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Unquestioned Answers or Unanswered Questions: Beliefs About Science Guide Responses to Uncertainty in Climate Change Risk Communication

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In two experimental studies we investigated the effect of beliefs about the nature and purpose of science (classical vs. Kuhnian models of science) on responses to uncertainty in scientific messages about climate change risk. The results revealed a significant interaction between both measured (Study 1) and manipulated (Study 2) beliefs about science and the level of communicated uncertainty on willingness to act in line with the message. Specifically, messages that communicated high uncertainty were more persuasive for participants who shared an understanding of science as debate than for those who believed that science is a search for absolute truth. In addition, participants who had a concept of science as debate were more motivated by higher (rather than lower) uncertainty in climate change messages. The results suggest that achieving alignment between the general public's beliefs about science and the style of the scientific messages is crucial for successful risk communication in science. Accordingly, rather than uncertainty always undermining the effectiveness of science communication, uncertainty can enhance message effects when it fits the audience's understanding of what science is.

KEY WORDS: Climate science communication; model of science; uncertainty

1. INTRODUCTION

With the increased speed of scientific and technological development, and improved access to scientific information across the society, effective communication of scientific research to the general public has become an acute problem. This problem is particularly apparent in certain areas of science that aim to communicate risks and may have significant implications for the general public, such as climate science.[1,2] One aspect of scientific information that is seen as particularly problematic for communication with the general public is the uncertainty inherent in most scientific findings. Science rarely provides answers or predictions with absolute certainty. Yet, ordinary people typically look for certainty when deciding how to act in their everyday lives. For an illustration of the different value given to uncertainty in scientific versus public spheres, one could consider the different meaning of the word "theory" in these domains. In the scientific sphere "theory" refers to a coherent set of statements describing the hypothesized state of the world, whereas in everyday language "theory" may be a dismissive term referring to a speculative and unverified view.

Recently, some researchers have responded to the challenge of communicating uncertainty in (climate) science by exploring how parameters of the message, such as aspects of its content and framing, might improve message understanding and impact among lay audiences.[3–5] There is also, however, a growing understanding that messages themselves are not the only determinant of success in scientific

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communication. The importance of taking into account the audience's beliefs and expectations and how these might interact with the message are being highlighted in research on risk communication.[6] Indeed, it is more likely that both recipients and communicators, as well as the aspects of the relationship between them, actively shape the process of communication and determine its outcomes.

In response to this understanding, some research has explored the expectations that scientists and general audiences have of each other, and how these expectancies shape the way (risk) communication is received.[7] For example, when audiences perceive negative intent or a hidden agenda from a communicator, even the most masterfully crafted message will fail to have an impact.[8,9] Extending this line of inquiry, we were interested in how beliefs about science itself might guide the way in which audiences interpret scientific communications about risk. With respect to the issue of communicating scientific uncertainties, it seems that interpretations of these are likely to be guided by what people think the purpose of science is—specifically, whether science is seen as the quest for absolute truth or as a debate between alternative positions. People who ascribe to the former (classical) model of science are likely to perceive uncertainty as undesirable as it interferes with the search for truth. However, people who ascribe to the latter (Kuhnian) model of science should be more open to ambiguity and uncertainty in science communication because this is the very stuff that science is built on. To the extent that this hypothesis is true, lay beliefs about science may have important implications for managing uncertainty in science communication generally, and in risk communication in particular.

The aim of this article is to explore general beliefs about science and how these influence responses to uncertainty in science messages about climate change risks. We start this exploration by briefly reviewing previous research on uncertainty in science communication (and, more specifically, risk communication). We then focus on possible models of science and suggest a hypothesis about the relationship between these models and perception of uncertainty. Finally, we test this hypothesis in two experimental studies.

1.1. Uncertainty and Science Communication

Traditionally, uncertainty has been seen as one of the central barriers to communicating scientific information. For example, studies of scientists have documented a perception that the public misunderstands uncertainty by seeing this as a sign of poor understanding of the subject.[10] This contrasts from the scientists' own perspective, from which estimated uncertainty may actually be a sign of a rather deep understanding. Indeed, scientists' beliefs about how uncertainty is interpreted may not be far from reality: other studies confirm that uncertainty in scientific statements is treated as problematic, and that sources who communicate uncertainty may not be seen as trustworthy.[11] Similar results were obtained in studies that looked specifically at risk communication. In particular, Johnson and Slovic[12] argue that uncertainty in risk communication is problematic—instead of informing the recipients, it tends to evoke confusion and anger. In their earlier work, these researchers stressed that the general public is mostly unfamiliar with uncertainty in risk assessments and science. Moreover, discussion of uncertainty in risk estimates may signal the source's incompetence to the audience.[13] As a result, uncertainty is unlikely to be eagerly communicated, nor keenly received, in communications between the scientific world and the public.

