Received: 24 August 2023 | Revised: 2 March 2024 | Accepted: 7 March 2024

DOI: 10.1111/gec3.12743

REVIEW ARTICLE

WILEY

Rethinking ‘causality’ in quantitative human geography

Jing Zhang | **Levi John Wolf**

School of Geographical Sciences, University of Bristol, Bristol, UK

Correspondence
Jing Zhang.
Email: jing.zhang.2021@bristol.ac.uk

Funding information
Economic and Social Research Council; Southwest Doctoral Training Partnership

Abstract

Causality is at the core of much contemporary discussion in social sciences, philosophy, and computer science—from the establishment of basic definitions of causality to developing methods for causal inference, this discussion is increasingly finding voice within geographical literature. However, geographers have long discussed (and differed) about the role “causality” plays in our work. We present a history of contemporary definitions of causality arising from philosophy and examine how these intellectual currents interact with past and present geographical thinking about causal relations. In particular, we focus on how new thinking about counterfactual causality can help re-route inquiry around a well-known impasse: law-based causality in geography. In other words, while different perspectives around “laws” of geography exist, we argue that it is more productive to put aside these differences and find common ground in counterfactual causal thinking. To demonstrate, we outline new kinds of scholarship enabled by counterfactual causality and contemporary challenges that counterfactual causality faces in spatial analysis. Throughout, we refer interested readers to contemporary work on spatial causal inference and methods useful for scholars interested in analysing causal relationships in geographical systems.

KEYWORDS
causality, counterfactual theory of causation, law, regularity theory of causation

1 | INTRODUCTION

Knowledge of cause and effect plays an important role in explaining past events and planning for the future. The last 70 years have witnessed the formation of statistical inference frameworks that revolutionised empirical approaches to causal inquiries. This progress in causal inference is part of a wider intellectual movement propelled by mutually-reinforcing social and academic forces such as the contemporary interest in evidence-based policy, the increasing availability and resolution of data, and the gradual improvement of philosophical theories about causality. In a way, intersection of these forces gives rise to a contemporary movement for causality, characterised by conceptual models of causation, formal models of causal dependence, and a tight focus on issues of identification and estimation of specific causal effects (Heckman, 2005). In turn, *causal inference*, the empirical quest for specific knowledge about the strength and direction of cause and effect relationships, has become a core aim for many scholars. These trends give rise to two specific bodies of work on causal inference. The Potential Outcomes (PO) framework (Rubin, 1974) approaches the inference of causal effect via an analogy to randomised experiments, while the Structural Causal Model (SCM) framework (Pearl, 2000) focus more intently on representing the network of causal relation that must be modelled in order to understand the system. These two contemporary methodological approaches to causal inference are both rooted in the same conceptual grounds, though: the counterfactual theory of causation (Lewis, 1973). Thus, despite their frequent disagreements, both main contemporary approaches to causal inference arise from the same philosophical basis.

This basis is distinct from that commonly found in geographical work. Indeed, spatial processes are often "special" (Anselin, 1989), and this remains the case for *spatial causal inference*, or causal inference in the presence of substantive geographic mechanisms. In recent years, spatial causal inference has received special attention. On the one hand, this is motivated by empirical research on topics that are irreducibly spatial. For example, policing and neighbourhood crime (Verbitsky-Savitz & Raudenbush, 2012), vaccination and disease spread (Zhang & Ning, 2023), land use and planning (Comber & Arribas-Bel, 2017), and air pollution and health (Giffin et al., 2022). This makes spatial causal inference a valuable methodological pursuit with real world impact. On the other hand, spatial causal inference is quite difficult: spatial processes tend to create more complex dependence structures than standard non-spatial causal inference methods admit, and it is often difficult or impractical to create experimental conditions where these spatial causal mechanisms can be choreographed.

Thus, it is no surprise that common geographical thinking about causality arises from a different philosophical basis. Recent efforts to document progress in spatial causal inference (e.g. Reich et al. (2021) or the special issue of Credit and Lehnert (2023)) mainly catalogue different ways geographers do causal inference, rather than identifying what makes this new work substantively different. We believe the field will benefit from clarifying the existing understandings of causality in spatial analysis to see what makes new attempts at spatial causal inference in geography so distinctive. We do this by first providing an overview of the history and state of contemporary thinking about "causality" in geography, and contrasting how this understanding differs from that embedded in two general approaches to causal inference (PO & SCM). Furthermore, the paper also speculates on the possible paths moving onward: we argue that the counterfactual theory of causation is both useful and flexible enough to underpin further efforts in spatial causal inference. Indeed, past critiques of quantitative human geography's positivist tendencies are intricately linked to the way causality has been conceptualized by quantitative human geographers.[1] We believe that the counterfactual theory of causation provides a more stable ground on which to build an effective framework for causal inference in geography. While we outline different perspectives about causal "laws" in geography, we ultimately argue that it is more productive to put aside these different law-based definitions of causality and find common ground in counterfactual causal thinking that enables new kinds of spatial causal inferences.

