both tacit and codified knowledge, and the tacit elements of knowledge cannot be transferred perfectly among scientists, scientists can never be fully certain that they have replicated a study perfectly. If, for example, a laboratory replicates an experiment and comes up with (slightly) different results, the scientists involved cannot ascertain whether the divergence in results means that the original claim must be rejected or whether the replication experiment has been carried out in the wrong way, that is, in a different way than was reported in the original claim[1]. In fact, replication studies seldom underlie scientific agreement, as many results become accepted without any other researcher ever attempting to replicate the studies underlying the results (Begley & Ioannidis, 2015).

Following this reasoning, Shapin (1984) argued that the establishment of an empirical knowledge claim as scientific is fundamentally driven by the perceived replicability of the experiment, and not necessarily by actual replications of the experiment. The codification of experimental results in a report can thus be considered as a "literary technology of virtual witnessing" (Shapin, 1984); that is, a means to convince the reader that the experiment described could be replicated in different places and at different times if one were to follow the description of the laboratory conditions as written down in the report. The disclosure of the laboratory conditions is essential to suggest that the report is trustworthy and the claim is credible if any scientist were to decide to attempt to replicate the experiment. It is for this reason that the description of laboratory conditions in itself is often sufficient for a knowledge claim to become established as scientific.

A replication study and the replication of a knowledge claim are thus two very different processes. In the case of the replication of a knowledge claim, some of the *implications* of the experiment are replicated as an input to carry out a new research project, without the study itself being replicated. Previous knowledge claims guide the production of future knowledge claims through their use in assumptions, methodologies, instruments, or interpretations (Dasgupta & David, 1994, p. 500). Research projects build on previous research by extending it to new domains, not by attempting to perfectly replicate past experiments. In doing so, previous claims are mobilized, and thus replicated, to support a new claim (Latour, 1987).

The replication process of knowledge claims becomes visible in codified form through referencing (Gilbert, 1977). The study of the diffusion of knowledge can in principle be done in a

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[1] The fundamental problem in replication experiments lies in what Collins called "experimenters' regress," which "arises because the skill-like nature of experimentation means that the competence of experimenters and the integrity of experiments can only be ascertained by examining results, but the appropriate results can only be known from competently performed experiments, and so forth. Other ways of testing for the competence and integrity of experiments, such as tests of tests, turn out to need 'tests of tests of tests' and so on" (Collins, 1985, p. 130). In short, to establish whether equipment is properly working, one can carry out an experiment with a "known" outcome, but this outcome has become established in other experiments using the equipment at hand. Alternatively, one may test the working of equipment using test equipment, but this moves the problem one level up ("tests of tests of tests"). Laboratories, then, can be understood as an infrastructure to "construct predictability," which is not to be confused with perfect replication (Nightingale, 2004).

purely scientometric manner, by studying the citation links between scientific articles. And, as a basic theory, one can adopt an evolutionary lens to understand the dynamics of scientific knowledge production: Often-cited claims get selected while seldom-cited claims get forgotten (Leydesdorff, 1998; Martinelli & Nomaler, 2014). The geography of scientific knowledge production, then, would focus on the spatial diffusion of knowledge claims.

4. PROXIMITY

I pose as the central research question for a geography of scientific knowledge: *What determines that a knowledge claim originating from one place becomes accepted as scientific in other places?* Following Shapin (1995, p. 261), the credibility of a knowledge claim depends on the relationship between the one(s) putting forward the claim ("claimant"), and the one judging its credibility ("evaluator"). As argued, previous knowledge claims guide the production of new knowledge claims through their use in assumptions, methodologies, instruments, or interpretations. The process of replication of a knowledge claim thus takes on the form of the use of a claim as a resource, or input, to establish a new claim. Since knowledge claims are replicated in subsequent knowledge claims in these manners, the chance of a claim being replicated will depend not only on its credibility but also on its usefulness in guiding new research projects. Thus, for a claim to be replicated as an input in a subsequent empirical research context, evaluators should consider the claim to be both *credible* and *useful*[2]. The question becomes how an evaluator establishes the credibility and usefulness of a claimant's knowledge claim.

