Accepted Manuscript version, Edited version published by *Erkenntnis* and available here:
http://www.doi.org/10.1007/s10670-025-01048-x

Beyond values: the introduction of subjectivity and its use in decision-making under uncertainty

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Abstract:
Within the philosophical literature, there has been a trend to discuss subjectivity, and its impacts on science, from the perspective of value judgments. While this discussion is necessary and has proven to be fruitful, I contend that the type of subjectivity referenced in this discussion extends beyond the use of values. In this paper, I argue that the type of subjectivity of concern in this literature is regarding some personal aspect of the individual and the use of this aspect in addressing the uncertainty present within scientific decision-making contexts. I begin by arguing that, while it is not explicitly stated, the current discussions of this subjectivity within the literature actually focus on instances of normative uncertainty present within these decision-making contexts, where I claim that values are used to address this uncertainty. In this way, I identify a connection between the use of values in science and the presence of normative uncertainty. However, other forms of uncertainty are also present in scientific decision-making contexts, modal and empirical uncertainty, which must also be addressed. Using examples from climate science, I show how these uncertainties are addressed by other means, specifically through a scientist's tacit knowledge and intuition. Subsequently, tacit knowledge and intuition are shown to maintain the same type of subjectivity as value judgments, where the use of this subjectivity is a necessary part of decision-making. In this way, I highlight additional vehicles of subjectivity and novel contexts of uncertainty where this subjectivity can be introduced into science. Thus, when someone recognizes the type of subjectivity, which is historically only associated with values, to be present in science they should no longer assume that the introduction was due to a value judgment. Ultimately, I conclude by discussing these other vehicles of subjectivity and their impact on epistemic reliability.

Keywords: Subjectivity; Uncertainty; Decision-making; Values; Tacit-knowledge; Intuition; Expert Judgment

1. Introduction

Value judgments are seemingly everywhere. In daily life we use value judgments to assist in simple decision-making, such as what side of the road to walk on or what to eat for dinner, as well as more consequential decisions, such as who we vote for in our elections. The widespread use of value judgments is a point that has not been missed by the philosophical community, specifically regarding their use in science. Here, values have been recognized in the managing of science, in steering the direction of science, in the actual doing or inquiry of science, and in the use of scientific information (Elliott, 2022). In turn, a robust literature has developed recognizing science as being, in a certain sense, value-laden. This value-ladenness has raised questions related to the use and, potentially more importantly, the misuse of values, where many of the concerns stem from the introduction of subjectivity into science through value judgments in decision-making.

The first of these concerns originates in the mid-1900s in response to the inductive risk argument. This argument, often attributed to Richard Rudner (1953), makes the case that in choosing to accept or reject a hypothesis one must appeal to values due to the risk of error. Rudner's argument rested on two key premises, (1) within a scientific domain, an aspect of the scientific process is for scientists to accept/reject hypotheses, and (2) this decision relies, in part, on ethical judgments regarding the seriousness or consequences of being wrong (Elliott and Richards 2017). At that time, the argument resulted in major discussions within the philosophical community, as it brought into doubt the value-free ideal[1] and, in turn, the objectivity of science. This is due to the argument specifically highlighting that not only are values used in scientific decision-making, but that this was a necessary aspect of science.

This discussion then went relatively cold within the literature until a series of highly influential works by Heather Douglas (2000; 2008; 2009) resurrected the argument. Douglas (2000) took this concept of inductive risk and argued that the concerns that originate from the potential for error in accepting/rejecting a hypothesis are not exclusive to this decision. Rather, Douglas contended that these concerns need to be considered throughout scientific decision-making, highlighting that the decisions made within the "internal stages of science", such as in the "choice of methodology, characterization of data, and interpretation of results", have an impact on the risk of being wrong (2000, 565). Douglas, in turn, highlighted a new context for the concerns of inductive risk, going beyond the decision-making discussed by Rudner, prompting new discussions on the use of values in other scientific contexts.

The recent literature on values has subsequently taken this expanded discussion of inductive risk and has highlighted general contexts of value use in science. Here, the use of values has been recognized in everything from the choice of research question and the communication of scientific findings (Elliott 2022; Helgeson et al. 2025) to measurements and metrics (Bocchi 2024). Contexts such as the identification of a research question are no longer concerned with the risk of error but are rather focused on the use of values within a more general discussion on scientific decision-making. This wider discussion of value-use has even been adopted by individuals in the scientific community, where a prominent example can be seen directly from the Intergovernmental Panel on Climate Change. In their latest Assessment Report (AR6) on the current state of climate science research, it is stated that "social values are implicit in many choices made during the construction, assessment, and communication of climate science information" (IPCC, 2021, §1.2.3.2). The philosophical literature has focused on these choices, and the variety of ways that values relate to choices (Ward, 2021), where some are concerned with how individual values used within decision-making affect the objectivity of science.

In general, I agree with the existing literature, subjectivity can be introduced into science through value judgments in decision-making, leading to valid concerns about the influence of this subjectivity. However, in this paper, I will argue that the concerns stemming from the introduction of this type of subjectivity extend beyond value judgments and include other non-value-laden judgments. I begin, in section 2, by discussing subjectivity and values in science. Here, I will define and outline the type of subjectivity that is at the heart of this discussion, that being, the use of personal aspects of an individual researcher(s) to address the uncertainty present within scientific decision-making contexts. Within the current literature, I identify those personal aspects to be non-epistemic values and the uncertainty which is addressed to be normative uncertainty. From this, I argue that the recognized widespread value-use in science is actually due to the role values play in addressing the normative uncertainty present within scientific decision-making

[1] Some have argued that inductive risk might not entirely undermine the value-free ideal (see de Melo-Martín and Intemann, 2016).

contexts. In this way, I identify a new connection between the general use of values in science and the presence of normative uncertainty in those contexts.