2 | CAUSALITY, LAW, AND QUANTITATIVE HUMAN GEOGRAPHY

To set the scene, the first wave of "quantitative spatial science," with its keen awareness of causal questions, took stage around the 1950s–70s (Harvey, 1969; Jones, 1956). It is in this phase where at least part of the intellectual frame of spatial analysis was set (Barnes & Wilson, 2014). This is around the same time as Lewis' initial 1960–1970s papers on counterfactual causation, slightly earlier than Neyman and Rubin's PO causal inference framework, and also much earlier than Pearl's SCM framework. Thus, the "quantitative spatial science" forming in the mid-to-late 20th century occurred largely without the benefit of counterfactual causation ideas—they did not have the chance to be built into our foundations. We contend that these initial conditions have left a mark on subsequent thinking about causality in quantitative human geography. To illustrate this, we structure the subsequent sections around the following set of questions: what are the main theories of causation adopted by human geographers and where did they come from? And, how did these causal theories inform geographers' ideas about causal inference?

2.1 | The regularity theory of causation and the law-causality nexus

Tracing back to early modern metaphysics, there is a long-held perspective that the ontology of causality is bound up with natural laws. Before Lewis' counterfactual dependence view on causation became popular, the dominant doctrine on how "causation" worked was the so-called Regularity Theory (Johansen, 2021) originating from the works of David Hume. According to Hume "We may define a cause to be an object followed by another, and where all the objects, similar to the first, are followed by objects similar to the second." (Hume, 1751, 7.2.29, p. 76–77). While many have developed this theory further, Hume's notion of causality (termed "constant succession") is consistently at its core. To borrow from Armstrong (2016), a regularity theory of causation is a conjunction of two propositions: (1) that causal connection is a kind of law-like connection (2) that laws are nothing but regularities in the behaviour of things. Within the philosophy of science, different versions of this regularity theory have emerged over time,[2] but they all tend to define "cause" alongside/on top of a definition of "law". Since regularity theory is so long-standing, many social and physical sciences have entangled their ideas of "law" and "cause" as well. We call this entanglement the "law-causality" nexus. It is intrinsic to regularity theory, but can exist in other causal theories, or work which does not self-consciously adopt a theory of causation.

So far, we have not directly defined what we mean by "law." For simplicity, let's say there are two orientations of understanding "law" that are relevant here: First, a more explicitly-positivist approach to geography sees law-causality as a fundamental part of explanation in human geography (Olsson, 1970).[3] Second, a "more relaxed" and conversational (Smith, 2004, p. 294) interpretation of "law" that we are accustomed to today. For instance, in Volume 94 (2004) of the Annals of the American Association of Geographers, a collection of papers prominent authors revisited Tobler's First Law of Geography, including Tobler himself. Despite consistent interest in laws, one point of agreement across a few of the authors (Goodchild, 2004; Miller, 2004; Phillips, 2004; Sui, 2004; Tobler, 2004) was that a strict definition of "law" is irrelevant if its empirical contents are useful to predict or understand a process. In this spirit, it is suitable to take the conversational interpretation of 'law' for most of the discussions in this paper. In either of the above senses, quantitative human geography in the mid-20th century saw "causality" entangled with "law," as arising from then-contemporary regularity theories of causation.

2.2 | Causality–law in 20th century human geography and its long shadows

The law-causality nexus has played a major role in shaping geographers' ideas about causal inference. On one hand, the law-causality view implicitly underpins how quantitative human geographers historically formulate domain theories. On the other hand, the critique of law-causality arising from critiques of positivism in geography (Johnston, 1986, pp. 26–31) has been so effective that the subsequent development of causal theory and methods has been delayed, as if causality got evicted from the discipline as collateral damage of theoretical debates about "law."

To elaborate: critical scholarship is often theoretical by design, but a theory of causality is often implicit within domain-specific theory or analytical practices where quantitative geographers work. This applies to many of the canonical theoretical models that originated in 20th century quantitative work. For example, the gravity model for spatial mobility (Reilly, 1931) has an explicit analogy to the physical law of gravity but its causation aspect is veiled both in terms of the interpretations and applications of the theoretical model. One "causation" aspect of a gravity model lies in the assumption that various "push" or "pull" factors can be intervened upon in order to increase the flows out of a given locale (Isard, 1956). For an urban movement example, improving the "push" factors may entail improving the mobility of a neighbourhood's residents so that they are better able to leave their locale; the resulting increase in flows would be a *causal effect* of manipulating on this factor. The actual mechanism by which the "pull" or "push" factor changes behaviour is dependent on the modelling context.[4] This causal interpretation is not always obvious, especially when the gravity model is applied primarily to predict flows, not the cause-hunting or effect-hunting which we commonly associate with causal inference.

One prominent "law" in contemporary geography is Tobler's first law (TFL) of geography, that "everything is related to everything else, but near things are more related than distant things" (1970, p. 236). Sui (2004) notes its influence as a "searchlight in geographers' explorations" (p. 273). Similar to the gravity model case, Tobler's original paper has a seemingly vague connection to the causality side of the causality-law nexus.[5] A "pro-law" perspective from Tobler (1970) is best embodied in its claim of generalisability: "a model of urban growth should apply to all cities now and in the future" (p.234). This ambition for generalisable or replicable geographic models successfully avoids the term "law" while still supporting the ambition to law-like causal relations (Tobler, 2004). Unlike the gravity model case, TFL did not borrow a law from physics, it proposed one for geography. The TFL paper is not about law-hunting (Smith, 2004; Tobler, 2004); it is instead "declaring" law (Barnes, 2004). This has earned it a long-lasting place in law related debates in geography. It establishes 'replication and generalizability' as a useful linguistic tracer to follow the law-causality nexus through subsequent scholarship in quantitative human geography.

