Reproducibility and Replicability in the Context of the Contested Identities of Geography

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Reproducibility and Replicability in the Context of the Contested Identities of Geography

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Abstract

This paper situates the current discussion of reproducibility and replicability taking place across the sciences within geographers' enduring discussion of nomothetic and idiographic approaches, best exemplified by the Hartshorne-Schaefer debate. The fundamental ideas of reproducibility and replicability are not new to the discipline. Geographers seeking to identify the regularities and laws of spatial distribution and location (nomothetic approach) use a scientific mode of inquiry that explicitly relies on the reproduction and replication of prior findings to correct error and progress toward a greater certainty of explanation. Alternatively, geographers that use synthesis and integration to identify and interpret characteristics that differentiate places (idiographic approach) call into question the replicability of explanations across space. Others have convincingly argued that the identity of the discipline is strengthened whenever we can integrate or operate between these two approaches. While the Hartshorne-Schaefer debate retrospectively set the stage for the development of geography from the 1950s to the present, it is surprising that direct discussions of reproducibility and replicability remain mostly absent from the geographic literature. Drawing from recent literature on reproducibility and replicability in the humanities and physical, social, and computational sciences, it is argued that a deeper focus on these issues will have varied impacts on the discipline. Adopting and improving reproducible practices in geographic research reliant on scientific methods will align geographic research with mainstream scientific inquiry. However, the discipline's ever growing diversity of theoretical perspectives and problem domains also makes it likely that a significant portion of geographic research, like many other fields in science, may not be affected by the issues and concerns of reproducibility and replicability. Moving forward, geographic research may continue to benefit from a pluralist framework that embraces both the nomothetic and idiographic approaches, particularly in a broader research environment increasingly defined by disciplinary synthesis and convergence.

Keywords: nomothetic, idiographic, reproducibility, replicability, GIScience, betweenness

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The Reproducibility Issue in Science and the Silence of Geography

The inability to reproduce and replicate prior scientific findings has caught the attention of the scientific community (Shavit and Ellison, 2017; NASEM 2019; Nature 2018), policymakers (Baker et al. 2019; Bollen et al. 2015), and the mainstream media (Economist 2013). In response, work is underway across the sciences to develop infrastructure, practices, and communication standards that support the full sharing of the empirical, statistical, and computational details of scientific work. Unlike other fields, geography as a discipline has until recently mainly remained silent on reproducibility and replicability (R&R) issues (Brunsdon 2016; Kedron et al. 2019). The existing geographic literature on the topic has demonstrated that it is currently challenging to reproduce published work (Singleton et al. 2016; Ostermann and Granell 2017; Nüst et al. 2018, Konkol et al. 2019), leading scholars to call for changes in research and teaching practices (Brunsdon et al. 2015; Arribas-Bel & Reades 2018; Granell et al. 2018; Holler 2019; Kedron et al. 2019; Muenchow et al. 2019). However, fundamental ideas about scientific epistemology, error correction, and the generalizability of explanations that rest behind R&R are not new to the discipline. They have, in fact, long been at the center of debates about the identity of the field and its position within the academy (Schaefer 1953; Hartshorne 1955; Turner 2002). Best exemplified by the well-known/well-documented Hartshorne-Schaefer debate (Schaefer 1953; Hartshorne 1955) and the literature that surrounds it (Gould 1991; Sacks 1974; Harvey and Wardenga 2006; Louden 2015), which frames the extent to which geography can be a positivist, law-seeking discipline, these enduring discussions can serve as a gateway for bringing current debates about R&R into geography.

Re-examining R&R in the context of geography offers the opportunity to analyze how we as a field collectively produce new knowledge, whether we do so reliably, and how we might improve that process. Defining the limits of R&R as a corrective mechanism in geographic research has implications for the practice of geography. As a discipline defined by its synthetic approach and wide range of subjects, geographers have always embraced multiple forms of knowledge production (Dickerson 1976; Harvey 2001; Turner 2002; Kwan 2004). Geographers seeking to identify the regularities and laws of spatial distribution and location (nomothetic approach) typically use a scientific mode of inquiry that relies on the R&R of prior findings to correct error and progress toward a greater certainty of explanation. Alternatively, geographers who use synthesis and integration to identify and interpret characteristics that differentiate places and regions (idiographic approach) often call into question whether explanations can be replicated across space. Indeed, as Entrikin (1992) and Whatmore (2002) so convincingly articulated through the betweenness framework and hybrid geography, geography's disciplinary identity can be strengthened whenever and wherever we can artfully integrate both nomothetic and idiographic approaches to understand human-environment interactions holistically.