However, decision-making in uncertain contexts extends beyond cases of normative uncertainty, as there are contexts of scientific decision-making where both empirical and modal uncertainty are also present. From this, in section 3, I will use examples from climate science to discuss how these other two forms of uncertainty are addressed in practice. Specifically, I will argue that tacit knowledge and intuition are used by scientists to produce judgments which address modal and empirical uncertainty, respectively. Subsequently, in section 4, I argue that tacit knowledge and intuition maintain the same type of subjectivity that I identified to be of concern within the existing literature's discussion on values. In this way, I highlight a broader list of subjective influences and further uncertain contexts where subjectivity is introduced. Thus, when one recognizes the presence of this type of subjectivity in science they should no longer assume that the introduction of that subjectivity was due to a value judgment. Rather, these additional vehicles of subjectivity are also necessarily involved in scientific decision-making contexts where various forms of uncertainty are present. I then end, in section 5, by discussing the unique epistemic impact of tacit knowledge and intuition, examining the concerns these vehicles of subjectivity raise for epistemic reliability.

2. Framing a conception of subjectivity

There are multiple ways to discuss objectivity and subjectivity in science, with many conceptions of objectivity utilized throughout the philosophical literature (Janack, 2002; Brown, 2019). However, the argument from inductive risk and the subsequent conversations on the general use of values has framed a specific discussion of subjectivity[2]. The key features of this account of subjectivity can be identified by examining the concerns raised by defenders of the value-free ideal of science.[3] While there are unique nuances to this argument, in general the value-free ideal states that "the justification of scientific findings should not be based on non-epistemic values" (Betz, 2013). Recent arguments in favor of this ideal have referenced similar conceptions, stating, "the prevailing version of the value-free ideal admits epistemic values to the context of justification and only insists on keeping nonepistemic values out of assessing the cognitive merits of theories" (Carrier, 2021). Within these accounts the perceived challenge to the value-free ideal rests on two aspects (1) the values themselves and (2) how they are, or are not, used in justifying scientific findings. These two points will provide the structure for identifying the relevant form of subjectivity being referenced in these discussions.

In general, the term 'values' has been used to reference a variety of matters within the philosophy of science literature. Some have argued against taking values to include a large set of matters, rather conceptualizing a broader set of contextual influences which include values (Hilligardt, 2022). However, I follow much of the existing literature and adopt a broad conception of values. In this way, values can be social, ethical, political, aesthetic, moral, as well as

[2] Some have argued that values are not wholly subjective and that focusing on "scientific integrity" is preferable (Brown 2019).
[3] See Brown (2024) for an overview of recent accounts and defenses of the value-free ideal.

others, and can even be represented by an individual's interests and priorities. This set of values are generally considered to be non-epistemic values. Additionally, another set of values which has been discussed in the literature includes values such as accuracy, consistency, simplicity, scope, fruitfulness, etc. (Kuhn, 1977). These values are often described as cognitive (Douglas, 2008, 4) or epistemic (Grimm, 2008), where it is argued that these values "promote the truth-like character of science", assisting science in achieving its epistemic goals (McMullin, 1982). In turn, this provides a demarcation between the set of epistemic values and the previously described non-epistemic values, where the previous set is often seen as not assisting in science's epistemic goals. However, there is an ongoing debate questioning if portraying values as epistemic vs non-epistemic is a useful distinction (Rooney, 1992; 2017). While I will not enter this debate[4], I want to highlight that although there are a variety of values which are used in decision-making, those promoting the value-free ideal, generally, are not concerned with the introduction of all values, they are concerned with non-epistemic values.

This specific focus on non-epistemic values provides a first indication of the conception of subjectivity used in these discussions. The set of non-epistemic values adopted by an individual are personal and often seen as being grounded in one's ethics (Schroeder, 2020), making the point of generation for these values to be within that specific individual. For any individual scientist there is the possibility that they have shared values with others in their scientific community, however, this is not necessarily the case. One's values are not derived directly from the scientific community, so any agreement between individuals on a singular value, or set of values, would be due to conditions outside of the scientific community. Conversely, it could be the case that members of a given scientific community have differing values, where individuals may have different political values or may weigh shared values differently. This difference in values or in the expression of values may result in a situation where individual scientists produce different judgments or even incompatible judgments. These considerations highlight a general concern for the use of non-epistemic values, that these values are dependent on the specific individual producing the judgment.

This is reflected in the concerns raised by defenders of the value-free ideal when they discuss the role of science in a democratic society. The use of non-epistemic values is seen as going against some principles of a liberal democracy, specifically related to autonomous decision-making (Betz, 2013). Due to the unique position of scientists in providing their specialized knowledge, and sciences' authoritative position in society for providing decision relevant information, an individual's values may dictate decision-making rather than allowing democratically elected decision-makers to play this role (Steele, 2012). Here, non-epistemic values can introduce some individual aspect or personal disposition of the expert into science, where this personal disposition can then influence the direction of political decision-making.[5] In this way, "the value free ideal ensures—in a democratic society—that collective goals are determined by democratically legitimized institutions, and not by a handful of experts" (Betz, 2013, 207).[6] The concern about introducing values can then be seen as a stand-in for the concern of introducing personal aspects of the

[4] See Elliott (2022, §2.1) for an overview.
[5] Parker and Lusk (2019) have shown how this can occur in the management of water resources.
[6] Lusk (2021) has argued against this, the "political legitimacy argument", highlighting avenues for addressing the political issues which arise from the use of values.

individual, where these aspects are not governed by some democratic process but are generated within the individual scientist. Ultimately, those focused on this type of subjectivity are worried about how these aspects of the individual can influence science, where values are seen as a kind of vehicle for introducing this subjectivity.

