



An instrumentalist approach to causation: The case of landslide research

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Abstract

Landslide risk offers a particularly interesting field of study for philosophers of science working on causation. Landslides are the result of complex causal dynamics, and the object of study of a variety of disciplines which are ultimately aimed at effective risk mitigation. For these reasons, causation is central to many instruments developed to study landslides. We illustrate four such instruments, and we show how each of them assumes a different concept of causation. This observation provides the ground for the defence of a pluralist account of conceptual causation. However, in defending this position we do not aim at establishing a universally correct account of causation. Instead, we examine the adequacy of different concepts for a specific purpose and in a specific context. We therefore supplement the descriptive observation of the plurality of concepts of causation involved in landslide research with the normative claim that this plurality cannot be reduced under a monist account, because the different concepts are necessary for different epistemic purposes. While our conclusions only hold for the specific case we analyse, the instrumentalist approach we propose can be generalised to other contexts and to other concepts.

Keywords Causation · Natural risks · Instrumentalism · Multi-disciplinarity · Conceptual pluralism · Adequacy for purpose

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1 Introduction

In the beginning of May 1998, the area around the town of Sarno, in the Italian region of Campania, was hit by an exceptional level of rainfalls, which disrupted the hydrogeological balance of the valley. Between the 5th and the 6th of that month, a series of 140 landslides hit Sarno and its neighbouring towns, with disastrous consequences: hundreds of buildings were severely damaged or collapsed, and 160 people died in the event.¹ To this date, the Sarno landslides series is the most severe hydrogeological disaster to hit the Italian peninsula in the last 40 years.

Landslides are an increasingly relevant phenomenon: in the past 50 years, the frequency of landslide disasters worldwide has become ten times higher due to climate change and rapid urbanisation (Ozturk et al., 2022). This trend is set to continue, given that climate change will affect the stability of slopes by impacting on various hydrogeological balances (Picarelli et al., 2021; Jakob, 2022).

Landslides are a natural risk, but although risk is a philosophically very dense notion which includes both epistemological and ethical dimensions, the philosophical literature on risk in general and on natural risks in particular is still relatively scarce (e.g. Hansson, 2004; Ebert, 2019; Roussos et al., 2021; Zanetti et al., 2023). Thus, focusing on landslides can contribute not only to putting some attention to an area largely neglected by philosophy of science, but also to the development of broader reflections on natural risk.

An important aspect of research on risk is that, given the possibility of negative consequences that the notion of risk carries (SRA, 2017), the ultimate focus is on risk mitigation. This requires studying the causal relations involved in the generation of hazardous events, as understanding causal dynamics is necessary for the implementation of effective risk management. As a complex phenomenon involving peculiar dynamics and human-nature interactions, landslides are studied from several perspectives to explain, predict, and guide risk management decisions. For this reason, analysing the assumptions entrenched in this type of research can provide interesting insights that may go beyond philosophy, as it is important that risk disciplines be able to share basic assumptions to engage in meaningful dialogue (Aven & Zio, 2014).

In this work, we focus on research on landslide risk as a particularly interesting field of study for philosophers of science working on causation. Landslides are a very complex phenomenon in terms of their causal dynamics, which involves geological, meteorological, hydraulic, and social aspects, among others. The causal complexity of landslides and the relevance of causation for risk management have led to a proliferation of instruments² to describe the causal dimension of the phenomenon, which is amplified by the multi-disciplinary nature of research on landslides. They thus provide an ideal case to develop an account of causation for multi-disciplinary research, and it is on this plurality of approaches that we focus our analysis.

¹ <https://servizio-nazionale.protezionecivile.gov.it/it/pagina-base/lalluvione-di-sarno-e-quindici/> (accessed 21/10/2025).

² Throughout this text, we will use the term *instruments* to refer to a series of methodological tools, ranging from maps to algorithms. We use this term instead of the more philosophically charged notion of *models*, as nothing in our discussion hinges on whether these instruments should be understood as models.

In this paper, we claim that instruments trying to capture different aspects of the causal dimension of landslides assume different concepts of causation. Their coexistence supports a pluralist view of causation; but while this perspective can accommodate several accounts of causation, it does not imply that anything goes. Thus, we supplement the descriptive claim that there is causal pluralism in the practice of scientists working on landslides with a normative claim that, borrowing from the literature on models (Parker, 2010, 2020), evaluates the adequacy of the concepts employed for the purposes for which they are used. This perspective falls within an instrumental approach to the philosophy of causation, which focuses not on which concept(s) of causation is (are) the correct one(s), but rather on how they relate with specific purposes and contexts.

To do that, the paper is structured as follows. In Section 2, we present four different causal instruments in the study of landslides. In Section 3, we argue that each of them assumes a different concept of causation. In Section 4, we explore the implications of this plurality for the philosophy of causation. In Section 5, we present our instrumental approach and how it uses the notion of adequacy-for-purposes to evaluate concepts. In Section 6, we apply the approach to the instruments discussed, and we argue that the plurality of causal concept they present is necessary for a complete understanding of landslide risk. In Section 7, we conclude by abstracting from this approach to broader debates and suggesting connections with further research. The methodology of observing scientific practice, identifying the concepts presupposed, and then arguing that the plurality that comes out is adequate for some purpose does not allow us to infer conceptual pluralism for all science. But while the conclusions we draw can only be specific to the research area we address, the instrumental approach we propose is general.

2 Representing the causes of landslides

Landslides are a natural hazard that may have large impacts on human lives, settlements, and landscapes. They involve the “downslope movement of soil, rock, and organic materials under the effects of gravity” (Highland & Bobrowsky, 2008, p. 4), and are typically classified according to characteristics of the event like type of movement (e.g. a flows, slides, or falls), type of materials (e.g. rocks, debris, or earth soil), movement kinematic, and geometry of the slope (Varnes, 1978). The variety of factors interacting in the generation of landslides is such that classifications can vary not only in terms of the types of landslides they propose, but also in terms of the best way to interpret specific events. The 1998 Sarno landslides, for instance, have attracted large attention from the scientific community, with the wealth of analyses available showing high degrees of disagreements on how to understand the event (Guadagno et al., 2011).