In contrast, and somewhat ironically, the causality-law nexus is easier to find in critiques of quantitative human geographers' work than in the body of work itself (Flowerdew, 1998). Indeed, some major critiques of quantitative human geography focus on its adoption of law-causality for their critiques. For example, Jones (1956) "anti-realist"[6] ontological critique of law-causality cautions against giving "cause and effect an objective reality which they may not really possess" (p. 374). Another related position is Smith (1979)'s critical stance towards geographers' practice of "seeking scientific laws and theories, by applying models and systems scientifically" (p. 357). This "scientific method" and other tools (such as hypothesis testing) are a "societal technology" which is in "generating both technology and ideology for the capitalist society" (p. 378), and should be critically deconstructed. Further, Barnes (2004) notes that the use of the term "law" "removes the relationship described from its local geographical and historical context, and makes it appear as if it is from nowhere and is timeless" (p. 280). Put differently, law-causality (including generalizability and replication) removes context from our causal statement, while Barnes sees context as "critical, and needs to be consistently remembered" (*ibid*). Thus, these critiques predicated upon law-causality span the entire intellectual history of quantitative spatial science and contemporary spatial analysis. In response, as "law" phased out of the analytical lexicon of human geography, "causality" in human geography also went by the wayside.

2.3 | The loose connection as a call for reflection

Figure 1 is a diagramme presenting in broad strokes our understanding of the streams of ideas that have influenced causal thinking in quantitative human geography. To summarise, the law-causality nexus arises from historically popular regularity theories of causality. These theories emerge in the work of quantitative human geographers and their critics from the start of geography's quantitative revolution. Even though law and causality were used interchangeably, we call the law-causality nexus a "loose" connection because it is contingent upon the regularity theories of causation popular in the mid-20th century. This historically formed loose connection presents us with an opportunity to reflect on the possible directions to take causality forward in quantitative human geography. We have at least two options: One option is to salvage the tradition of finding causality-laws with an up-to-date theory defining what a "law" is and how it can be obtained and used in human geography without falling too far into the shadows of past ideological debates.[7] Option two is to break the link between "law" and "causality" with the counterfactual theory of causation, and focus on causality from there. We believe the second option could very well be more productive than attempting to fix the causality-law nexus. In the rest of this paper, we will elaborate on this argument, first revisiting some theoretical work on causality-laws in human geography and then folding the counterfactual theory of causation back into the discussion.

3 | DOUBLING DOWN OR MOVING BEYOND CAUSALITY-LAWS?

Having reviewed the causality-law tradition in 20th century quantitative human geography, we now turn to its legacy in the discipline's current practice to assess whether it is plausible to double down on causality-laws. First, we revisit the middle ground position in meso-geography as a contemporary refinement of the causality-law tradition. And this leads to our proposition to move beyond causality-law.

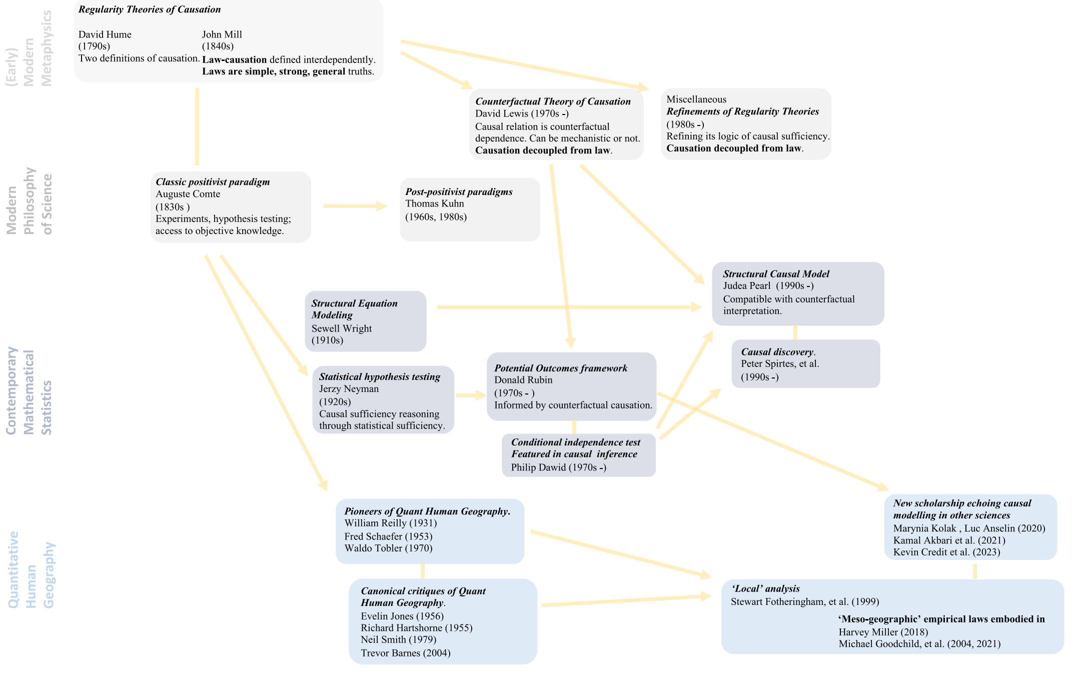

FIGURE 1 Streams of ideas. (From left to right representing progression of history).