I will approach this question by focusing on the relationship between the claimant and the evaluator. To characterize the relationship between claimant and evaluator, I will make use of notions of proximity as developed in economic geography (Balland, Boschma, & Frenken, 2015; Bellet et al., 1993; Boschma, 2005; Rallet, 1993; Torre & Rallet, 2005). Proximity simply denotes the inverse of the distance between two scientists. Proximity can refer to physical proximity in the literal sense of physical distance separating two scientists (which Rallet and Torre tend to call *geographical proximity*), or it can refer to other forms of proximity. The thesis that is developed in detail below holds that the more distant the claimant and evaluator are in physical and nonphysical spaces, the less probable the claimant's knowledge claim is being replicated by the evaluator.

To be able to judge a claim, cognitive proximity (Nooteboom, 1999) seems to be by far the most important factor. *Cognitive proximity* in a narrow sense can be defined as the extent to which two scientists share the code of communication that is used in a particular disciplinary context. Following this narrow definition, cognitive proximity allows an evaluator to decode the written report containing the knowledge claim and to assess its credibility and usefulness. Cognitive proximity, in the sense just defined, is consistent with the idea that knowledge can be transmitted as information as long as the sender and receiver use the same code of communication to code and decode the message (Cowan, David, & Foray, 2000). The idea that knowledge can be exchanged as codified information provided that two agents share the same codebook has been criticized on several grounds (Balconi et al., 2007; Nelson, 2003; Nightingale, 2003). A codebook can be seen as a language that must be shared between agents to allow for verbal and written communication.

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[2] The two main replication criteria are also visible in the almost standard setup of scientific papers. Usefulness is mainly dealt with in the review section, showing how it builds on previous research. Credibility is mainly dealt with in the methodology section, where the procedures are specified that should be followed in an attempt to replicate the experiment itself. It is often during the review process that the "right" level of credibility and usefulness is negotiated with the claimant having to give in by qualifying its claims as being credible only under particular assumptions or particular contexts, and, therefore, being relevant only to a small domain of scientific inquiry (Myers, 1985). Ultimately, of course, the findings may still be judged as being more or less relevant and more or less credible than the author has stated in the published version.

However, because languages cannot be fully formalized, the meaning of symbols referring to empirical objects remains to some extent tacit. A language cannot be taught, but must be learned in localized practices by participating in material contexts in which a language is used in a specific way. In this context, Balconi et al. (2007, pp. 840–843) distinguish between tacit knowledge of the physical ("skill-like") type and of the cognitive type. The latter type is often overlooked, but may be more important in understanding the replication process of knowledge claims. What is more, in the codification process of tacit knowledge of the physical type (e.g., into computer algorithms), new tacit knowledge of the cognitive type is being created concerning the appropriate use of codified information in particular research contexts[3].

Generally, the evaluator cannot fully judge the credibility and the usefulness of a claim from a text alone. As text length is limited, many details will be left out. What is more, the tacit knowledge involved in the experiment is not transmitted with the text. Thus, an evaluator would benefit from having similar tacit knowledge as was involved in carrying out the experiment. These "intellectual skills" (Balconi et al., 2007, p. 842) allow an evaluator to "read between the lines" and better understand how the experiment was carried out, whether the observational reports are trustworthy, and how likely the experiment is to be replicated with a high degree of precision. Thus, cognitive proximity in a broader sense can be taken to mean the extent to which claimant and evaluator share both codified and tacit knowledge regarding the experimental context in question. It is cognitive proximity that allows scientists to judge a knowledge claim without any face-to-face interaction between claimant and evaluator; cognitive proximity is what makes Shapin's "virtual witnessing" possible. From reading a text, a "competent" evaluator can judge its credibility and usefulness[4].