The centrality of causal knowledge in landslide research, the complexity of aspects participating to the occurrence of landslides, and the multi-disciplinary nature of the field, which involves contributions from geology, geotechnics, hydraulics, structural engineering, urban studies, and forestry – to name a few, have led to the development of several methodological instruments that provide some piece of causal informa-

tion. With no pretences of completeness, we illustrate here four of these methods, the causal nature of which will be explored in the next section.

Landslides are a geophysical phenomenon that concerns areas displaying specific geological, hydrological, climatic, and environmental features. Consequently, the assessment of landslide hazard often employs *susceptibility maps*, which express the likelihood of the occurrence of landslides in a region given some geo-environmental conditions (Rossi et al., 2010). These maps relate hazard occurrence with the presence of factors that make that occurrence more likely: Foumelis et al. (2004), for instance, estimate susceptibility in their area of interest using factors like geological constitution, land cover, slope gradient and curvature, thickness of soil, and presence of close seismic faults. These have a geographic distribution and are stable characteristics of a specific area, so the degree to which slopes are susceptible to slide can be represented on a map. Susceptibility maps thus provide important causal information, as they track factors that contribute to the occurrence of a landslide. A susceptibility map will tell us that a slope has a certain likelihood to slide, in virtue of it displaying some stable characteristics that play a causal role in the phenomenon.

Susceptibility maps have been used to represent the risk of landslides in the Sarno area as well. De Riso et al. (2008) develop a map that represents the predisposition of slopes in the Sarno river basin to slide in a quick mudflow, in correlation with their geological and geomorphological features. The features they considered include slope gradient, thickness of pyroclastic deposits, presence of trails and/or roads in the middle-upper sector of the slopes, kart springs, traces of previous landslides, and rock formations. These features are correlated with the “predisposition to slope instability” and determine the “potential instability” of a slope (p. 6).³ They were selected on the basis of the existing literature and the personal experience of the authors, and then assigned a weight according to their statistical relevance in an inventory of 187 historical quick mudflows.

The procedure followed by De Riso et al. (2008) in the construction of a susceptibility map shows that there are two main ways to identify the factors that may affect landslide susceptibility: expert judgement, i.e. plausibility according to current scientific knowledge, and quantitative methods which observe statistical correlations. The development of *machine learning models* has provided a new set of tools for the study of landslides, and nowadays expert judgements are increasingly supported by the analysis of big data (Merghadi et al., 2020). Models like random forest, decision trees, and artificial neural networks are applied to data coming from inventories of historical landslides.⁴ This information is organized in Geographic Information System (GIS) format, which maps it in a spatial form, so that it can include the geo-environmental characteristics of the areas involved in previous landslides. Through machine learning, the algorithms identify the factors responsible for the landslides included in the inventory they were fed. The more similar an area is to areas hit by landslides in the past in terms of the factors selected by the algorithms, the more likely it is to experience landslides in the future.

³Originally “predisposizione al dissesto dei versanti” and “franosità potenziale” (our translation).

⁴See Merghadi et al. (2020) for an overview of these methods and of their applications to landslide research.

Susceptibility maps study the causal nexus of landslides at the large area scale, i.e. at the scale of the broader geographical region. However, causal research can be conducted also at the scale of the individual slope, in order to describe the factors at play in that specific context and predict the characteristics of the slide that could originate were that particular slope to fail.

An important instrument to investigate the slope scale is provided by *computational models*, which are now routinely used for several applications in geotechnical engineering (Augarde et al., 2021). These try to model what would happen given a specific parameterization of all the factors involved, both predisposing and forcing, so assuming a specific way in which the slide accelerates. Computational models describe how the components of the slope and the external factors interact, thus generating a landslide with given characteristics. These instruments can adopt a continuum or a discontinuum approach, where the first represents geomaterials as a continuous material (e.g. finite element method) and the second discretizes them into particles that interact dynamically (e.g. discrete element method). The behaviour of these materials to different events and under different conditions is then calculated with physics-based equations.

D'Ambrosio et al. (2002), for instance, construct a computational model to simulate the debris flow in one of the landslides involved in the Sarno 1998 event. To do that, they divided the relevant area in regular cells of identical shape. Each cell has attributes, like altitude or water content of the sliding mass, which are considered to be “essential for the rheologic description of the phenomenon” (p. 1578). Once the simulation is initiated, the state of these attributes is determined by the state of the neighbouring cells, according to rules that describe the relative process for each attribute. The evolution in the states of the cells simulates the evolution in the actual slide. The principle of this methodology is that of simulating complex phenomena “in terms of local interactions among the elementary portions in which the phenomenon can be, conceptually, subdivided” (p. 1577).

The causal dimension of landslides is not limited to the factors behind their occurrence. Landslides are often involved in cascades of chain events, usually involving other hazards: events changing the slope balance may include earthquakes, floods, fires, and droughts, and landslides themselves can add to the cumulative impacts of these hazards. For this reason, the effective assessment and management of landslide risk require adequate consideration of all the relevant risks affecting the area – i.e., they require a multi-risk approach.