The goal of this paper is to situate the emerging discussion of R&R taking place across the sciences within geography's ongoing search for an identity generally, and discussion of the Hartshorne-Schaefer debate between nomothetic and idiographic approaches in particular. In doing so, we aim to encourage the discipline to think more broadly about the complex, multi-faceted implications of R&R for the practice of geographic research in the years ahead. Many of the issues and implications we address here are echoed and explored in further detail in the papers included within this Forum (2019-1338.R1; 2019-1339.R1; 2019-1321.R1; 2019-1337.R1; 2019-1342.R1).

The remainder of this paper is organized into four sections. The following section outlines key points in recent discussions of R&R from across the sciences. The third section links those discussions to the long-standing debate between nomothetic and idiographic approaches to geography and the Hartshorne-Schaefer debate. Transcending the dichotomy of nomothetic vs. idiographic, the fourth section articulates a betweenness framework that recognizes the need for aspects from both approaches to guide emerging convergence research in the age of big data and geography's fine-tuned response to the on-going discussions of R&R. The last section contains a summary and conclusion.

Reproducibility, Replicability, and a Space for Geography

R&R have come to mean different things to different people in different disciplines, in sometimes contradictory ways (Barba 2018; Plesser 2018). For conceptual consistency, we follow the definitions adopted by the National Academy of Sciences, Engineering, and Medicine (NASEM) and the National Science Foundation (Bollen et al. 2015; NASEM 2019), which were themselves informed by body of work in both the social and natural science. *Reproducibility* is obtaining results consistent with a prior study using the same materials, procedures, and conditions of analysis. *Replicability* is obtaining consistent results across studies that aim to answer the same question, but with each study collecting and using its own data. More succinctly, research is reproducible when the same data and the same methods produce the same result. Research has been replicated when new data are collected and the same, or similar, methods are used to produce a result that is consistent with prior studies. Ultimately, repeated replication of a result contributes to the credibility of the underlying claims, and when results can be repeated across time, space, and populations, they contribute to the *generalizability* of a claim.

The ability to reproduce and replicate prior findings is a crucial form of error correction in scientific inquiry. As a method of generating knowledge and testing beliefs, science uses deductive reasoning and inductive empirical evaluation to make claims about phenomena and relies on the repeated testing of prior work to assess the certainty of those claims. Failures to reproduce or replicate prior findings create concern about the reliability of scientific knowledge (Ionannidis 2005), but failures can occur for many reasons, not all of which are harmful to progress. As outlined by in a recent NASEM (2019) consensus

report, potentially *helpful* sources of non-replicability are a product of studying complex systems that have inherent variation with imperfect tools and knowledge. Failing to replicate a result because we are not yet able to fully conceptualize or capture a system is not necessarily a negative but rather is often the first step toward new pathways of research and ultimately scientific progress. At the same time, non-reproducibility and non-replicability may be the product of inadequate communication of data collection protocols, experimental or statistical procedures, or publication bias, among other reasons. In geographic context, non-reproducibility and non-replicability are often attributed to the role of place as processes and behaviors are often contingent upon location and locale. A contingency that can also change through time. The emergence of computational and data-intensive approaches in science means that a failure to reproduce or replicate results may also originate from inadequate sharing of information about computational artifacts and environments. These *unhelpful* sources of non-reproducibility and non-replicability inhibit scientific progress.

Recognizing the existence of helpful and unhelpful sources of R&R failures is important because it reinforces the fact that successfully reproducing or replicating a finding does not imply truth and validity, and failing to reproduce or replicate a finding does not imply untruth. Prosper-René Blondlot's 1903 discovery of N-rays (Broad and Wade 1982) was replicated hundreds of times (Tretkoff, 2007) but was demonstrated by simple intervention to be a product of observation bias (Wood 1904). Robert Millikan received the Nobel Prize for measuring the quantal electrical charge, but he likely masked uncertainty in his estimate through selective reporting (Broad and Wade 1982; Franklin 1997). In the end, when operating correctly, R&R is a powerful corrective mechanism, which facilitates the assessment of the credibility of claims, not absolute truth or certainty. Perhaps one useful lesson that can be drawn from recent history and the unfolding story of Elizabeth Holmes (Carreyrou 2018) is that we need to pause and review new claims and reflect on the things we think we know before heavily investing in new technology or scientific explanation.