A cautious approach to uncertainty is not unique to science communication. Research from other domains suggests that people are generally averse to vague information in principle.[14–16] When making personal choices, people tend to discount uncertain information in the process of decision making,[17–19] and to be less inclined to act in response to information that conveys uncertainty rather than certainty.[20,21] When engaging in collective behavior, uncertainty can also undermine effective action. For example, in collective goods dilemmas introducing vagueness about the degree to which a shared resource might be replenished leads to higher rates of self-serving (as opposed to cooperative) behavior.[22]

The potentially negative effects of uncertainty on effective action identified in experimental work can be seen in responses to the real-world issue of climate change. Here, scientific uncertainty about the impacts of climate change has been suggested to contribute to people's unwillingness to sacrifice self-benefit to mitigate climate change.[23] The idea that uncertainty may undermine the effectiveness of scientific messages has led researchers to explore factors that mitigate against these negative effects. For example, one set of studies varied the framing of risk messages about climate change such that these focused on either uncertainty about negative outcomes or uncertainty about the logically equivalent positive outcome.[4] This research found that when scientific messages focused on the negative impacts of climate change, increasing levels of uncertainty in these messages undermined individual intentions to act against climate change. However, when messages were framed more positively by focusing on the chances of *avoiding* negative outcomes, increasing levels of uncertainty in these messages did not undermine individual motivations to act on climate change. On the basis of these patterns, the researchers suggest that although uncertain pessimism may indeed interfere with effective action, uncertain optimism may actually motivate action. Indeed, previous research demonstrates that uncertainty in risk estimates may signal not only lack of competence, but also communicators' honesty and trustworthiness.[13] As such, uncertainty itself may not always be a barrier for effective communication.[5]

1.2. Models of Science

The features of specific messages, such as their framing,[4] are unlikely to be the only factor relevant to understanding how people respond to scientific uncertainty. More general processes that guide how people orient to communication in the first place should also determine the effects of specific messages. In this regard, how people orient toward science itself seems relevant to understanding the effects of science communication. This idea sits well with a broader literature showing how prior expectations color responses to communication over and above the features of specific messages.[8,9,24,25] For example, in research on risk communication, the importance of understanding the audience's beliefs and expectations before constructing the communication is explicitly highlighted.[6] Although the public does hold beliefs about science that are likely to be consequential for communication,[26–28] to date the precise role of such beliefs in determining responses to specific scientific messages has remained relatively underexplored. What kinds of beliefs might be relevant for understanding how the public approaches uncertainty in science communication? To answer this question, we consider how uncertainty is represented in different philosophical models of science.

A brief look at the philosophy of science suggests two main models of science favored in different periods of history. The classical model of science dates back to Aristotle (its proponents include Newton, Pascal, Descartes, Kant, and, more recently, Husserl and Bolzano[29]). According to this model, things exist independently of one's knowledge about them and can be objectively discovered and proved. The aim of science, then, is to uncover the objective truth about the physical world and to provide a solid proof of the validity of this knowledge. Importantly, this model suggests that there is a single version of truth to be discovered: true knowledge is exempt from debate because it can be unquestionably proven. Thus, the classical model of science presents good science as a set of *unquestioned answers*—it suggests that each question has one correct answer that needs to be discovered.

An alternative model of science developed at a later moment in history through the works of such philosophers as Karl Popper and Thomas Kuhn.[30–32] According to this model, science is seen as a series of paradigms (or general ways of seeing the world and theorizing about it) that engage in debate and conflict and substitute one another in the process of science development (i.e., paradigm shifts). Importantly, because each paradigm uses a unique set of untestable presuppositions, each "discovery" is only valid within its particular paradigm. According to this perspective, knowledge (or a theory) cannot be objectively proved to be "true." The only way to move toward the "truth" is to eliminate hypotheses that are *not* true (i.e., the principle of falsification). This opens up an opportunity for simultaneous existence of multiple versions of truth with equal epistemological status, and suggests that the function of science (as a social enterprise) is to debate these different versions. In sum, this more contemporary model presents science as a set of *unanswered questions*—it assumes that each scientific question has a number of possible answers equally valid within an active scientific paradigm.