Multi-risk research studies the relations between different risks threatening the same geographical area. In multi-risk contexts, the occurrence of a certain hazardous event may initiate cascading effects involving other hazards, leading to cumulative impacts that may be higher than the sum of those due to each individual hazard (Ross, 2022): the Irpinia earthquake in Italy (1980), for instance, caused the reactivation of several landslides, which damaged towns that had already been hit by the shock (Martino & Mugnozza, 2005). Note that the cumulative impacts are due not only to the causal relation between hazards. What is relevant to understand multi-risk is not only that a certain event can trigger another event, but also that the event can alter the vulnerabilities and the exposures to other risks. After an earthquake, building foundations may be damaged and made more vulnerable to subsequent events

like aftershocks, floods, or landslides. There may have been evacuations, which have changed the amount of people and resources exposed to other risks in the area. Risk management must take into account these connections, as interventions aimed at the mitigation of some risk may contribute to the mitigation of other risks – or, instead, exacerbate them, requiring difficult trade-offs. To illustrate, while wooden structures are less vulnerable than masonry to seismic risk, they are more prone to fire damages, with potentially disastrous consequences.

One way to model the relations between risks is with *Bayesian networks*. Marzocchi et al. (2012) and Liu et al. (2015), for instance, propose networks where the nodes correspond to the various relevant hazards and vulnerabilities, with directed links that represent the conditional dependencies of these variables: e.g. changing the value of one hazard can lead to a change in the value of the vulnerability to another hazard. More precisely, Bayesian networks are models that represent a set of variables and their conditional dependencies with a directed acyclic graph (Sperotto et al., 2017). These variables include probabilities, which are passed to all descendant nodes.⁵

Tierz et al. (2017) propose a Bayesian network to model risk of lahar events in the Vesuvian area, including the Sarno valley. Lahars are a violent flow of mud, pyroclastic materials and water, which may be very deep and move rapidly. They are one of the hazards related to volcanic eruptions, although they do not need an eruption to occur (Vallance & Iverson, 2015). The Bayesian network developed by Tierz et al. (2017) is a model of the volume of material that is mobilized at the initiation of the lahar as a consequence of pyroclastic volume and rainfall intensity. A feature of Bayesian networks like the one they present is their manipulability: once a specific node state is observed, then the probabilistic values of the child nodes can be modified with a Bayesian update; alternatively, it is possible to calculate the likelihood of observing a specific combination of node values (p. 18).

3 Accounts of causation in landslide research

The instruments that we have discussed in the previous section are somewhat illustrative of the methodological variety that exists in landslide research. At the large scale, susceptibility maps represent the geographical distribution of landslide hazard based on the observation of some geo-environmental conditions, while at a narrower scale, landslides are addressed with computational models, which describe the functioning of a specific slope. In their interactions with other risks and in their causal chain, landslides can be modelled with Bayesian graphs. And more recently, large inventories of past landslides can be studied with machine learning tools, thus further increasing the methodological richness of the field. Each of these instruments provides information that can be more or less directly causal, and as such they imply some understanding of what causation is. In this section, we argue that the concepts of causation underlying the instruments presented are all different.

⁵ But note that in multi-risk management variables go beyond probabilities, as they include the values of vulnerabilities, exposures, and hazard magnitude, as well as their probabilities.

Let us start with susceptibility maps. As we have seen, factors that determine landslides susceptibility are stable characteristics of the area. These are factors that make the area susceptible to landslides, but by themselves they do not initiate the slope movement. In principle, it is possible that highly susceptible areas never experience landslides, if nothing ever intervenes to change the balance. The notion of susceptibility thus rests on a distinction of the causal factors behind landslides in two categories. *Predisposing* factors are those that make an area prone to the phenomenon, like the presence of water tables, fragility of the geological material, or the slope geometry and structure (McColl, 2022). These are the factors that identify an area as susceptible to landslides, and make a slope slide given the right conditions. These conditions are the *forcing* (or *triggering*) factors, i.e. factors like seismic shocks, intense rainfalls, or human interventions that alter the balance of the slope triggering an acceleration of the slide, thus initiating the movement (Crozier, 1986).

Susceptibility maps are causal instruments because they are used to represent landslide hazard based on some causal factors behind the occurrence of the phenomenon. These causal factors are features that predispose a certain area to experience slope movements: the area has the *disposition* to landslides. In the philosophical literature, dispositions are properties of things or systems that produce certain effects under some conditions, but that can also remain unmanifested if those conditions do not obtain (Illari & Russo, 2014). According to dispositional accounts of causation, effects are manifestations of one or many dispositions, that are triggered by events or properties that create the necessary conditions (e.g. Bird, 2007; Mumford & Anjum, 2011). For example, a glass breaks because it has the dispositional property of fragility, which is triggered by impacting on the floor – but it would not be any less fragile if it never hit the ground. Two of the characterizing features of dispositional accounts are a distinction between dispositional properties and triggering factors to generate an effect, and the possibility that dispositions stay unmanifested. Similarly, susceptibility maps rely on a distinction between predisposing and triggering factors, where the first ones are those that “*predispose* slopes to failure” (McColl, 2022; italics added). But these ones are insufficient in themselves to generate a slope movement, to the extent that susceptibility does not imply the occurrence of landslides. Susceptibility maps therefore assume a dispositional account of causation: indeed, susceptibility itself is described with dispositional language, as “the *propensity* of an area to generate landslides” (Guzzetti et al., 2006; italics added).

The identification of the predisposing factors represented on a susceptibility map is facilitated by the use of machine learning models. The assumption behind this procedure is that “the past is the key to the future” (Guzzetti et al., 2006; Merghadi et al., 2020), meaning that future events will happen under the same conditions that generated similar events in the past, so that, if we can identify the conditions responsible for those past events, then we will be able to predict future events on the basis of the presence of those conditions. Thus, this procedure is clearly inductive in nature: it generalizes to future events characteristics observed in past events. More specifically, it follows a *variational* type of induction, which relies on evidence that “tracks changes in a phenomenon resulting from systematic variations of circumstances” (Pietsch, 2021: p. 29). Machine learning models collect data from databases of past landslides, which have occurred under varying conditions, and by

detecting the systematic variations in the events they identify the conditions playing some causal role in their determination. The causal information that machine learning provides is the (systematic) observation of correlations between combinations of factors and landslide occurrence: machine learning identifies “the association between landslide occurrences and landslide causative predictors without the requirement for an assumed structural model” (Merghadi et al., 2020: p. 6).