3.1 | Finding the middle ground: Scale as a fix for the law-causality nexus

The law-view of causality, in all its variants depending on the definition of law, still has a presence in geography research. While geographic law-seeking still exists in contemporary literature (see, for example, Alessandretti et al., 2018), most of the work engaging contemporary law-seeking is still grappling with the implications of the "local" revolution (Fotheringham & Brunsdon, 1999). The clearest statement of this revision of the law-causality nexus is Miller (2018)'s articulation of the increasingly-crowded "middle ground between description-seeking and law-seeking" (p. 605) called "meso-geography." Proponents of meso-geographic analysis occupy "intermediate positions in the longstanding debate between nomothetic and idiographic" (Goodchild & Li, 2021). In this sense, "meso-geography seeks generalizations, but not universal laws," where generalizations are "the *causal* relations holding in a range of environments." (Miller, 2018, p. 605). This is still a law-causality nexus, and regularity is still the rubric meso-geographers use to assess law-cause relations. Indeed, a law-causal relationship has value because of the "range of environments" over which the relation holds, which tells us how weak its generalization/replicability[8] is. An objection from non-geographers (paraphrasing King, 1996) is that this weakness disappears as our understanding improves. In contrast, meso-geographers suggest this weakness is intrinsic to geography, because "some but not all aspects of a geographic principle or model are replicable across space" (Goodchild & Li, 2021, p. 3). Understood properly, this is the first law of geography itself (Goodchild, 2004). In other words, meso-geographers' "laws" have jurisdictions, and laws enforced differently in different places should still be seen as laws. Thus, this perspective uses geographical *scale* generally (and local analysis specifically) to fix the law-causality nexus. Putting aside other critiques of the meso-geography position, its local "laws" almost washed out the theoretical edge of the concept of "law" compared with its historical predecessors. This leads us back to the question of the empirical content and usefulness of the term "law" in human geography (See Section 2.1). In current practice, it is no longer productive to argue for (against) the reliability of a causal analysis via inciting (refuting) the existence of laws in the common geographical sense. In this sense, meso-geography as a fix for causality-law in fact made "law" a redundant concept.

3.2 | Moving beyond law: The counterfactual theory of causation

While the meso-geographic perspective is popular in geographical analysis, there are other ways to move beyond the law-causality nexus. Specifically, David Lewis' counterfactual theory of causation, has been used in two major analytical frameworks to provide a workable definition of "causality" that avoids the law-causality nexus and its generalizability/replicability successor terms altogether. Further, we argue that it may answer or avoid current critiques of the meso-geographic perspective, and thus can provide a useful general framework for understanding cause and effect in quantitative human geography. In this section, we give a brief theoretical introduction to the counterfactual theory of causality, methodological implications, and current applications.

The counterfactual theory of causation currently underpins two major causal inference frameworks, and is also compatible with wider approaches to causal modelling. At the core of this theory is the concept of 'possible worlds'. To illustrate this concept, we ask the reader to consider the many ways your life may have turned out differently, if not due to specific moments of luck or circumstance. This premise of an imagined present that emerges from a changed past is common in media (e.g. *It's a Wonderful Life*, mentioned by Phillips (2004)'s discussion of TFL), but it is also incredibly powerful when thinking about causality independent of law. Lewis defines "possible worlds" as a set of worlds that all share the same basic physical laws but have different things going on inside of them. Then, "causality" can be defined by the events that differentiate the worlds, the incidents and accidents that, were they to have not occurred, would push us from one possible world into another. In Lewis's words,

> "We think of a cause as something that makes a difference, and the difference it makes must be a difference from what would have happened without it. Had it been absent, its effects – some of them, at least, and usually all – would have been absent as well"
>
> (Lewis, 1973, p. 161).

Thus, counterfactual theory of causation defines causal dependence between a cause *C* and effect *E* as "*If C had not occurred, then E would not have occurred*." A "counterfactual" itself is simply a statement about something arising from non-factual conditions ("If the sun were blue, then grass would be red"), but counterfactual causality focuses on the existence (or removal) of the antecedent *C necessarily* giving rise to effect *E* ("If the price were higher, then they wouldn't buy it"). This is quite distinct from the law-causality nexus, which requires causal relationships to be repeatable over time and space. Indeed, a law's value is bound up in how strongly it holds *as is* within our one world. In contrast, a counterfactual perspective never directly observes causality at all. This is due to the "fundamental problem of causal inference" (Holland, 1986), we can only observe one of the many potential outcomes for a given set of events and conditions, and so cannot measure causal effects directly. Thus, the core concern for counterfactual causal inference frameworks, such as PO or SCM, is the estimation (or simulation) of these unrealised potential outcomes, rather than the process of finding regularities among realised outcomes themselves that is common in the hunt for causality-laws.