The focus on non-epistemic values, and the introduction of these personal aspects of scientists, is not the only point of concern, defenders of the value-free ideal have also focused on a specific way that values are used. This second point, the focus on the context of justification as the specific location of value use, can also assist in identifying the type of subjectivity being referenced. The distinction between the context of discovery and the context of justification originates with Hans Reichenbach (1938). Here, the context of discovery generally refers to the process of producing scientific information and the context of justification generally refers to the process of evaluating that information. Within Rudner's argument, he states that values are used in "accepting or rejecting the hypothesis" (1953, 2), placing this choice firmly in the context of justification. This acceptance/rejection as a choice that is influenced by non-epistemic values is the point of contention for the introduction of subjectivity. Here, value-free idealists argue that non-epistemic values should play no role in the decision-making regarding justification (Koertge, 2000). However, decision-making that is influenced by non-epistemic values is allowed within the context of discovery. In turn, this argument makes a distinction between the context of discovery and the context of justification, allowing non-epistemic values to be used in one context but not the other.

However, others have argued that the demarcation between these contexts, in terms of the influence of values, is not so clear. Specifically, it has been highlighted that the context of discovery can impact the evaluation of the hypothesis/theory, where the use of values in the prior will undoubtedly affect the later (Elliott and McKaughan, 2009; Bueter, 2015). Following this, the concerns that arise from value-laden decision-making should not only be relegated to the context of justification. Rather, the entire chain of science, from conceptualization through justification, must retain the focus when discussing the concerns of subjectivity in scientific decision-making. With this in mind, we must be clear on the specific role values are playing within scientific decision-making more generally to fully capture the conception of subjectivity that is of concern.

Decision-making contexts, whether they are examples of inductive risk or capture a broader example of value use in science, maintain some level of uncertainty. For the inductive risk case, Douglas highlights that not all decisions within the internal stages of science are subject to the problem of inductive risk. Rather, when the uncertainty about the state of the world is very low "the chance of error is so small that consequences of being wrong become insignificant" (Douglas, 2000, 577). These discussions of inductive risk, and the use of values, are then intimately tied to the uncertainty present within the decision-making context. Here, it is quite clear that at least a minimal level of empirical uncertainty, the uncertainty about the state of the world, must be present in these contexts. This, in turn, is the type of uncertainty recognized by Douglas and is the uncertainty generally highlighted in these discussions. However, once this minimal level is met the subsequent risk of being wrong, which requires the evaluation of consequences, retains the focus. If one does not consider the consequences to be serious then the risk of being wrong would be negligible or unimportant for the decision. Thus, it is not the level of empirical uncertainty which should be seen as the center of the inductive risk problem but rather how serious one considers the potential consequences to be. However, what is or is not serious is unclear and not defined within any decision-making context. This highlights an additional form of uncertainty present within that context, normative uncertainty, the uncertainty regarding what is “desirable or what *should* be the case” (Bradley and Drechsler, 2013). This instance of normative uncertainty is regarding the seriousness or desirability of the consequences, where the expert must address this uncertainty before they can make a decision on accepting/rejecting the hypothesis.

To address this normative uncertainty, the scientist must identify a notion of desirability. While normativity is complex, with theories of normativity having multiple conceptualizations (Finlay, 2019), I take a simple account. Normativity can be seen as a human notion of desirability which is identified personally within the individual producing the normative judgment. In this way, an individual’s conception of what is desirable can be multifaceted, it can be based on a single consideration or on a larger set of considerations. However, within the inductive risk example, values are being used to provide the normative content necessary to identify a conception of desirability and address the normative uncertainty present within the context of accepting/rejecting a hypothesis. The normative uncertainty should then be seen as being present within the context of the decision-making and not necessarily within the individual making the decision. Here, it could be clear to the individual what is or is not desirable, however, this conception of desirability is provided by that individual’s values and is not a feature of the general decision-making context. In this way, the individual comes to the decision-making context, recognizes, potentially implicitly, the presence of normative uncertainty and using their values adopts a conception of desirability. This conception of desirability then addresses the normative uncertainty by providing an account of what should be considered desirable/serious, allowing the scientist to evaluate the consequences and, subsequently, make a decision on accepting/rejecting the hypothesis. Values, in turn, are not being used to address the empirical uncertainty present within these contexts, rather, they are used to address the normative uncertainty present within inductive risk contexts.

This is similar to instances of the broader use of values in science, which should also be seen as instances of normatively uncertain decision-making contexts. While the decisions made within these normatively uncertain contexts proliferate throughout science, I will use examples from climate science to show how values are used by scientists to address the normative uncertainty. Take the example of selecting a research focus, where there are a variety of potential focuses. In climate science, an expert can perform their research on any number of systems or phenomena related to the climate, such as the Atlantic Meridional Overturning Circulation or the El Niño Southern Oscillation. They may also choose to focus on one area of the world, such as the Northern Hemisphere or Mainland Europe, and the systems that impact these regions. In turn, there is normative uncertainty as to what would be a desirable research focus.