Seeking to both preserve the corrective function of R&R and exploit its capacity to open new avenues of research, several fields are working to address unhelpful sources of non-reproducibility. Among the most prominent examples are computer science, stemming from a long-standing desire for complete reproduction (Claerbout and Karrenbach 1992); psychology, stemming from concerns related to sample sizes and statistical procedures (OSC 2015); and medicine, stemming from the high stakes of failure (Collins and Tabak 2014). Work in these fields has alternatively focused on aspects of computational, statistical, and empirical reproducibility (Stodden 2014). To ensure detailed information is provided about data, code, and software environment, efforts to improve computational reproducibility have developed infrastructure in the form executable notebooks (Yin et al. 2017) and containers that bind data, code, and environment (Nüst & Hinz 2019; Brinkman et al. 2019). In this forum, 2019-1339.R1 outline how these

research artifacts and tools may be combined in research compendia and 2019.1337.R1 offer a five-star guide to reproducible GIS software development. Work on statistical reproducibility has centered on the transparency of modeling choices, sample size and statistical power (Ioannidis and Trikalinos 2007; Munafo et al. 2017), and pre-registration to avoid p-hacking and HARKing—hypothesizing after results are known (van't Veer and Giner-Sorolla 2016; Nosek et al. 2018). Leamer's (1983) early development of extreme bounds analysis, which encouraged researchers to report the entire range of estimates possible under alternative reasonable model specifications, was a forerunner in the economics literature of many of these contributions. In addition to the measures above, R&R research in the experimental sciences has sought to change the reporting and publication culture by altering reporting standards (Sandve et al. 2013; Stodden et al. 2014), enforcing journal-mandated sharing of research artifacts (McNutt 2014; Stodden et al. 2018), and implementing badge and credit systems that certify reproducibility (Kidwell et al. 2016). As 2019-1321.R2 argue, this form of active institutional realignment will be essential to the development of R&R in geography because a movement toward R&R should not be assumed when it does not align with existing economic incentives within academia and the publishing industry. Critically, these discussions and actions do not call the scientific method into question. Instead they seek to correct practice through the measures outlined above.

To some extent, progress has been field-specific in that R&R efforts have sought to correct the specific tools and approaches that were developed to suit the phenomena studied by that field. This approach to R&R has left a gap in the current discussion. Specifically, what are the key sources of non-R&R when scientific approaches are integrated and/or linked with other ways of knowing, and what role should R&R play in assessing the credibility of claims produced under those circumstances?

The Geographer's Craft: R&R and the Discipline's Contested Identity

The sheer intellectual diversity of geography requires that the precise meaning of R&R in the context of geographic research be given careful scrutiny. As a discipline, geography is defined by its integrated approach(es) to the study of spatial phenomena more so than a single subject of research. Geographers study topics as diverse as geomorphology, cultural identity, economic organization, and ecology by mixing a variety of tools and approaches as they practice their craft (Freeman 1961; Sheppard 1995). This synthesis-based approach is a historic strength of geography as it has allowed the discipline to claim a bridging role across fields of study and ways of knowing (Turner 2002). Actively engaging in the current R&R debate by examining the role of R&R in the practice of geography may similarly bridge gaps in our current understanding of the production of knowledge. Doing so has the potential to improve our discipline's credibility and public trust.

Although we only found one paper (Davies 1968) devoted to replication during the peak of the quantitative revolution, R&R are implicitly entwined with the major disciplinary debates in geography during the post-war WWII period. Exemplified by the Hartshorne-Schaefer debate, literature about identity and approach of geography commonly frames the discussion around Windelband's (1893) division of nomothetic and idiographic approaches to knowledge. The idiographic approach is based on what Kant described as a tendency to specify and is typical of the humanities (Thomae 1999). As outlined by Hartshorne (1939; 1955), geography is an idiographic science that seeks to understand the characteristics of a bounded region through integrated study. This chorological understanding reduces space to place and links the field to the interpretation of place-to-place differences (Cox 2014). Idiographic work is often linked with understanding the meaning of contingent, unique, and often cultural or subjective phenomena. In contrast, the nomothetic approach is based on what Kant described as a tendency to generalize through the abstraction of attributes and their examination in relation to other attributes and is typical of the natural sciences. In geography, it describes the effort to derive laws that explain spatial patterns of phenomena through scientific inquiry with an emphasis on explaining underlying processes. While he was in disagreement with the nomothetic approach, Hartshorne did stress the importance of describing and classifying places and phenomena and admitted that there was room to use laws of generic relationships to maximize scientific understanding. In his view, however, there should be no hierarchy between these two approaches.