4 | COUNTERFACTUAL CAUSALITY IS PREFERABLE TO LAW-CAUSALITY

In light of past critiques of causality-laws and contemporary critiques of their successors, we believe that the counterfactual theory of causation provides a more stable ground in which to build effective causal inference techniques in geography. We see this as the case for three main reasons. First, a counterfactual definition of causality *resolves past critiques* of laws in spatial science. Second, it *connects geographers to useful methods* developed in contemporary statistics and computer science for analysing causal questions. Third, it *provides something for geography to do* in causal processes. We discuss each of these in turn.

To start, working with a counterfactual definition of causality places distance between "causality" and past theoretical tensions regarding laws in human geography. The counterfactual theory of causation offers an ontology of causality based on causal dependence. The dependence-based definition of causality does not rely on any preconception of causal "power" that requires us to define who produces/enforces causal relations. That is, counterfactual causality requires us to define mechanisms that give rise to events, but does not commit these mechanisms to a universal or "generalisable" context. Put differently by Jones (2010), this liberates causal inference to "[seek] not generalization, but specification: what works for whom in a set of circumstances, and what is preventing change?" (p. 23). It also unites geographical "context" with the many other kinds of social and individual contexts that mediate our causal relations (Merlo, 2018), returning context to notions of causality (Barnes, 2004). Therefore, counterfactual causality does not require us to entangle causality with law, creating space for practitioners to move spatial causal inference beyond law.

Second, adopting a counterfactual causation framework connects the practice of spatial causal inference to a broader set of methodological resources. Two robust and popular frameworks for causal inference, the PO approach and the SCM approach, are both based upon counterfactual causality, not law-seeking. Akbari et al. (2023) provide a systematic review of recent spatial causal inference work spanning these two methodological approaches. For the clearest view of how contemporary spatial analysis meshes with causal inference, Kolak and Anselin (2020) provide a comprehensive overview of the links between PO-based causal inference and geographical concepts such as spatial dependence and heterogeneity. Building upon this methodological common ground will enable geographers to contribute to common understandings of social processes while also contributing novel ways of representing and analysing these processes using geographical thinking and data.

Third, the topic of causal discovery, which has attracted major research investment from computer science and statistical causal modelling communities, would be more accessible to geographers if we were to adopt ideas of counterfactual causation. Causal discovery is the exploratory analysis of observational data to formulate a set of consistent hypotheses about structured cause and effect relationships (Spirtes & Zhang, 2016). Currently, causal discovery methods ignore statistical structures that commonly arise in spatial processes, such as spatial dependence and heterogeneity. The application of causal discovery methods to geographic data is a challenging yet potential fruitful research direction. In terms of the basic workhorse concepts and theorems, there is a significant overlap between what we normally refer to as 'causal inference' and 'causal discovery'. Simply put, causal discovery is automated model specification search for models in causal inference. Therefore, familiarity with key counterfactual causal inference frameworks is essential for geographers interested in applying/extending causal discovery techniques to large geographic datasets.

This leads us to our final point: geography can *do* more under a counterfactual causality than a law-based one. For meso-geographers, geographic scale is an emergent property of a causality-law, and methods for analysis allow us to "distinguish the scales of the various processes that operate on the landscape" (Goodchild & Li, 2021, p. 3). However, as Gibbons and Overman (2012) argue:

> A better approach to estimating parameters that represent spatial interactions or to deal with omitted variables in spatial contexts, is to precisely delineate the research question, and focus on the key parameter of interest
>
> (*ibid*, p. 180)

Counterfactual causal inference methods follow this advice by specifying scale and geographical interactions explicitly. As one of a few ways, mediation effects can induce spatial heterogeneity in a causal intervention, especially when the mediator variable is not distributed in the same way as the treatment. Second, as Kolak and Anselin (2020) discuss, treatment effects themselves may not be stable over space; as a consequence, the heterogeneity in the estimated treatment *effect* may simply reflect heterogeneity in how treatment was *applied*. Third, spatial interference between treated individuals can induce similarities between individual outcomes. Here, proximity and interaction structures the heterogeneity of treatment. Indeed, beyond these specific methods, *how context works* is a critical part of a counterfactual causal model (Jones, 2010) that, by definition, characterises what outcomes would be if the context were different.

5 | MOVING FORWARD WITH COUNTERFACTUAL CAUSATION IN HUMAN GEOGRAPHY

While counterfactual causality can provide a promising theoretical framework for causal inference in geography, there are still issues with its implementation in spatial analysis. Some of these issues are explicitly empirical, pertaining to the kinds and qualities of data geographers tend to access, while others are more theoretical, reflecting the theoretical commitments geographers must make in order to build upon counterfactual causation as a core concept for geographic analysis.

For geographers, Oshan et al. (2022) shows "scale" is a very complex concept, and the term is used in a large variety of ways. As a consequence, it is no surprise that scale emerges as the key concept in meso-geographic fixes for law-causality. However, even counterfactual causal inference methods are challenged by the "scale" of counterfactual explanations. For example, "It's one thing to say 'smoking causes cancer,' but another to say that my uncle Joe, who smoked a pack a day for 30 years, would have been alive if he had not smoked." (Pearl & Mackenzie, 2018, p. 260). Spatial analysts nearly always work at the level of specific, observed patterns in spatial data (i.e., they talk about "uncle Joe"), and we must work together on common geographical mechanisms in order to build upwards to larger conceptual scales of analysis. This *emphasises* replication as a principle—rather than accepting a "weak" replicability, we must rigorously work together to understand *where and why replicability fails.* Spatial analysts must get specific about what "scale" or "context" *does* in their analyses for counterfactual causality to be relevant (Petrovic et al., 2020). Put differently, "weak replicability" (Goodchild & Li, 2021) should instead be framed as "strong contextuality:" our specific explanations of why context counts should be sufficient to understand when a given causal mechanism might operate and when it might not.