Akin to the inductive risk context, the scientist may utilize a set of values to identify a conception of desirability, addressing the normative uncertainty, and allowing for the selection of a research focus. The scientist may adopt aesthetic values and choose to study some aspect of the system they find beautiful, such as coral reefs, identifying a desirable research focus based on this value. Alternatively, they may adopt social values related to the threat to human life and choose to study extreme weather events, such as heatwaves or floods, addressing the normative uncertainty in this way. Ultimately, one can identify a multitude of values, or sets of values, which can be used to ground the conception of desirability necessary for the selection of one research focus over another. The evaluation and selection of the focus is then dependent, in part[7], on the weights an individual assigns to these values, where a different judgment could be produced based on different assigned weights or different sets of values. In this way, by addressing the normative uncertainty one is not resolving or eliminating the uncertainty. Rather, the uncertainty is still present in the context, the scientist is only momentarily overcoming the uncertainty within their specific instance of decision-making to allow the decision to be made. This is why the same decision-making context can result in different decisions[8] depending on how the scientist, addressing the normative uncertainty present within that context, identifies a conception of desirability.

Ultimately, the literature's recognition of the use of values in these examples of inductive risk and broader scientific decision-making is due to values containing the normative content necessary to address the normative uncertainty present within these contexts. However, as discussed, the point of generation for the normative content is within that individual and due to a personal aspect of that individual scientist, the specific value(s) they utilize. This highlights the type of subjectivity of concern within these discussions on values. Specifically, subjectivity is referring to a personal aspect of the individual scientist, their values, and their use in addressing the uncertainty, normative uncertainty, present within the decision-making context. While I agree that the concerns regarding this type of subjectivity are a relevant point of inquiry, in what follows, I will argue that this type of subjectivity extends beyond values and their use in addressing the normative uncertainty present within decision-making contexts[9].

3. Scientific decision-making and addressing uncertainty

Aside from normative uncertainty, other forms of uncertainty, modal and empirical, are also present within scientific decision-making contexts.[10] Modal uncertainty is regarding "what *could* be the case" or what is possible, i.e. conceivable, feasible, etc. (Bradley and Drechsler, 2013; Bradley, 2017, §3.3). This form of uncertainty can be in terms of the possible states of the world as well as the possible consequences of an action/event. Empirical uncertainty is regarding "what *is* the case" (Bradley and Drechsler, 2013). Aside from the uncertainty about the present case, empirical uncertainty can also be concerning what has been the case in the past or what will be the case in the future (Bradley and Drechsler, 2013). Ultimately, recognizing the presence of these other uncertainties within scientific

[7] Considerations related to the resource availability, such as time, funding, and the status of previous research, also affect the choice of research focus.
[8] Others have highlighted this disagreement as an example of the contingency present within the context (Brown, 2019).
[9] The uncertain decision-making contexts I am concerned with are, in Ward's (2021) terms, those where this type of subjectivity is used as a reason for a choice, whether that be for motivation or justification.
[10] These forms of uncertainty are not reducible to any one form of uncertainty (Bradley and Drechsler, 2013) and it could be the case that there are multiple forms of uncertainty present in any one decision-making context.

decision-making contexts leads to the question – if values are used to address normative uncertainty, how are these other forms of uncertainty addressed by scientists?

It is quite clear that to make any decision, whether it is in the context of science or not, an individual would rely on their set of stored information, what some have called "theoretical knowledge" (Majszak and Jebeile, 2023). Within science, this set of knowledge can be referencing a variety of pieces of information, including the information gained during an individual's formal education as well as their state-of-the-art understanding of the domain. When applied by the scientist, theoretical knowledge, in part, places "physical limits on the judgment of an expert, not allowing the judgment to be a wild guess or result in conclusions which are not physically possible under the current best understanding of the topic within the field" (Majszak and Jebeile, 2023). However, given that we are discussing contexts with some level and form of uncertainty, there is incomplete or inadequate information to produce a judgment exclusively based on theoretical knowledge. Scientists must then rely on something more to produce a judgment which can address the uncertainty.

To address modal uncertainty, one would need to produce a possibilistic judgment. This judgment would provide the modal content necessary to identify a conception of possibility and subsequently allow for the decision to be made. Possibilistic judgments can be regarding many different types or scales of modality, where a variety of lines have been drawn demarcating different types of possibility. This includes logical possibility, nomological possibility, practical possibility and a variety of other demarcations. I focus on conceptions of practical possibility, as it is akin to the modal uncertainty present within many scientific decision-making contexts. Practical possibility recognizes that there are existing constraints within decision-making contexts, including resource constraints, such as time or money, data constraints, such as measuring limitations or data availability, as well as many other constraints which must be addressed within the practice of science.[11]

Within climate science there are many cases of modal uncertainty. Take the context of the methodological choices needed when building climate model parameterizations. These parameterizations, also described as "mini-models" (Lloyd, 2015, 61), are used within a larger climate model to provide a representation of some process which occurs at spatial scales too small for the larger model to capture, such as cloud formation. However, the parameters constructed to represent these processes require tuning. Here, the judgments from scientists are needed to decide which parameters to tune and which optimization metrics are used (Hourdin et al., 2017). In these cases, there are methodological considerations like balancing computational cost and representational accuracy that the scientist must contend with (Jebeile et al., 2023). Thus, there is modal uncertainty present within this context, where the expert asks themselves – what is a feasible or possible combination of methods and parameter values to produce the desired model structure, given the existing practical constraints? To answer this question and address the uncertainty, the scientist must identify and utilize a conception of possibility.