R&R play different roles within the spatial (nomothetic), chorological (idiographic), and human-environment approaches to studying geography. With its search for morphological laws and adoption of the scientific method, the spatial approach implicitly recognizes R&R as a means of establishing the geographic bounds and credibility of an explanation. We would expect the details of these law-like statements to vary across space (Goodchild 2004). Replication of an analysis across regions would help establish the locations in which a spatial pattern-process relationship holds, while also identifying the variables and confounders involved in that relationship. Harvey (1969) identifies these functions as fundamental building blocks of any explanation of geographic phenomena and the construction of theory. For the more straightforward case of reproduction, given the same data and methods (and by necessity the same time and location), the reproduction of a spatial analysis would act as a check of existing knowledge. However, the use of R&R to create geographic theory faces further questions. Spatial and temporal heterogeneity and scale are at least two important issues complicating R&R. If geographic attributes have different and wide variances in space and time, it may be difficult to establish consistency criteria to make decisions about when replications have been achieved. Similarly, the influence of confounding variables simultaneously operating at many spatial and temporal scales complicates R&R by making any analysis subject to the spatial and temporal boundaries of a study.

What role, if any, R&R will play within the idiographic approach that favors explanation of the unique and contingent is not yet well defined. Because purely idiographic work has limited interest in generalizing that explanations of the character of a region beyond the bounds of the region under examination, replication does not serve the scoping role outlined above. If geography is interpreting place-to-place differences through the synthesis of unique combinations of location attributes, then reproduction, although still possible and desirable, would be very difficult or almost impossible because synthesis often involves creative or tacit knowledge of the synthesizer. That knowledge is often not well documented through the scientific method and therefore is often hard or impossible to reproduce or replicate.

Turner (2002) identifies a critical feature shared by the idiographic and nomothetic approaches. Specifically, that both approaches tie understanding to the study of the spatial attributes of phenomena, which he contrasts with a parallel human-environment tradition within the discipline. Turner argues for geography as a science of human-environment relationships formed by interactions between phenomena that, if studied in isolation, would not explain their collective relationship. The coupled human and natural systems framework that typifies the human-environment approach attempts to balance structure- and agent-based explanations of phenomena. This sub-field has long struggled to develop theories of land use in part because, like the nomothetic, its practitioners seek generalizable explanations, but like the idiographic, attempt to develop them through synthesis and integration of complex regional systems studied a particular points in time. R&R can act as a corrective mechanism within the approach, but to make it operational, we must address the multiple unhelpful sources of non-reproducibility that arise simultaneously when mixed methodologies are used to explain complex phenomena.

Betweenness, Convergence, and Geographic Research in the Age of Big Data

Now is an important time to build on the traditions of geography and bring the discipline into the discussion of R&R because our increasing ability to acquire and analyze geographic data is moving questions about the practice of geography to center stage. Moreover, Miller and Goodchild (2015) argue that the emergence of a ‘data-driven’ geography may create the opportunity to open pathways between idiographic and nomothetic knowledge. Data-driven geography might achieve this goal by fostering the development of middle-range theories (Merton 1967) that explain a bounded set of phenomena through the examination of how local and specific interactions create emergent behavior. If we are moving toward a fourth scientific paradigm (Hey et al. 2009) in which the rate of discovery is defined by the collaborative, computational analysis of big geographic data, then defining and developing R&R frameworks within the discipline will be critical to our ability to assess and understand new research.

Captured by the NSF (2019) concept of convergence research, this change in the scientific community will catalyze scientific discovery and innovation by creating deep integration through transdisciplinarity and stakeholder synergy. Intellectually, convergence research dovetails with geography's tradition of synthesis but does not necessitate an idiographic approach. As the development of data analytics, deep learning, and AI tools accelerate, our discipline would benefit from a holistic approach that capitalizes on the complementary strengths our different traditions provide. To geographers arguing the merits of one tradition alone, Entrikin (1992) offers a more synthetic/holistic framework organized around the concept of place. To understand place, Entrikin (1992, page 5) notes this "requires that we have access to both an objective and a subjective reality. From the decentered vantage point of the theoretical scientist, place becomes either location or a set of generic relations and loses much of its significance for human action. From the centered viewpoint of the subjective self, place has meaning only in relation to one's own goals and concerns. Place is best viewed from points in-between." The betweenness of place offers us an inclusive guiding framework for a geographic scholarship that synergizes both nomothetic and idiographic approaches. Betweenness also entails that we need to pursue R&R whenever and wherever possible but at the same time leaves plenty of higher-level synthesis and integration of empirical evidence to improve our understanding of the world we live in, and at times even change it for the better.