Beyond the context of human geography, the counterfactual theory of causality itself is still an ongoing philosophical project with unresolved issues. For example, the causal semantics of counterfactual statements is still contested, especially in the differences between inferential and prediction tasks (Briggs, 2012; Fisher, 2017). Further, there is also debate about the differences that arise when intervening on a causal *variable value* versus intervening on causal *mechanism* (Lee, 2015, 2017). While some quantitative geographers "may feel ill equipped or just not inclined to enter the philosophical debate" (Flowerdew, 1998, p. 296), it is important for us to cultivate these practices within quantitative geography. For us to benefit from this richer contemporary discourse around causality, it is important to pay attention to and (when appropriate) participate in these philosophical and conceptual debates. It is likely that spatial analysis built upon counterfactual causality will need further theoretical development to help ground the different types of tasks that arise in practice.

6 | CONCLUSION

This review reflects on causal theories that are used in contemporary quantitative human geography. Historically, causal inference has been associated with the formulation of scientific explanations. Therefore, causality was often associated with positivist law-seeking science. This historical intellectual context has contributed to contemporary thinking about "local" laws in geography. As the paradigms of scientific explanation evolve, causality is increasingly freed from law-based terminology and concepts. As an alternative to the causality-law tradition in quantitative human geography, a counterfactual theory of causality opens up new possibilities for spatial causal inference. Using a counterfactual theory of causality, we can better understand geographic processes, our connection to other social scientific disciplines, and provide clearer theories and evidence for how geographical processes work. In this way, geography stands to benefit substantially from adopting the more flexible and intellectually fruitful notion of counterfactual causality.

ACKNOWLEDGEMENTS

Jing Zhang is funded by the UK ESRC Southwest Doctoral Training Partnership and the Allen Turing Institute.

ORCID

Jing Zhang https://orcid.org/0009-0009-0679-7173
Levi John Wolf https://orcid.org/0000-0003-0274-599X

ENDNOTES

[1] In Neil Smith's words (1979, p. 364, paragraph 2) "'objectivity', the fact-value dichotomy, and a cause-effect view of reality" are "the most firmly held tenets of positivism".

[2] For instance, an empiricist interpretation would define "law" and "causality" both in terms of experienced regularities, while a "realist" interpretation might see "law" as the enforcer of a "causal" relationship. For contemporary literature with origins in the Regularity Theory, see for example, works of Stuart Glennan (2010).

[3] Regularity theory was not the only view on "law" in the 20th century, as we will shortly discuss. However, it *was* the version of law that is most prevalent in the quantitative spatial science of the mid-20th century.

[4] The "law of distance decay" present in these models has context-dependent mechanisms, too—even though it was one of the most hotly-contested regularity laws in 20th century geography (Oshan, 2021).

[5] In Tobler's urban growth model, a causal interpretation can be established as "population growth in a grid cell is caused by population growth in nearby cells," although this is not directly stated by the author or the work he cited.

[6] Also see Mäki and Oinas (2004) on the frictions between human geography and realism.

[7] As examples of this kind of approach, see the efforts to define a 'critical realist' (Jones, 2010) or a 'strategic positivist' (Wyly, 2009) mode of inquiry.

[8] Note that the idea that geographic research might exhibit "weak replicability" is distinct from the desire for reproducible geographic research (Kedron et al., 2021), such that a result can be generated again using the documented procedures, code, data, and analysis.

REFERENCES

Akbari, K., Winter, S., & Tomko, M. (2023). Spatial causality: A systematic review on spatial causal inference. *Geographical Analysis*, *55*(1), 56–89. https://doi.org/10.1111/gean.12312

AlessandrettiSapiezynski, L. P., Sapiezynski, P., Sekara, V., Lehmann, S., & Baronchelli, A. (2018). Evidence for a conserved quantity in human mobility. *Nature Human Behaviour*, *2*(7), 485–491. https://doi.org/10.1038/s41562-018-0364-x

Anselin, L. (1989). What is special about spatial data? Alternative perspectives on spatial data analysis. *NCG Technical Report*, 89–94.

Armstrong, D. M. (2016). *What is a law of nature?* Cambridge University Press.