What machine learning helps us understand is that landslides can have different causal histories: there are no conditions that are both necessary and sufficient for a slope to fail. A specific condition can be causally relevant for the occurrence of a landslide on one occasion, but be absent in other cases; or there may be circumstances in which that condition is present, but no landslide results. Observing the systematic variations of circumstances for the occurrence of landslides permits the identification of the predisposing factors of a landslide as INUS conditions, i.e. as Insufficient but Non-redundant components of an Unnecessary but Sufficient set of conditions (Mackie, 1974).⁶ In a classic example, the fact that the TV is left on is insufficient on its own to cause a fire, but it becomes a cause of the house burning as part of a set of conditions (the TV is on, its cable is damaged, there is a gas leak...) that is sufficient to start the fire but not necessary, as other sets of conditions could have caused it. Similarly, by looking at databases of past cases, the algorithms identify that, e.g., the predominance of vegetation with shallow roots played a causal role in some events when conjunct with, e.g., heavy rainfalls and steep slopes, but not when other circumstances were present.

Computational models, on the other hand, generate the characteristics of the landslide that results from the interactions of several factors at different scales. In doing that, they describe the mechanism that brings about that landslide. According to mechanist perspectives, causal relations are distinct from spurious correlations because they can be explained by a mechanism (Illari & Russo, 2014). There are several mechanistic accounts of causation, which understand mechanisms in ways that can be significantly different (e.g. Machamer et al., 2000; Glennan, 2002; Woodward, 2003; Bechtel & Abrahamsen, 2005). Nonetheless, the various notions of mechanism share a common scaffolding, the central elements of which are parts, or entities, that interact or engage in activities in an organized way giving rise to a certain phenomenon (the effect) (Illari & Williamson, 2012).⁷ For example, the heart pumps blood because it is composed of parts (ventricles, valves, aortas) that expand and contract in a specific spatial and temporal arrangement (Bechtel & Abrahamsen, 2005). Similarly, computational models for landslides describe how the interactions between different factors with a specific spatial and temporal organization bring about a landslide phenomenon with given features.

Indeed, the language used to talk about these methods is often mechanistic in nature. Augarde et al., for instance, identify the role of discrete element method in the

⁶More recent theories of causation based on regularity that share the same intuitions as Mackie’s include, e.g., Strevens (2007), Wright (2011), Baumgartner (2013).

⁷This “minimal mechanism” definition (Craver et al., 2024) does not include mentions to regularities or correlations between variables, as included e.g. in Woodward’s (2003) account. This is appropriate for computational models, which do not try to describe a *general* mechanism for landslides, but rather the concrete mechanism for a *specific* landslide.

future as one of “improving understanding of the link between the real particle scale and macro observed behaviour” (2021: p. 1729). On the same notes, Ghirelli et al. contend that computational methods can be used to test the “(i)dentification and interpretation of the mechanism and factors controlling the behaviour and the evolution of the landslide”, and as such they are “an important tool to support and substantiate hypotheses and geological interpretations of the mechanisms and factors influencing the behaviour of landslides” (2023: p. 01). Discontinuum methods represent the geomaterials themselves as mechanisms, given that they are modelled as a collection of particles that “interact through their contacts with other particles and boundaries” (Urmi et al., 2023: p. 16).

Finally, Bayesian networks model the dependencies between different events. The causal information contained in this sort of networks is twofold. First, Bayesian networks show that one node X causally depends on another node Y by showing that, given Y, X is conditionally independent from its non-descendant nodes (plus some necessary assumptions, see Hitchcock, 2021), thus implying a notion of causation as probabilistic dependence, i.e. focusing on the idea that causes (tend to) raise the probability of their effects (see Fitelson & Hitchcock, 2011 for a review of some accounts of probabilistic causation). Second, the interactions modelled in Bayesian networks are manipulable: we can observe how the value of some variable changes by changing the value of its parent nodes. This allows us to explore the effects of a potential measure of risk management: “The effect of measures can be examined by assigning a fixed distribution to the input variable of interests (i.e. those directly affected by the interventions) and to determine how probabilities distribution of the output variables change in response” (Sperotto et al., 2017: 328). Manipulationist accounts of causation contend that for C to cause some effect E means that, if one changed C, then E would also change (Woodward, 2003). Note that both probabilistic and manipulationist views of causation are fundamentally based on difference-making (Illari & Russo, 2014), i.e. they see causes not as something that produces an effect (as is the case for mechanisms), but as something that makes a difference to the obtaining of that effect. Indeed, Bayesian networks do not explain *how* a certain effect is produced, but only that it depends on some cause.

4 Implications for the philosophy of causation

Causation is one of those foundational topics in philosophy which enjoy a long history and are still central to many debates. Throughout this history, philosophical accounts of causation have tried to answer the question of what causation is, i.e. of what it is for something to cause something else. Answers have been very varied, and the discussion is still open and lively (see e.g. Ingthorsson, 2021; Papineau, 2022; Kim, 2023 for recent contributions). But this question has not only received several different answers – it is also open to different interpretations. In the literature there are two main ways to interpret the question of causation (see e.g. Godfrey-Smith, 2010; De Vreese, 2010), although these are not the only philosophically interesting questions that can be asked about causation (Illari & Russo, 2014; Russo & Illari, 2025). On one hand, there is the metaphysical question, answers to which try to

provide a picture of what causal relations are in the world; on the other hand, there is the conceptual question, which asks what we intend when we say that something is a cause, i.e. it tries to describe the concepts we use to distinguish between causal and non-causal relations.