[11] Practical possibility is also impacted by the scientist's theoretical knowledge, specifically in the choice of theory, where this choice is impacted by values, as previously highlighted.

Within scientific practice, this process has been described as an "art", where a "substantial know how from a limited number of people with vast experience with a particular model" is necessary (Hourdin et al., 2017). Here, the scientist's tacit knowledge, on top of their theoretical knowledge, is key for providing this know-how and identifying what is practically possible in the concrete building and tuning of parameterizations. Tacit knowledge has been characterized as an "informal" (Collins, 2004) and "personal" form of knowledge (Polanyi, 1958; 1966), where a scientist can only acquire this knowledge by working within their specific epistemic community (Collins and Evans, 2007, 6). In this way, tacit knowledge is often characterized as the knowledge an expert develops by performing the science within their domain. This results in knowledge gained through the experiences of working with a scientist's "instruments of investigation", including computer simulations or physical models as well as observational equipment, such as thermometers or anemometers (Majszak and Jebeile, 2023). This know-how then enables one to perform many activities within their domain, i.e. to conduct research through experimentation, to make calculations, to analyze data, and to ultimately write and publish papers (Majszak and Jebeile, 2023).

In the climate parameterization context, scientists develop their tacit-knowledge through the experiences they have working with, designing, and building parameterizations in the past, as well as other professional experiences. This set of knowledge provides the modal content necessary to identify a conception of practical possibility within the decision-making context at hand. In turn, the scientist can use this conception of possibility and determine if the desired process(es) can possibly or feasibly be represented in the parameterization.[12] This is an important process as it allows the scientist to exercise "the part of the expert judgment that cannot easily be translated into objective functions or expressed mathematically as uncertainties" (Hourdin et al., 2017). However, this same scientist, using the same tacit and theoretical knowledge, may produce a different conception of possibility within a different decision-making context. In this way, producing possibilistic judgments is dependent on the specific decision-making context, highlighting that the modal uncertainty is present within the context itself.

To address the final type of uncertainty, empirical uncertainty, a descriptive judgment is necessary. However, producing such a judgment would require a description of the past, present and/or future state(s) of the context in question. This process would necessarily be done with incomplete information about the target, as the judgment is produced under some level of uncertainty. The descriptive judgment must then contain the empirical content necessary to provide a description of the target, filling the gap in the existing information. In this way, the judgment must go beyond what is already known, containing more information than what was present within the existing set of information. To see how this is done in practice, I return to climate science for an example.

[12] This is a simplified account; the complete decision-making context involves additional uncertainties which the expert must also address. However, with this example I wish to only highlight how the expert addresses the modal uncertainty.

Take the example of climate tipping points, which can be characterized, in very general terms, as "a critical threshold beyond which a system reorganizes, often abruptly and/or irreversibly" (IPCC, 2021, 2251), where the negative effects of crossing such a tipping point could be catastrophic for humans.[13] However, the climate tipping point context is marred by deep uncertainty (Lam and Majszak, 2022; Armstrong McKay, 2024; Kopp et al., 2025). This uncertainty is due, in part, to a lack of agreement among the latest generation of climate models (CMIP6) in capturing tipping behavior across different systems (Terpstra et al., 2025). Thus, it is unclear which systems have well established tipping points, resulting in empirical uncertainty regarding the actual state of the world. Expert judgment has subsequently played a role in addressing this uncertainty, where the use of a structured elicitation protocol, outlined in the set of papers by Lenton et al. (2008) and Kriegler et al. (2009), has proven to be beneficial. In this protocol, experts were asked to provide judgments on a variety of issues, specifically, (1) the identification of individual tipping points, (2) the potential interactions between those tipping points, (3) the potential for a cascade of tipping points, as well as (4) the likelihood of triggering the identified tipping points under several scenarios (Kriegler et al., 2009). Through their participation in this protocol the experts provided a description of the state of the world, along the four highlighted points, where this complete description was not previously captured within the scientific literature.

The production of a judgment in this context has been described as "holistic" (Lam and Majszak, 2022, §3.2), where scientists produce these judgments by "incorporating not only model results, but also insights from empirical data and theoretical considerations" (Kriegler et al., 2009, 5044). The scientist's intuition is key for putting these pieces of information together. The concept of intuition, or what is occasionally called "intuitive insight" (Dörfler and Ackermann, 2012), maintains a long history within multiple literatures, where discussions generally refer to this concept as an inner mental process of the individual. Some have described this process loosely as the partially imaginative process of "having an idea" (Medawar, 1969), with others describing it as a skill or the ability of the expert to make "good judgments" (Collins, 2010, 149). In more specific terms, this process can be seen as having a few general qualities, such as the "suddenness of their origin, the wholeness of the conception they embody, and the absence of conscious premeditation" (Medawar, 1969). Thus, intuition at the very least is a personal aspect of the expert and can be considered as a creative feature of the individual. Here, I take intuition to be the expert's creative ability to bring together potentially disparate pieces of information, to organize these pieces, and then build on this set of information, producing something greater than the original set. In this way, intuition is an epistemically ampliative process.