Obviously, few people are cognitively close; typically, high levels of cognitive proximity will only be found in small communities that make up highly specialized subdisciplines that reproduce themselves by training their own successors. This explains why most claims in science are assessed on credibility and usefulness only within these small communities—often connected to a journal—and without any interference from actors outside these communities. Actors outside these communities, including fellow scientists and (a large part of) the public, derive the credibility and usefulness of claims indirectly from the peer assessment carried out within these small subcommunities (Shapin, 1995, pp. 269–271).

The assessment of a claim in terms of credibility and usefulness is often carried out without any interaction between claimant and evaluator. In the role of peer reviewer, or reader, the evaluator will judge a report without feedback from the claimant. As long as the claimant and evaluator have sufficient knowledge in common, claims can be assessed at a distance. Yet, the subsequent *replication* of a knowledge claim as an input in new experiments typically necessitates, or at least benefits from, face-to-face interaction to *transfer* tacit knowledge, instruments, materials, further information, and so on. It is for this reason that some form of interaction between claimant and evaluator often precedes the replication of a knowledge claim in a subsequent claim. This can vary from personal correspondence or small talk to more intensive forms of interaction, including site visits, temporary exchange of personnel, and collaborative research projects. All these forms of interaction are examples of close face-to-face interaction rendering these interactions fundamentally different from written communication or oral presentation involving a one-to-many form of interaction.

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[3] This also means that even attempts by scientists to reproduce results from the raw data collected by others (as opposed to replicating) may be hard, as tacit knowledge may still be involved in knowing how to use software, follow data entry procedures, and collect results. What is more, in some cases, the software may operate differently depending on the hardware used.

[4] Indeed, anonymous peer review is based on such judgments without any interaction between claimant and evaluator (even if the editor generally, but not necessarily, acts as a mediator interacting with both parties).

However, colocation is not a sufficient condition for tacit knowledge sharing to take place (Boschma, 2005). A key question that follows is under what conditions scientists are willing to share tacit knowledge, information, and other resources[5]. Although scientists' main incentive is to see their knowledge claims being replicated (Hull, 1988), they have little incentive to see their resources being replicated, because sharing resources allows other researchers to pursue the same research lines and to pre-empt future publications (Dasgupta & David, 1994). Since reward in science is allocated on the basis of priority in research findings (whatever the exact ways in which priority is established), the incentive to share resources is limited. What is more, sharing resources is a costly affair, especially for tacit knowledge that requires teaching and on-the-job training, while compensation schemes for sharing activities are rare.

An important reason why scientists nevertheless share resources quite regularly is the risk of reputational loss. Within the subcommunities in which scientists are operating, those unwilling to share tacit knowledge will run the risk that third parties will no longer share resources with them once they are notified about their unwillingness (Dasgupta & David, 1994, p. 504). In this respect, the concept of *social proximity* can be used to explain the willingness of scientist A to share resources with scientist B. Social proximity, following Granovetter (1973), may refer to the number of fellow scientists that A and B know in common[6]. The higher this number, the higher the reputational consequences once word gets out that A does not behave cooperatively, given that B will warn those that A and B know in common about A's noncooperative behavior. Thus, the higher the social proximity between claimant and evaluator, the higher the willingness of the claimant to share tacit knowledge and other resources with the evaluator, the higher the probability that the evaluator will replicate the claim in subsequent claims. As for cognitive proximity, social proximity is typically high in small subcommunities in which the members frequently meet, carry out peer-review, and engage in collaborative research projects. Given the specialized nature of scientific knowledge production, cognitive and social proximity will tend to be highly correlated (Breschi & Lissoni, 2009).

5. CONTROVERSIES

Although the proposed focus of the geography of scientific knowledge is on the replication of knowledge claims rather than of underlying laboratory experiments, this focus does not imply that replication studies do not influence the dynamics of scientific knowledge production. One may ask under what conditions scientists have an incentive to engage in replications of experiments. Most attempts to replicate an experiment involve a costly investment. The returns on such an investment depend on the status of the knowledge claim that resulted from the experiment in question. When a knowledge claim is considered to be credible and useful for scientists' further research, there is little interest in devoting resources to replication attempts. If such an attempt fails to replicate the earlier reported findings, fellow scientists will generally believe that the replication experiment has been carried out incorrectly. And, if the replication experiment succeeds in replicate the earlier reported findings, it will be regarded as replicating "the obvious." In both cases, the results of the replication experiment may be deemed unworthy of publication in

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[5] A related question is under what conditions scientists want to share material objects relevant for research. There is evidence that scientists are reluctant to share materials if competition is fierce and the cost of sharing is high (Walsh, Cohen, & Cho, 2007). Exchange of materials differs, however, from the sharing of tacit knowledge, because the former does not require face-to-face interaction *per se*.