Both the metaphysical and the conceptual questions are interesting for philosophy of science. The metaphysical question provides philosophical contributions to the scientific endeavour of understanding the nature and structure of reality by trying to describe a specific aspect of it, namely causal relations. The conceptual question analyses causal discourse, which is central to most scientific practice, and thus provides an important key to understanding science. This is the question we focus on here: the richness in the causal instruments available to address landslides mirrors a plurality of ways to understand the concept of causation. We will therefore bracket metaphysical questions about the nature and structure of causation.⁸

Answers to both questions have often attempted to present “The One Theory” (Russo & Illari, 2025) of causation, i.e. a universal theory that would provide necessary and sufficient conditions for relations to be causal (e.g. Glennan, 1996, Dowe, 2000, Strevens, 2013, Mumford & Anjum, 2011) or to identify relations as causal (e.g. Godfrey-Smith, 2010; Pearl, 2009). Monist accounts like these understand either metaphysical or conceptual causation as ultimately reducible to one thing. However, while monism respects the *prima facie* idea that causation is a single thing, at least for the moment all these attempts have been met with counterexamples to both their necessity and sufficiency (Maziarz, 2025; Reiss, 2009). For this reason, some authors have developed pluralist accounts of either metaphysical or conceptual causation (e.g. Anscombe, 1971; Cartwright, 2004; Godfrey-Smith, 2010; Hall, 2004; Kim, 1984; Psillos, 2010), proposing analyses of causation that embrace the complexity of our intuitions and rely on a plurality of irreducible relations or concepts.

We support a pluralist account of conceptual causation, at least for the field of landslide research. In the previous section we have seen how different methodological instruments that are used in landslide research to provide information about the causes of landslides rest on different assumptions about what causation means. Scientific practice in this field seems to refute conceptual monism: at least as far as landslides are concerned, there is a plurality of concepts of causation involved.

However, in itself this is not sufficient to condemn monism. The monist could say that while practitioners do use a plurality of causal concepts, this plurality is only apparent – all these concepts can be reduced to a single notion of causation. The observation of what happens in scientific practice is not a good ground to reject a monist approach, because philosophical analysis may be able to reconcile all instances of other concepts under a single notion. Moreover, a pluralist approach that

⁸Of course, the two inquiries are not unrelated. Our causal concepts are intended to represent something in the world, whatever that may be, so that the metaphysical nature of causation may have an impact on the conceptual tools we develop to represent it. Conversely, metaphysical causal relations can only be known through our conceptual framework, and thus also the accuracy of our metaphysical accounts can only be evaluated in light of our causal concepts. But in principle, the two questions may receive different answers. One could take the nature of causal relations to be unique, in the sense that there is only one type of relations that are causal in the world, while also believing that, when talking about causation, we employ several distinct concepts.

were simply based on the observation of a plurality of concepts risks being vacuous: if the observation is sufficient to support pluralism, then one could argue that anything goes – scientists could use whichever concept of causation, and that concept would be a legitimate concept of causation simply because there is someone using it.

In the next section, we will argue for a pluralist account of causation by replying to these two challenges. First, we will propose an instrumental approach to causation, which provides grounds to evaluate normatively different concepts of causation – thus avoiding the charge that anything goes. Then, we will apply this approach to the instruments discussed in the previous sections, and show how a monist approach would be at least instrumentally inadequate – thus grounding our rejection of monism on something beyond the simple observation of scientific practice. While our discussion will be applied to the specific case of landslide research, the approach can be generalised to all contexts where causal concepts are used.

5 An instrumental approach to causation

Despite the variety discussed in the previous section, most research in the philosophy of causation has adopted what we may call a descriptive perspective. Different accounts aim to describe an aspect of reality, namely the nature of causation or the causal concepts that we employ to identify it. The justification for these approaches is therefore equally descriptive: it is the accuracy of the accounts that is discussed, and counterexamples are used to show where this accuracy fails. In some sense, then, pluralist accounts may equally be looking for “The One Theory” of causation: they may try to provide a true description which is unique, albeit composed of more ingredients than one, and which presupposes that other accounts are incorrect because they fail to adequately describe the relevant phenomenon. They may aim at constructing a universal answer to the question of causation.

However, normative perspectives are open to both metaphysical and conceptual accounts. In developing an account of what causal relations are, one can provide normative indications for what scientists should look for when they look for causal relations.⁹ Similarly, some authors have independently proposed alternative approaches to conceptual causation that go beyond the purely descriptive. De Vreese (2006) defends what she calls an “epistemological-methodological” view, which investigates causal concepts as instruments to attain knowledge within scientific practices. Price (2001) pleads for a “pragmatist” approach to causation that looks at the role that concepts play for specific actors and in specific contexts. Woodward (2014, 2021) supports a “functional” perspective, which starts from the idea that causal information and reasoning serve some goals. Regardless of the different labels, the three authors share a common perspective on how to investigate causation, which focuses (i) on the role it plays to achieve some purpose, and consequently (ii) on the context of practice where it is used. Given that this perspective sees causal concepts as instru-

⁹We are grateful to an anonymous reviewer for drawing our attention to this point.

ments to achieve some goal, we will provisionally call it *instrumentalist*.¹⁰ Notice that this approach has room for both descriptive and normative questions. Descriptively, it can ask what causal tools are employed within a specific context and for a specific purpose; normatively, it can ask which causal tools would be best suited to achieve that purpose in that context.