In the highlighted tipping point context, the scientist must, at least in part, use their intuition to creatively and uniquely link together the pieces of information about the target. They take what is currently known about the domain and then build on this set of information. In this way, they use their theoretical knowledge and intuition to produce a judgment about the actual state of the world. Ultimately, the output of this process contains more information than what was provided as an input, as the description of the world was not included in the original set of theoretical knowledge. The

[13] There are recognized difficulties in defining climate tipping points (see Armstrong McKay et al. 2022; Lam 2023; Kopp et al. 2025).

scientist's descriptive judgment can then be seen as momentarily filling the epistemic gap in the theoretical knowledge, allowing for the identification of potential tipping points, their potential interactions and other descriptions. In this way, the scientists were able to produce judgments which addressed the empirical uncertainty present in this context, providing a representation of the system which went beyond what was already known.

4. The subjectivity of tacit knowledge and intuition

Recall the type of subjectivity which, in section 2, I identified to be the focus of the values in science literature. Here, subjectivity was defined as (1) a personal aspect of the individual scientist, which is (2) used to address the uncertainty present within a decision-making context. As described in section 3, tacit knowledge and intuition are both used to address uncertainty within scientific decision-making contexts, specifically modal and empirical uncertainty. In this way, tacit knowledge and intuition fulfil the second half of this definition of subjectivity. I will, in turn, focus on the first half of the definition and argue that tacit knowledge and intuition also fulfil this condition, being a personal aspect of the individual scientist, and should then be seen as vehicles for the same type of subjectivity associated with values.

As stated, tacit knowledge is a kind of know-how, which can only be acquired by working within an epistemic community (Collins and Evans, 2007, 6). This know-how is seen as being consistently shared within a given epistemic community, making it largely locally consistent within a domain of research; however, it may not be consistent across domains (Majszak and Jebeile, 2023). The inconsistency across domains is generally due to tacit knowledge being incommunicable to others. The often-used example of this know-how is the type of expertise used when performing tasks, like riding a bicycle.[14] In this example, an individual can sit and read about the different mechanical processes necessary to ride a bicycle, however, until that individual gets on the bicycle and starts peddling they cannot acquire the tacit knowledge necessary to ride a bicycle. After acquiring the tacit knowledge, this individual can go to a friend and tell them how to ride a bicycle, attempting to relay the knowledge through their testimony. However, the knowledge is incommunicable in the sense that until this friend also sits on the bicycle and starts to peddle for themselves, they cannot acquire the tacit knowledge. Thus, the formation of tacit knowledge is reliant on the individual's experiences.

This highlights the personal nature of tacit knowledge, where the generation of this knowledge is dependent on the specific scientist. Due to the incommunicable nature of tacit knowledge, the point of generation for this knowledge must be within the individual where the knowledge resides. As shown in the bicycle example, one cannot acquire this knowledge through testimony; rather, it is the individual's interpretations and reflections on their own experiences which provides the basis for that individual to generate their specific set of tacit knowledge. In this way, tacit knowledge is a personal type of knowledge (Polanyi, 1958; 1966). While individuals within the same domain have a higher tendency to have similar experiences, working with the same tools/methods, and as a result may produce similar tacit knowledge, the generation of any single individual's tacit knowledge is exclusively based on that individual. In this way, tacit knowledge is a personal aspect of the individual, even if the generation utilizes a similar set of

[14] Collins (2010) defines this as somatic tacit knowledge.

experiences across scientists in a domain. Tacit knowledge is then in line with the account of subjectivity in question, being a personal aspect of the individual scientist.

Similarly to tacit knowledge, intuition is difficult to communicate or neatly place into an argument. As stated, intuition is an ampliative process, where a scientist brings together different pieces of information and then builds on the set to produce something epistemically greater than the original set. From this, an intuition can be examined relative to two features, the filling material of the intuition and the inductive skill of the scientist themselves. This first feature, the filling material, is the information that is used as the starting point from which the intuition builds, often consisting of the scientist's theoretical knowledge. While the specific set of theoretical knowledge which any scientist maintains is dependent on the individual, the generation of that knowledge is not dependent on that specific scientist.[15] In this way, the use of theoretical knowledge is not the relevant point of inquiry when discussing the subjectivity of a scientist's intuition, as it does not maintain the same personal aspect of the scientist as was identified for values and tacit knowledge.

The second aspect, the inductive skill of the scientist, then retains the focus for this discussion on subjectivity. This process allows the intuition to be epistemically ampliative, however, it is not well-defined. While there are a variety of formalized models which attempt to explain this process, with varying degrees of success depending on the context (Hayes et al., 2010), there is no set way for an individual to perform this inductive process. Rather, moving from limited information to a specific descriptive judgment is done through a unique process within the mind of the scientist. The reliance on the individual expert's abilities to produce an intuition highlights that one cannot provide a "logical method of having new ideas" as within every discovery there is "a creative intuition" (Popper, 1959). While the intuition is, in part, based on the expert's theoretical knowledge, the skill of implementing the inductive process is entirely dependent on the individual's abilities. Thus, the intuition's point of generation is a personal process which is based on the skill of the individual scientist. From this, the scientist's intuition is a personal aspect of the individual used to address uncertainty in a decision-making context and is then subjective in line with the previously identified conception.