Barnes, T. (2004). A paper related to everything but more related to local things. *Annals of the Association of American Geographers*, *94*(2), 278–283. https://doi.org/10.1111/j.1467-8306.2004.09402004.x

Barnes, T., & Wilson, M. W. (2014). Big data, social physics, and spatial analysis: The early years. *Big Data & Society*, *1*(1), 1–14. https://doi.org/10.1177/2053951714535365

Briggs, R. (2012). Interventionist counterfactuals. *Philosophical Studies*, *160*(1), 139–166. https://doi.org/10.1007/s11098-012-9908-5

Comber, S., & Arribas-Bel, D. (2017). Waiting on the train: The anticipatory (causal) effects of crossrail in ealing. *Journal of Transport Geography*, *64*, 13–22. https://doi.org/10.1016/j.jtrangeo.2017.08.004

Credit, K., & Lehnert, M. (2023). A structured comparison of causal machine learning methods to assess heterogeneous treatment effects in spatial data. *Journal of Geographical Systems*, 1–28. https://doi.org/10.1007/s10109-023-00413-0

Fisher, T. (2017). Causal counterfactuals are not interventionist counterfactuals. *Synthese*, *194*(12), 4935–4957. https://doi.org/10.1007/s11229-016-1183-0

Flowerdew, R. (1998). Reacting to ground truth. *Environment and Planning*, *A*, *30*(2), 289–301. https://doi.org/10.1068/a300289

Fotheringham, A. S., & Brunsdon, C. (1999). Local forms of spatial analysis. *Geographical Analysis*, *31*(4), 340–358. https://doi.org/10.1111/j.1538-4632.1999.tb00989.x

Gibbons, S., & Overman, H. G. (2012). Mostly pointless spatial econometrics? *Journal of Regional Science*, *52*(2), 172–191. https://doi.org/10.1111/j.1467-9787.2012.00760.x

Giffin, A., Reich, B. J., Yang, S., & Rappold, A. G. (2022). Generalized propensity score approach to causal inference with spatial interference. *Biometrics*, *79*(3), 1–12. https://doi.org/10.1111/biom.13745

Glennan, S. (2010). Mechanisms, causes, and the layered model of the world. *Philosophy and Phenomenological Research*, *81*(2), 362–381. https://doi.org/10.1111/j.1933-1592.2010.00375.x

Goodchild, M. F. (2004). The validity and usefulness of laws in geographic information science and geography. *Annals of the Association of American Geographers*, *94*(2), 300–303. https://doi.org/10.1111/j.1467-8306.2004.09402008.x

Goodchild, M. F., & Li, W. (2021). Replication across space and time must be weak in the social and environmental sciences. *Proceedings of the National Academy of Sciences*, *118*(35), e2015759118. https://doi.org/10.1073/pnas.2015759118

Harvey, D. (1969). *Explanation in geography*. Edward Arnold.

Heckman, J. (2005). The scientific model of causality. *Sociological Methodology*, *35*(1), 1–97. https://doi.org/10.1111/j.0081-1750.2005.00164.x

Holland, P. (1986). Statistics and causal inference. *Journal of the American Statistical Association*, *81*(396), 945–960. https://doi.org/10.2307/2289064

Hume, D. (1751). *Philosophical essays concerning human understanding*. M. Cooper.

Isard, W. (1956). *Location and space economy*. MIT Press.

Johansen, M. (2021). Taking stock of regularity theories of causation. *Philosophy Compass*, *16*(5), e12735. https://doi.org/10.1111/phc3.12735

Johnston, R. J. (1986). *On human geography*. Basil Blackwell.

Jones, E. (1956). Cause and effect in human geography. *Annals of the Association of American Geographers*, *46*(4), 369–377. https://doi.org/10.1111/j.1467-8306.1956.tb01515.x

Jones, K. (2010). The practice of quantitative methods. In B. Somekh & C. Lewin (Eds.), *Research methods in the social sciences*. Sage.

Kedron, P., Frazier, A. E., Trgovac, A. B., Nelson, T., & Fotheringham, A. S. (2021). Reproducibility and replicability in geographical analysis. *Geographical Analysis*, *53*(1), 135–147. https://doi.org/10.1111/gean.12221

King, G. (1996). Why context should not count. *Political Geography*, *15*(2), 159–164. https://doi.org/10.1016/0962-6298(95)00079-8

Kolak, M., & Anselin, L. (2020). A spatial perspective on the econometrics of program evaluation. *International Regional Science Review*, *43*(1–2), 128–153. https://doi.org/10.1177/0160017619869781

Lee, K. Y. (2015). Causal models and the ambiguity of counterfactuals. In *Logic, rationality, and interaction: 5th international workshop, LORI 2015, Taipei, Taiwan, October 28-30, 2015. Proceedings* (Vol. 5).

Lee, K. Y. (2017). Hiddleston's causal modeling semantics and the distinction between forward-tracking and backtracking counterfactuals. *Studia Logica*, *10*(1), 79–94.

Lewis, D. (1973). Causation. *The Journal of Philosophy*, *70*(17), 556–567. https://doi.org/10.2307/2025310

Mäki, U., & Oinas, P. (2004). The narrow notion of realism in human geography. *Environment and Planning A*, *36*(10), 1755–1776. https://doi.org/10.1068/a36306

Merlo, J. (2018). Multilevel analysis of individual heterogeneity and discriminatory accuracy (MAIHDA) within an intersectional framework. *Social Science & Medicine*, *203*, 74–80. https://doi.org/10.1016/j.socscimed.2017.12.026

Miller, H. J. (2004). Tobler's first law and spatial analysis. *Annals of the Association of American Geographers*, *94*(2), 284–289. https://doi.org/10.1111/j.1467-8306.2004.09402005.x