The normative perspective opens questions about the evaluation of causal concepts. From an instrumentalist point of view, this evaluation does not concern the accuracy with which a certain account of causation captures the real content of causal concepts. Instead, it concerns the adequacy of this account with respect to a given purpose and in a given context. This move mirrors the adequacy-for-purpose proposal in the literature on scientific models: according to the proponents of this view, models should not be evaluated (only) in terms of the accuracy with which they represent their target, but (also) for their adequacy to achieve some purpose (Parker, 2010, 2020; Currie, 2017). Following the idea of adequacy-for-purpose to evaluate models, we here adopt the notion of adequacy-for-purpose for the evaluation of concepts.

An implication of the instrumentalist approach is that it is possible that different concepts of causation may be more adequate (either descriptively or normatively) in different contexts or for different purposes. This includes a degree of relativism which, however, does not exclude the possibility that, in principle, there is one and only one true account of metaphysical or even conceptual causation: there may be some ways to understand causal relations which are useful for a specific goal, but that may be inadequate as descriptions of what causal relations are in the world (or of what a universal concept of causation would look like). The adequacy of an account relative to some context and some goals may have no direct implication for the general accuracy or truth of that account. Thus, it is possible that a pluralist instrumentalist approach may be consistent with a monist metaphysical account: it may be the case that there is only one way in which a relation can be causal, but that in some context it is more adequate for our purposes to adopt more than one concept of causation. Conversely, it is also possible to support a monist instrumentalist approach (because it may turn out that e.g. there is one concept of causation that serves all functions of causal discourse) or a pluralist non-instrumentalist approach (because the matter of fact may be that e.g. there is no single thing we mean when we talk about of causation, but a plurality of concepts regardless of context or function). Instrumentalism and pluralism are orthogonal dimensions: instrumentalism is a type of question – i.e., it asks which causal concept(s) is (are) used and is (are) most adequate for a specific purpose in a given context; while pluralism is a type of answer, which can be given to the metaphysical, the conceptual, or the instrumentalist question. In itself, then, instrumentalism does not imply pluralism (and vice versa).

We adopt this instrumentalist perspective to address the notion of causation within the specific context of scientific practice in the study of landslide risk. We believe that, in this context, this approach is useful because it fulfils two functions. First, it

¹⁰ “Instrumentalism” is a traditional term in philosophy of science, where it indicates a position opposed to scientific realism with respect to the interpretation of theoretical objects. While our instrumentalism shares with the traditional one the view that something is justified on the basis of its success in application, our focus is narrower and possibly reconcilable with more realist positions. The label is adopted to refer to what the “pragmatist” and “functional” approaches cited have in common.

permits to unearth the assumptions about causation hidden in the different scientific methodologies. Second, it can identify the role that these assumptions play, and thus normatively suggest which assumptions would be best suited to play that role. Both these functions can help in the construction of a shared framework between the different disciplines involved. The multi-disciplinary nature of landslide research means that there may be some lack of common ground in terms of methodological, conceptual, and even philosophical assumptions among the practitioners. Unearthing what the assumptions about the nature of causal relations are, and which causal tools are better suited to support specific scientific goals, may help avoid potential misunderstandings in the foundations of risk research.¹¹ For this reason, we are interested in the instrumentalist perspective on causation in landslide risk: what is causation in the practice of those studying landslides, and what should it be?

Within this instrumentalist perspective, our position is made of both a descriptive and a normative claim. Descriptively, we have contended that the sciences working on landslide risk employ a plurality of causal concepts (Sect. 3). Normatively, in the next section we will argue that this plurality is instrumentally required to have a complete understanding of landslides. Thus, our work is a defence of conceptual pluralism in the study of landslide risk. In doing that, we assume that the goals of science for which causal relations are needed include – although they may not be limited to – explanation, prediction, and action-guiding. Whether these are the goals that science should have or not is a separate philosophical question; here, we assume that these are among the purposes that scientists themselves attach to their role in society, and we will examine the usefulness of different accounts of causation in line with (some of) the purposes of the scientific community of reference. While our focus is on the epistemic purposes of the instruments we discuss – i.e., how different concepts of causation are required to gain a full understanding of landslide risk – arguments on the same line could be constructed for the practical, more policy-related purposes of the same instruments, which are particularly relevant for risk sciences aimed at risk mitigation. However, given that the relationship between scientific instruments and policymaking is important, but somewhat indirect and mediated by other considerations, we limit the analysis to the epistemic purposes, which allow for more direct conclusions.

6 Different concepts for different purposes

In Section 2, we discussed how various methods are used to investigate the causal dimension of landslides. In Section 3, the analysis of these methods led us to infer, for each of them, the assumption of a different approach to causation. The observation of this plurality in the practice of scientists is sufficient to provide a *descriptive* pluralist answer to our instrumentally motivated question of causation. However, in order to provide a *normative* answer – i.e., in order to claim not only that scientists use a

¹¹ Anjum and Rocca (2019), for instance, have argued that some aspects of mainstream scientific methodology, like the focus on quantitative studies with large datasets, are rooted in some philosophical assumptions about causation.

plurality of concepts of causation to study landslides, but also that this plurality is good in terms of adequacy for purpose – we need to show that the different accounts cannot be reduced to a monist perspective without failing to perform their functions.