In turn, I have identified a larger list of subjective influences on science, including tacit knowledge and intuition. This is placed in contrast to the current discussion of this type of subjectivity, which has only been attributed to the use of values. Additionally, while I previously argued, in section 2, that the general recognition of values in science is due to their use in addressing normative uncertainty, I have now identified two further uncertain contexts where this subjectivity is used, modally and empirically uncertain decision-making contexts. What remains clear is that all vehicles of subjectivity, values, tacit knowledge, and intuition, maintain an intimate connection with the three forms of uncertainty, as these vehicles allowed the scientist to address the uncertainty in the decision-making contexts. The

[15] To be clear, individual scientists are contributing to their domains and, in this sense, are contributing to the set of theoretical knowledge. However, they are not the only source of the knowledge nor the point of generation for this knowledge.

use of this kind of subjectivity can then be seen as a necessary feature of addressing uncertainty across scientific decision-making contexts.

5. The impact on epistemic reliability

There are a variety of potential concerns which stem from the use of tacit knowledge and intuition in these uncertain contexts. I return to the demarcation between the context of discovery and the context of justification to assist in providing a focus for this discussion. Specifically, I will discuss the impact of the different vehicles of subjectivity in the context of discovery, as the previously discussed examples from climate science would be situated here. While I agree that the demarcation between these two contexts does not provide sufficient separation to contend that the introduction of subjectivity only influences the context of discovery (Elliott and McKaughan, 2009; Bueter, 2015), this distinction can still be useful.

Specifically, this distinction highlights where the decisions are taking place and some relevant epistemic considerations. Recall that the context of discovery focused on the production of information, this presents unique epistemic concerns which stem from the impact of introducing this type of subjectivity into science. As discussed in section 2, concerns regarding the use of values may include, non-epistemic values not promoting truth, negative impacts on the autonomy of decision-makers who use scientific information, as well as negative impacts on public trust in science (see Elliott, 2022). It is argued that because non-epistemic values have no necessary connection to truth, their use can lead scientists to promote work which is in line with a certain set of non-epistemic values (Hudson, 2021). This raises genuine epistemic concerns of the information being less likely to be true, where laypersons may worry about the value-ladenness of scientific claims, impacting the perceived trustworthiness of those claims and science in general. From the perspective of the context of discovery, the trustworthiness of the information and the process of producing the information then becomes a relevant concern.

To ensure trustworthiness, one may suggest that the vehicles of subjectivity have no place in science and that their use should be barred. However, as shown, these vehicles are necessary for addressing uncertainty, presenting a challenge for their complete removal. To better ensure trustworthiness of the information production process, one can focus on the epistemic reliability of that process. It is argued that "both scientists and philosophers of science believe the validity of experimental results to rest partially in the ability of experimenters to reproduce these results" (Hudson, 1994). Thus, the epistemic reliability of scientific information can be seen in reference to the reproducibility of that information. This sense of reliability is a pragmatic one, concerning the ability to reliably reproduce the information under a similar set of circumstances (Hudson, 1994). In this way, a condition for this reproducibility is the ability to set a framework or conditions under which the information is reproducible, given that the conditions are constantly held. One can utilize this concept of reproducibility within the two previously discussed examples to examine the impacts of tacit knowledge and intuition on epistemic reliability.

Within the climate model parameterization example, tacit knowledge was used to address the modal uncertainty present in the context of constructing a model parameterization to represent a target phenomenon. The scientist was shown to use their tacit knowledge to identify a conception of practical possibility and produce a possibilistic judgment, where the scientist then made decisions in accordance with that judgment. Thus, the introduction of subjectivity was through this decision-making context. From the perspective of the impact of tacit knowledge on reproducibility, the focus is then on maintaining consistency in the decision-making for subsequent modeling efforts. A consistent framework of use for the identification and documentation of the subjectivity within these judgments would then be needed to maintain the epistemic reliability. This can be possible within the highlighted example as the expression of tacit knowledge, while not explicitly stated given its incommunicable nature, is captured in the decisions, where these choices can be well documented in an associated methods section or in supplementary documents. Here, even small choices can, potentially, be documented and subsequently implemented in future efforts which aim to replicate a given result. In this way, the impact of subjectivity on the production of the information can, in theory, be accounted for within a single instance of the building of a model parameterization, allowing for reproducibility and limited impacts on epistemic reliability.

While this single use may result in limited concern for the epistemic reliability of the production process, it is important to recognize that the subjectivity used to address the modal uncertainty is implicitly included in the body of scientific knowledge. The use of this subjectivity can then become epistemically detrimental to the production of further information through its role in the production of previous information. Given that the possibilistic judgment is regarding what is practically possible, there could be concerns that future researchers may look at the past decision-making, done in accordance with one conception of possibility, and have their subsequent research follow this same structure. This can be detrimental in two ways.

First, by focusing on past decisions, one may be inclined to extend these choices to different contexts. This can be detrimental because it is assuming a kind of 'plug and play' structure for these choices, where a choice that worked within one context is assumed to work in another. However, tacit knowledge is incommunicable, so it is unclear what conception of practical possibility was produced given the specific modal uncertainty present in that context. In this way, the modal uncertainty may be different, even in similar contexts, and require a different conception of practical possibility. Second, this may not allow subsequent researchers to exercise their own tacit knowledge to address the modal uncertainty. There is no unique 'best' way to address the modal uncertainty in these contexts. Thus, by focusing on the choices of past researchers, this may limit a future researcher's willingness to exercise their own tacit knowledge to address the uncertainty. They may even be under the false impression that the documented choices are the only way to address the modal uncertainty. Ultimately, additional conceptions of practical possibility would not be produced in the same or unique contexts, limiting the expression of the sets of tacit knowledge. From these considerations, there are genuine epistemic concerns for future inquiry.