[6] Social proximity as defined here follows the older notion of tie strength proposed by Granovetter as the degree of overlap of two individuals' friendship networks (Granovetter, 1973, p. 1362). Note that the measure of social proximity proposed here differs from the measure of social proximity as the shortest geodesic distance in the coauthor network (Breschi & Lissoni, 2009).

scientific journals. Given that investments in replications of credible knowledge claims have low returns, whatever the outcome of the replication experiments, few scientists engage in such research (Collins, 1985).

By contrast, if a knowledge claim is considered *controversial*, meaning that its acceptance would contradict many previous claims on which scientists have built their research in the past, scientists will have an incentive to engage in replication (Collins, 1985, p. 19). In such contexts, replication exercises have the explicit goal to replicate an experiment so as to confirm or disconfirm a claim. Given the problem of "experimenters' regress" (see footnote 1), there cannot be a *fully* agreed methodology that distinguishes between correct and incorrect experiments. What is more, controversies often arise with the advent of new instrumentalities rather than from theoretical advances (de Solla Price, 1984), which implies that both technological and methodological uncertainties may exist regarding the assessment of experimental evidence. That is why the outcome of controversies is contingent, at least to some degree, upon the entrepreneurial ability of each participant to find the resources required to improve experiments technologically as well as methodologically, and upon the rhetorical ability to convince fellow scientists of the methodological soundness of their own experiment (Latour, 1987). If, over time, no agreed methodology emerges, the different positions can lead a research community to fragment into two subcommunities characterized by their own methodology (Hull, 1988). Alternatively, agreement may emerge on one particular position, or a synthesis between different positions, and the community remains intact.

In science and technology studies, scientific controversy constitutes a longstanding separate topic of research, including studies looking at the formation of new coalitions supporting a new paradigm (Jasanoff, 2020; Kuhn, 1962). Similarly, within our proximity framework, the distinction between controversial and uncontroversial knowledge claims has important consequences. Whereas collaborative behavior regarding the sharing of resources can be explained from cognitive, social, and physical proximity in the case of uncontroversial knowledge claims, this explanatory scheme no longer works for controversial knowledge claims. Characteristic of controversy is that there is no agreement on the conditions under which replication attempts can be considered true replication, due to the problem of experimenter's regress (Collins, 1985). One can thus expect that, even more so than in uncontroversial contexts, scientists may be unwilling to share tacit knowledge and other resources, which otherwise are crucial to arriving at a common understanding of divergent results in replication attempts. The radical uncertainty regarding the outcome of a controversy, which generally lasts for several years, forces each scientist to "take sides." To participate in the controversy, a scientist must allocate time and resources between the established, mainstream research program and the emerging, controversial research program.

Following the spatial analogy implicit in the proximity concept, it can be argued that taking sides can be analyzed as a form of mobility. Following the proximity framework, one can distinguish between cognitive mobility (e.g., moving from the established research trajectory to a competing research trajectory), social mobility (leaving the established community to join a new subcommunity), and mobility in the literal physical sense (moving between physical sites). Mobility in the physical sense is crucial, because the establishment of cognitive and social proximity often requires face-to-face interaction between likeminded scientists. That is, colocation enables the creation of new social networks and joint cognitive investments in emerging research programs, including manuals, software, equipment, and, of course, laboratories. Ideally, mobility would lead to permanent colocation of those who wish to join an emerging research trajectory so as to be able to work together on-site on a permanent basis.