The sciences related to natural risks aim to describe a specific hazard in terms of its spatial dimension, its frequency, and its magnitude: we want to know what sort of event we should expect where and when. In describing landslide hazard, the notion of susceptibility addresses only the spatial dimension. Susceptibility “is the degree to which an area can be affected by future slope movements, i.e. an estimate of *where* landslides are likely to occur”, and therefore it “does not consider the temporal probability of failure (i.e., when or how frequently landslides occur), nor the magnitude of the expected landslide (i.e., how large or destructive the failure will be)” (Rossi et al., 2010, p. 129). The purpose of susceptibility maps is “to predict the geographical location of future landslides” (Guzzetti et al., 2006), and not their probability. The identification of predisposing factors that have the potential to generate a landslide given the right conditions is necessary to map risk and determine which areas and which slopes need specific attention. The presence of predisposing factors in a certain area does not directly imply that landslides are more frequent in that area: the occurrence of landslides requires both predisposing factors and triggers, and in the absence of triggers even the most susceptible slope may never fail. With susceptibility maps, researchers want to capture the potential that a slope has to slide. This cannot be done by modelling the mechanisms of the possible landslides that would occur in that area – not only because the scale is too large to construct a computational model that could represent the whole area, but also because a mechanism would lose sight of the conditions that make an area more prone to landslides, regardless of the exogenous shocks that trigger the acceleration. Neither can it be done by looking at causes as probability enhancers: firstly because there is no direct link between susceptibility and frequency, and secondly because doing so would hide the distinction between predisposing and triggering factors, which is central to understanding the spatial dimension of landslides. For the purpose of predicting the geographical location of future landslides, a dispositional account of causation is necessary.

On the other hand, at the slope scale, modelling mechanisms allows us to describe the characteristics of a specific landslide, predicting its acceleration and providing grounds to calculate its impacts. In order to do that, the factors causing the landslides need to be considered in their interactions, not in their distinctions between predisposing and triggering. The purpose of a computational model is to illustrate a specific way in which a slope can slide: it describes the magnitude dimension of landslide hazard, but it does so for the landslide that would happen under specific conditions. In order to do that, what is needed is a computation of the interactions between the different factors affecting the slide in all its relevant components. We need to know things like the velocity that the slide would assume given the gradient and geometry of the slope, so that we can predict the impacts that this specific landslide event would have. The issue is not the potential that a slope has to slide, or whether a certain factor would enhance the probability of a slide – indeed, computational models tend to be deterministic. In order to predict the impacts that a landslide would have given a specific parameterization of the characteristics of both predisposing and triggering factors, we need to understand the mechanism whereby the interaction of these fac-

tors generate a specific volume, velocity, and reach of the sliding masses. To do that, a mechanistic perspective is required.

The purpose of machine learning models for landslide research is to identify the geomorphological conditions that favour the acceleration of a slide. This can be done on the basis of expert judgements and geological theories, which explain the role of different factors in the generation of a landslide. But the application of machine learning algorithms that learn from large datasets comprising inventories of historical landslides allows the identification of predisposing factors without theoretical assumptions – which means that they may identify the causal role of factors that our theories overlooked, as well as describing the combinations of different conditions that make them causally relevant or not. This pre-theoretical identification is done by observing correlations in the data between sets of geomorphological features and landsliding events. Considerations of the mechanisms behind these correlations are irrelevant to their identification. A certain geological condition is identified as a cause of landslides not in virtue of the part it plays in the generation of a given volume of moving mass or of how it predisposes a certain area to slide, but because it correlates with the occurrence of landslides in the inventory used as dataset. Of course, this correlation can be expressed in probabilistic terms, as there is an observed frequency of landslides occurring when that condition is present in the dataset. Indeed, we do not claim that a regularity account of causation is required by all machine learning applications. However, in the case of landslides, the acceleration of a slide typically depends on the interaction of several factors. There is no single factor that, by itself, guarantees the occurrence of a landslide: what matters is that it does when joint with other factors. Machine learning contributes to the identification not much of single factors, but rather of clusters of factors that determine landslides. For this reason, the purpose of identifying the factors that cause the acceleration of a slide requires an INUS-based account of causation.

Ultimately, the main purpose of multi-risk assessments is to support the design and selection of effective risk-reduction measures in the relevant area. Ignoring multi-risk interactions is problematic because it can lead to “inefficient or controversial risk management strategies” (Sperotto et al., 2017: 321). Thus, action guiding is central to the use of Bayesian nets at the multi-risk scale. Huang et al. (2023), for instance, apply Bayesian nets in their study explicitly “to support the choice of appropriate response strategies” (2023: 1011). In general, to be effective an action needs to intervene on the factors that make a difference to the obtaining of the effect that one wants to achieve or avoid. To perform the function of guiding risk management, multi-risk research identifies the factors in the causal nexus around risks that make a difference to the impacts of potential hazards.

For this reason, the focus is on the identification of difference-making factors, and on the extent to which potential interventions are going to modify the resulting overall impacts. Thanks to the directed links between variable nodes, Bayesian nets allow to do just that. Mechanistic or dispositional information can be crucial in understanding the causal history of landslides, and therefore they can be used to produce the theories that inform the construction of the nets. But for decision-guiding purposes, the focus on how effects are produced by their causes shifts towards seeing causes as those factors that make a difference to the effects. Ideally, the causal information

provided to decision-makers not only identifies the elements that can be manipulated to intervene on the overall impacts, but it does so in a format that is easy to understand and to include in the decision-making processes. In this direction, seeing causes as probability changers translates causal information into inputs that are ready to be used in decision-aiding instruments like cost–benefit analysis or multi-criteria analysis, which typically require probabilistic data. Moreover, in the context of multi-risk, information comes in different forms from different disciplines: as Huang et al. put it, “emergency decision makers may get increasingly perplexed and fail to make the best decisions due to the complexity of various disasters and the heterogeneity of information from several sources” (2023: 1011). Probabilistic information is therefore valuable also because it provides a uniform format in which to translate diverse and complex content. Thus, for the purposes of supporting decision-making, manipulationist and probabilistic perspectives on causation are particularly apt.

We can therefore see not only that the plurality of causal instruments employed in the study of landslides is mirrored in a plurality of accounts of causation, but also that this causal pluralism is desirable to adequately perform the different functions that these instruments play. All the accounts discussed are necessary, and none of them is sufficient, to achieve a complete understanding of the landslide phenomenon, as they involve different scales and are used to pursue different purposes. A reductionist account of causation would thus miss something important about landslide risk – be that the distinction between predisposing and triggering factors, the model of the mechanism predicting the actual realization of a landslide, the identification of conditions that correlate to the phenomena, or the way in which changing specific variables change the overall impacts.