Miller, H. J. (2018). Geographic information science II: Mesogeography: Social physics, GIScience and the quest for geographic knowledge. *Progress in Human Geography*, *42*(4), 600–609. https://doi.org/10.1177/0309132517712154

Olsson, G. (1970). Explanation, prediction, and meaning variance: An assessment of distance interaction models. *Economic Geography*, *46*, 223–233. https://doi.org/10.2307/143140

Oshan, T. M. (2021). The spatial structure debate in spatial interaction modeling: 50 years on. *Progress in Human Geography*, *45*(5), 925–950. https://doi.org/10.1177/0309132520968134

Oshan, T. M., Wolf, L. J., Sachdeva, M., Bardin, S., & Fotheringham, A. S. (2022). A scoping review on the multiplicity of scale in spatial analysis. *Journal of Geographical Systems*, *24*(3), 293–324. https://doi.org/10.1007/s10109-022-00384-8

Pearl, J. (2000). *Models, reasoning and inference*. Cambridge University Press.

Pearl, J., & Mackenzie, D. (2018). *The book of why*. Penguin.

Petrovic, A., Manely, D., & van Ham, M. (2020). Freedom from the tyranny of the neighborhood: Rethinking sociospatial context effects. *Progress in Human Geography*, *44*(6), 1103–1123. https://doi.org/10.1177/0309132519868767

Phillips, J. D. (2004). Doing justice to the law. *Annals of the Association of American Geographers*, *94*(2), 290–293. https://doi.org/10.1111/j.1467-8306.2004.09402006.x

Reich, B. J., Yang, S., Guan, Y., Giffin, A. B., Miller, M. J., & Rappold, A. (2021). A review of spatial causal inference methods for environmental and epidemiological applications. *International Statistical Review*, *89*(3), 605–634. https://doi.org/10.1111/insr.12452

Reilly, W. J. (1931). *The law of retail gravitation*. Pilsbury.

Rubin, D. B. (1974). Estimating causal effects of treatments in randomized and nonrandomized studies. *Journal of Educational Psychology*, *66*(5), 688–701. https://doi.org/10.1037/h0037350

Smith, J. (2004). Unlawful relations and verbal inflation. *Annals of the Association of American Geographers*, *94*(2), 294–299. https://doi.org/10.1111/j.1467-8306.2004.09402007.x

Smith, N. (1979). Geography, science and post-positivist modes of explanation. *Progress in Human Geography*, *3*(3), 356–383. https://doi.org/10.1177/030913257900300302

Spirtes, P., & Zhang, K. (2016). Causal discovery and inference: Concepts and recent methodological advances. *Applied Informatics*, *3*(1), 1–28. https://doi.org/10.1186/s40535-016-0018-x

Sui, D. Z. (2004). Tobler's first law of geography: A big idea for a small world? *Annals of the Association of American Geographers*, *94*(2), 269–277. https://doi.org/10.1111/j.1467-8306.2004.09402003.x

Tobler, W. (2004). On the first law of geography: A reply. *Annals of the Association of American Geographers*, *94*(2), 304–310. https://doi.org/10.1111/j.1467-8306.2004.09402009.x

Tobler, W. R. (1970). A computer movie simulating urban growth in the Detroit region. *Economic Geography*, *46*(sup1), 234–240. https://doi.org/10.2307/143141

Verbitsky-Savitz, N., & Raudenbush, S. (2012). Causal inference under inference in spatial settings: A case study evaluating community policing program in chicago. *Epidemiologic Methods*, *1*(1), 106–130. https://doi.org/10.1515/2161-962x.1020

Wyly, E. (2009). Strategic positivism. *The Professional Geographer*, *61*(3), 310–322. https://doi.org/10.1080/00330120902931952

Zhang, W., & Ning, K. (2023). Spatiotemporal heterogeneities in the causal effects of mobility intervention policies during the COVID-19 outbreak: A spatially-interrupted time series (SITS) analysis. *Annals of the Association of American Geographers*, *113*(5), 1112–1134. https://doi.org/10.1080/24694452.2022.2161986

AUTHOR BIOGRAPHIES

Jing Zhang is a PhD candidate in Geographic Data Science at the School of Geographical Sciences, University of Bristol. Jing's PhD project centres around causal modelling and spatial analysis. For methodological work, Jing's current focus is computational causal models. The goal is to develop computational statistical approaches to causal inference with spatial data. The idea is to bring in alternative techniques where canonical causal inference models are insufficient in quantitatively describing causal relations with underlying spatial structures. For empirical work, Jing works on policy sensitive topics in political and economic geography, drawing critical reflections from her practice in the real estate sector.

Dr. Levi John Wolf is an Associate Professor in Quantitative Human Geography at the University of Bristol's Quantitative Spatial Science Lab, Fellow at the University of Chicago Center for Spatial Data Science, Editor for Environment and Planning B: Urban Analytics & City Science, and Fellow at the Alan Turing Institute. He works in spatial data science, building new methods and software to learn new things about social and natural processes. He has worked on problems about redistricting, elections (psephology), segregation, inequality, and urban systems.

How to cite this article: Zhang, J., & Wolf, L. J. (2024). Rethinking 'causality' in quantitative human geography. *Geography Compass*, e12743. https://doi.org/10.1111/gec3.12743