The mobility dynamics of scientists along cognitive, social, and physical dimensions may greatly affect the dynamics of scientific knowledge production and the establishment of new research trajectories. The more people join a particular research trajectory, the more resources become available to produce, and the more likely that knowledge claims will be replicated in subsequent research projects[7]. The reason why critical mass matters is that experiments that are intended to confirm a claim are typically carried out differently than experiments intended to disprove a claim, and experiments done by proponents will more often find confirming evidence and experiments done by opponents will more often find the opposite (Collins, 1985). What is more, there exists a publication bias in that experiments with positive results are more easily accepted by scientific journals than experiments yielding insignificant or negative results (for a review, see Dwan, Altman, et al., 2008). This is not to say that empirical evidence "in itself" does not play a role. On the contrary, the accumulation of empirical evidence is generally decisive in settling controversies. Yet, this process cannot be understood solely as a process of inductive reasoning, as scientists do not share the epistemological foundation required to agree on what counts as a replication, which would be necessary to aggregate such evidence.

6. CONCLUDING REMARKS

The geography of scientific knowledge production is understood as a process through which locally produced knowledge claims become accepted as scientific elsewhere. Even if scientists, in principle, can replicate each other's knowledge claims just by referencing, face-to-face interaction remains important in the replication of knowledge claims to transfer the supporting tacit knowledge. By sharing tacit knowledge through face-to-face interaction, scientists are better able to judge the credibility and usefulness of a claim and, thereby, to build upon each other's findings in a cumulative manner.

The proximity framework provides a theoretical explanation of the empirical observation that the probability of citation between two articles goes up with physical proximity (Frenken, Hardeman, & Hoekman, 2009). Recent studies, however, found that the effect of physical proximity is quite small once cognitive proximity is properly controlled for (Head, Li, & Minondo, 2019; Wuestman, Hoekman, & Frenken, 2019), which also indicates the positive correlation between physical and cognitive proximity. Furthermore, a study showed that social proximity between countries also plays a role in explaining citation patterns, even after controlling for physical proximity (Hellmanzik & Kuld, 2018). These initial findings call for more refined research on citation patterns based on different notions of proximity, opening up a new, theoretically informed research program in the (quantitative) studies of science, which can also leverage past research on proximity in innovation studies (Balland et al., 2015). Here, the geography of scientific knowledge production can build on a longer tradition in science studies on the measurement of cognitive proximity using co-occurrence data (Van Eck & Waltman, 2009) and can find inspiration in more recent attempts to combine physical, cognitive, and social proximity measures in a single research design (Baccini, Barabesi, et al., 2020; Head et al., 2019; Wuestman et al., 2019).

In all, the proximity framework provides an analytical framework in which different theoretical traditions can be combined and translated into a single research design, here, to explain the replication logic of knowledge claims. As such, it speaks to repeated calls for more theorization in the field of scientometrics (Cronin, 1981; Leydesdorff, 1998; Fortunato, Bergstrom, et al., 2018). In the present contribution, I have drawn primarily on theories in economic geography and science and technology studies that stress the role of tacit knowledge sharing among scientists as supportive of the understanding and acceptance of new claims. In doing so, I have limited myself to reflections about the role of, and interplay between, three forms of proximity: physical, cognitive, and social.

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[7] Also known as increasing returns to adoption (Arthur, 1989).

A further extension can be envisaged by including more proximity dimensions, in particular the role of institutional proximity. A lack of institutional proximity would characterize the relations between scientists and other actors in society (Ponds, Van Oort, & Frenken, 2007). This would extend the proximity framework presented here with its sole focus on knowledge diffusion between scientists operating under the same academic institutions to knowledge diffusion between actors operating under different institutions, including firms, governments, and NGOs.

ACKNOWLEDGMENT

The paper builds on a longer previous version, which has appeared as a working paper (Frenken, 2010).

COMPETING INTERESTS

The author has no competing interests.

FUNDING INFORMATION

The author received funding under the NWO Vici program, number 453-14-014.

DATA AVAILABILITY

Not applicable.

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