It is important to note that the different instruments are not in conflict, but rather play complementary roles in constructing our understanding of landslide phenomena. Machine learning models support expert judgements in the identification of clusters of factors that generate landslides; susceptibility maps identify the areas where these factors are more present, so that we can determine the geographical distribution of landslide hazard and identify the slopes that are more prone to slide; computational models describe the interactions of all causal factors in a specific slope, modelling the impacts that the landslide generated by a specific mechanism would have; Bayesian network allow us to represent the dependencies between different risks and different events, so that we can explore how the final result would change if things changed at previous steps of the chain.

Note that these instruments do not simply provide different types of evidence for the same causal claim. Susceptibility maps and computational models, for instance, address causal relations at different scales of the landslide phenomenon (the large scale vs the slope scale). Furthermore, one could argue that susceptibility maps do not provide novel evidence about some causal claim – rather, they represent spatially some characteristics of an area which are relevant for the occurrence of landslides, but evidence for this causal relevance comes from other tools. Computational models and machine learning may provide novel evidence of two different sorts, but while the first ones provide evidence of *token* causation, the latter help identify *type* causal relations, and therefore the two do not provide different kinds of evidence for the same causal claim. Finally, Bayesian networks may be interpreted as a medium

between new evidence and correspondingly adequate degrees of belief, rather than as an instrument to unearth novel evidence. Thus, the pluralism at play here cannot entirely be understood as evidential pluralism (for which see Russo & Williamson, 2007; Maziarz, 2025).

While they are often the result of interdisciplinary collaborations, the different instruments tend to be more familiar to different disciplines: for their focus on geomorphology and the spatial dimension, for instance, susceptibility maps tend to come from geology, whereas computational models require the modelling techniques of engineers. Whether each causal concept is more natural to a specific discipline among those involved, and not just to an instrument, is an open question. Indeed, this pluralism may be typical of disciplines studying geological phenomena in general: according to Kleinhans (2024: p. 654), “(w)hat geoscientists consider a ‘cause’ depends on their methodology, suggesting the existence of a variety of conceptualizations of causality”.

7 Conclusions

In this work, we have developed a pluralist account of conceptual causation for the multi-disciplinary study of landslide risk. We have done so adopting an instrumentalist perspective, which rather than looking for a universally correct answer to the question of causation tries to explore it in relation to a specific purpose and a specific context. Descriptively, we have claimed that there is a coexistence of different notions of causation; normatively, we have argued that this plurality is necessary to obtain a complete understanding of landslide risk, because different concepts are adequate for different purposes. From an instrumentalist perspective, what is valid in one context is not necessarily valid for a different context, which means that our application focused on landslide risk sets tight limits to the scope of our pluralist answer. However, we believe that our application provides a crucial illustration of how an instrumentalist perspective on conceptual causation may work and what its merits are. It is a perspective that stands in constant dialogue with the sciences, both by observing their practices and instruments and by shaping tools that can enrich their methodologies. Furthermore, it is a perspective that need not wait for The One Theory of causation to be established. While others look for the true nature of causation or for its conceptual structure, the instrumentalist perspective expands the set of questions that can be asked about causation, by investigating not only what it is, but also how it is used, when, and by whom – and by developing a normative dimension that evaluates the causal concepts in virtue of their adequacy for purpose.

In that respect, our instrumentalist perspective falls neatly within the “mosaic” approach defended by Russo and Illari (2025): it is important to expand the range of questions that philosophy asks about causation, even though that may lead to a multiplication of the answers and methodologies employed. A “mosaic” philosophy of causation depicts a broad, plural picture of causation, thus embracing the complexity of this concept and of its role in our daily and scientific lives. The mosaic approach supports the idea that there are many questions that can be asked about causation and science, and that the traditional focus on trying to identify or define what causation

is has relegated other inquiries to the margins. We contend that instrumentalism is one of these other possible inquiries. We contribute to enriching the debate on causation by developing an instrumental perspective and applying it to the specific case of landslide risk. We believe that landslides provide an interesting case, for the multi-disciplinary nature of the research studying them and because exploring landslides can contribute to a broader understanding of risk.

To our knowledge, the notion of adequacy-for-purpose developed to evaluate models has not yet been applied to the evaluation of concepts. Here, we do not propose a full account of how a general conceptual pluralism can be based on adequacy-for-purpose: we apply this idea to pluralism about a specific concept – causation – and within a specific context – landslide research. However, we believe that this can be a first step in that direction by motivating this line of research. More in general, the application of the adequacy-for-purpose criterion to the evaluation of concepts puts the focus on the normative dimension of conceptual analysis, which often remains implicit and to some extent under explored.

Finally, in supporting a pluralist view of causation, our work can be seen as part of a pluralist philosophy of science, which studies the complexities of scientific practices against a view of science as a single entity (Ludwig & Rupy, 2024). Just as our instrumentalism, scientific pluralism can have a normative content, by going beyond the description of scientific practices to actively advocating for metaphysical, epistemological, and/or social plurality as beneficial for science (Chang, 2012). One may object that, as a form of pluralism, causal pluralism should explain how the different concepts of causation are all concepts of the same thing, i.e. causation. However, the thrust of this possible objection is weaker for instrumentalism than for other forms of pluralism. Instrumentalists do not claim that there is no such thing as a unified concept of causation – rather, our pluralism claims that there is no unified concept of causation *in a specific context of practice*. The people using a plurality of concepts in that context may have an independently formed unified concept of causation for other contexts: however, such a concept may be too general to be of practical use (Mitchell & Alexandrova, 2021), and may need to be operationalized in more specific ways for the purposes of science.

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Declarations

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