Entrikin's suggestion is a geographic reflection of an argument advanced by Medawar (1967), which recognizes that explanation (in the scientific sense) requires the imagination of an unseen world or relationship that is formed into a hypothesis, which we collectively and scrupulously examine against a range of possible alternatives (nomothetic). However, imagining that unseen possibility depends on a rich understanding of the world as it can be or has already been seen. That vision requires a description and synthesis of geographic phenomena (idiographic). Both the vision and the scrupulous examination are crucial in a world of data/computational complexity and scientific questions addressed through convergence research.

Using R&R to Look Inside and Outside of Geography

Geographers produce new knowledge in many different ways, but Geography as a discipline is most likely to thrive when its practitioners link approaches from the physical, natural, and social sciences and the humanities. Difficult though it may be, such integration lies at the heart of the discipline's claim to play a bridging role across realms of understanding. We argue that bringing R&R to the forefront of geographic research and practice offers at least two avenues to further this position.

First, looking within the discipline, studying and developing R&R creates an opportunity to reinvigorate and move forward longstanding debates about the essential qualities of geographic understanding (Harvey 2001), the central identity of the field (Hartshorne 1955; Schaefer 1953), and its position in the academy (Turner 2002). The opportunity arises because R&R requires conceptual and procedural transparency. Openly displaying the mechanisms of knowledge production creates the conceptual space to engage in the collaborative co-development of new forms of knowledge production. Examining how variation and co-variation of phenomena in time and space constrain our ability to use R&R to establish reliable knowledge could similarly shape the use of R&R more broadly. This form of productive critique and critical engagement could preserve the topical breadth of the field and its position as a bridge across the sciences and humanities.

Second, extending lessons learned from the study of R&R within geography beyond the boundaries of the discipline offers an outwardly focused avenue toward convergence research. The forms of disciplinary, theoretical, and stakeholder integrated convergence research is predicated on building and refining different understandings of not only the phenomena under study but the methods of inquiry used. At a minimum, moving toward R&R in geography can improve the transparent communication of the scientific study of spatial phenomena. By capitalizing on the topical breadth of the discipline, R&R research in geography should offer lessons as to what does and does not work when stakeholders and researchers work together to fuse modes of inquiry. We find a sympathetic view in 2019-1338.R1 review of cognate disciplines and early replication attempts of rural settlement theory.

At the same time, we recognize that linking the broader scientific community's discussion of R&R with geographers' enduring debates will not be without incident and is likely to have varied impacts on the discipline. Adopting and improving reproducible practices in geographic research reliant on the scientific method will align geographic research with mainstream scientific inquiry. Geography's overall image and credibility will undoubtedly be improved if we can undertake concerted efforts to make geographic research more reproducible or worthy of R&R. However, the discipline's ever-growing diversity of theoretical perspectives and problem domains also makes it likely that a significant portion of geographic research, like the many other fields in science, may not be affected by the issues and concerns of reproducibility and replicability. It is particularly intriguing that science has enjoyed enormous progress despite non-reproducibility (Shiffrin et al. 2018).

Geography is poised to both benefit from and contribute to the advancement of R&R across the sciences. Adopting the best practices in R&R emerging from an open science perspective, geographers can align their work with mainstream science and continue to elevate public trust and respect in geographic scholarship. At the same time, placing R&R within the discipline's long-standing intellectual debates can advance our understanding of the role R&R has to play in different forms of research. The

topical and methodological breadth of geography provides fertile ground to develop and test interventions designed to address stubborn sources of non-R&R and exploit helpful sources of non-R&R.

Moving forward, geographic research may continue to benefit from a pluralist framework that embraces both the nomothetic and idiographic approaches, particularly in a broader research environment increasingly defined by disciplinary synthesis and convergence. The emerging data-driven approach will significantly facilitate both intra-, inter-, and trans-disciplinary synthesis and convergence. As Kuhn (1977) demonstrated for the broader fields of science, the creative tensions between space vs. place, nomothetic vs. idiographic, reproducible vs. non-reproducible will be essential to propel intellectual enterprise forward.

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