Aside from the tacit knowledge used to address modal uncertainty, intuition, as a vehicle for subjectivity, was shown to be used in addressing the empirical uncertainty within the climate tipping points example. Here, it was highlighted that producing empirical judgments about tipping points is beset with deep uncertainty. Given this deep uncertainty, scientists can't agree on the appropriate model of the system nor the probability of specific outcomes/scenarios, resulting in problems for utilizing classic decision theoretic frameworks (Helgeson, 2020). Thus, it is unclear what systems have the potential to tip as well as how they interact with other systems and the associated likelihoods of tipping. As a result, the expert must take their theoretical knowledge and use their intuition to produce something greater than the sum of the parts. In this example, this resulted in the expert constructing a representation of the system, identifying potential tipping points, including their interactions, and the likelihood of a tipping event under a number of proposed scenarios. Here, the subjectivity is being used to make a statement about the current and potential future state of the world, addressing the empirical uncertainty.

Unlike the subjectivity used to address modal uncertainty, which is implicitly included in the body of scientific knowledge, the subjectivity used to address empirical uncertainty is explicitly included. Here, the scientist's intuition was necessary for identifying the representation of the state of the world, where this representation is then the direct point of reference for any claim about the system. This can introduce increased concerns for the epistemic reliability of the information, as these judgments are no longer regarding procedural decisions but are instead providing a description. Since these judgments are produced by an opaque inductive process it is difficult to document how the scientist arrived at the specific representation. This results in less transparency in the production of the information and a potential problem for its reproduction, as you would not be able to follow the specific line of reasoning to reproduce the judgment. Additionally, given the deep uncertainty in this context, other scientists, using their unique intuitions could produce a different representation of the system and its associated likelihoods, potentially negatively impacting the consensus among experts.

However, these concerns regarding the reliability of the information can be diminished. Specifically, one can look at the descriptive judgments from the perspective of a robustness like reasoning. In general terms, robustness reasoning contends that when multiple independent lines of evidence produce the same conclusion or claim then this adds validity or confirmatory support to said conclusion (Lloyd, 2015; Schupbach, 2018; O'Loughlin, 2021). This reasoning is relevant for this context of addressing empirical uncertainty in two ways. First, if multiple scientists come to the same judgment, then one may argue that this judgment is relatively robust. However, maintaining the necessary independence between scientists would need to be investigated given that, in general, the judgments utilize a shared set of theoretical knowledge across experts. Nonetheless, one can still use this line of reasoning to characterize the robustness of the inductive skill of the scientist and how their individual mind builds on an incomplete set of information to produce the intuition, as this is not shared across experts. Ultimately, if multiple scientists, using their unique inductive skills, independently[16] come to the same judgment then one can see robustness in the reproducibility of said judgment.

Second, if there are multiple lines of evidence which support a representation of the system and the interactions between sub-processes then there will be less of a reliance on intuition. Here, there would be a larger set of theoretical knowledge, which can be documented to provide the justification, increasing the reproducibility of the information and decreasing the reliance on the expert's inductive skills. Thus, depending on the level of empirical uncertainty which needs to be addressed there will be a corresponding reliance on intuition, making the associated concerns a matter of degree. While the use of intuition for addressing empirical uncertainty does pose a risk for the epistemic reliability of the information, there are meaningful steps that can be taken to recognize these concerns, however, more work must be done to manage the effects.

6. Conclusion

This paper discussed the vehicles which introduce subjectivity into science and the impact this type of subjectivity can have on epistemic reliability. Here, I first identified the type of subjectivity referenced within the literature on values in science, this being, a personal aspect of the individual scientist used to address the uncertainty present within a decision-making context. I then argue that, while it is not explicitly stated, the current discussion of this subjectivity within the literature actually focus on instances of normative uncertainty present within these decision-making contexts, where values are being used to address this uncertainty. In this way, I have uniquely identified a connection between the use of values in science and the presence of normative uncertainty. However, I subsequently argued that the use of this type of subjectivity is not exclusive to these examples of value use in science. In this way, I present a message to philosophers – when you recognize the presence of this type of subjectivity in science you should not assume that the introduction of that subjectivity was due to a value judgment.

To show how this subjectivity is also introduced into science beyond the use of values, I discussed two examples from climate science as cases of modally and empirically uncertain scientific decision-making contexts. To address these uncertainties, I argued that two additional aspects of the scientist are used. Tacit-knowledge was shown to be used in producing a probabilistic judgment, providing the modal content necessary to address the modal uncertainty in the climate model parameterizations example. Intuition was shown to be used in producing a descriptive judgment, providing the empirical content necessary to address the empirical uncertainty in the climate tipping points example. In this way, I identified two additional vehicles which introduce subjectivity into science when various forms of uncertainty are present. Thus, I contend that the use of this type of subjectivity is a necessary feature of addressing uncertainty across scientific decision-making contexts.

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[16] Maintaining independence would need to be investigated as there may be additional pressures for judgments to conform.

I concluded by discussing the epistemic concerns, highlighting the unique impacts tacit knowledge and intuition have on the epistemic reliability of scientific information. Genuine concerns regarding the reliability of the information production where identified, demonstrating the need for careful evaluation of the subjectivity and highlighting a need to develop further management tools for the variety of vehicles of subjectivity. To be clear, epistemic reliability is not the only genuine concern which stems from the use of this subjectivity in science. Rather, given the necessary use of values, tacit knowledge, and intuition in addressing multiple forms of uncertainty, additional work must be done to discuss the further impacts in greater detail.

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