It is easy to see that uncertainty has different status within each of these philosophical models of science. The classical model assumes that although uncertainty about the "truth" is possible at early stages of scientific inquiry, as science progresses, uncertainty should decrease until it is finally eliminated. When truth is discovered, there is no space for uncertainty. In contrast, the model of science as debate suggests that uncertainty is an integral part of scientific research, and that there is no "final" stage of the scientific process where this uncertainty is resolved. Within this framework, some degree of uncertainty will always be attached to scientific knowledge because of its paradigm-specific nature. Given this, people should respond very differently to uncertainty in scientific statements as a function of the model of science they ascribe to. Advocates of the classical model of science are likely to report stronger intolerance to uncertainty than those who share Kuhnian understanding of science.

1.3. Present Research

Although most members of the general public are unlikely to have elaborate models of science akin to those developed by Descartes or Popper, it is still conceivable that they may hold specific beliefs about the purpose and nature of science. Indeed, previous research has demonstrated that the public is not insensitive to what science conveys about its principles and purposes while communicating its findings.[33–35] To the extent that this is true, lay beliefs about the nature and purpose of science may be an important lens through which people interpret scientific information. In this article we are specifically interested in how such beliefs guide responses to uncertainty in scientific statements about risk.

Our general prediction was that people who ascribe to the model of science as a search for absolute truth (i.e., a classical model of science) will be demotivated by uncertainty in scientific statements because uncertainty is inconsistent with what they see science to be. Conversely, for people who ascribe to a model of science as a forum for debating different versions of truth (i.e., a Khunian model of science), the presence of uncertainty in scientific statements about possible risks should not be demotivating because uncertainty is consistent with how they see science.

We tested these ideas by exploring intentions to engage in pro-environmental behavior following exposure to scientific messages about risks of climate change that varied in levels of communicated uncertainty. In Study 1, we assessed beliefs about the purpose of science and examined their role in shaping responses to uncertainty. In Study 2, we directly manipulated beliefs about science (i.e., as the search for truth vs. a process of debate) to test their causal role in guiding responses to uncertainty in science communication.

2. STUDY 1

In Study 1 we premeasured participants' beliefs about science in terms of the two major philosophical models of science. That is, we assessed whether people believed that scientific questions have only one correct answer (a classical model) versus multiple possible answers (a Khunian model) before exposing them to climate science statements with different degrees of uncertainty (lower vs. higher). We then assessed participants' intentions to act in an environmentally sustainable way as an indicator of whether the message was motivating or demotivating. We expected that participants who believe that scientific questions have only one correct answer will express weaker environmental intentions than those who believe that multiple answers are possible when facing a higher (rather than lower) degree of uncertainty.

In addition to manipulating the degree of uncertainty, we also manipulated the source of this uncertainty. Uncertainty in scientific statements can be caused by a variety of factors.[36,37] On the one hand, uncertainty may arise from the data themselves, and statistical analyses may produce estimates of the uncertainty around a given finding based on the variability in the data. Alternatively, uncertainty can arise from variation between experts—for some phenomena scientists may be in broad agreement (low uncertainty), whereas for other phenomena there may be a considerable disagreement between experts who approach the topic from different perspectives (high uncertainty). Although beliefs about the nature of science are relevant to both of the above types of uncertainty, it may be that these beliefs guide responses to expert uncertainty more strongly than responses to data uncertainty given that it is the former type of uncertainty that the different models seem to speak to most directly. On this basis, we also explored whether the predicted interplay between beliefs about science and communicated uncertainty depended on the specific source of that uncertainty.

2.1. Method

2.1.1. Participants and Design

One-hundred-eight adults participated in the study (26 males and 82 females, mean age 20.4 years). Participants were recruited from a student participant pool of a British university. A 2 (uncertainty level: high vs. low) $\times$ 2 (uncertainty type: data vs. expert) between-subject design was used. Participants were randomly allocated to one of the four conditions. Participants' beliefs about science were premeasured before the experimental manipulation. The dependent variable was participants' willingness to engage in environmentally sustainable behavior.

2.1.2. Materials and Procedure

Participants received an e-mail with an electronic link to the online survey. First, participants' beliefs about science were measured. Three items were used to measure these: "There may be more than one correct answer to most scientific questions" (recoded), "For most scientific questions there is only one correct answer," and "Uncertain answers to scientific questions are a sign of imperfect knowledge." Participants reported their agreement or disagreement with each item on a seven-point scale from 1 (strongly disagree) to 7 (strongly agree) and the three items were combined into a single index on which higher scores represented stronger commitment to a classical model of science ($\alpha = 0.72$; $M = 3.67$, $SD = 1.31$).

On the next page, participants were given a brief explanation of the Stern Review ("a government report prepared by leading climate change experts from the UK, . . . which details the likely impacts of climate change"). They were then asked to read six statements that were said to be taken from the Stern Review and concerned possible impacts of climate change. The type of uncertainty (i.e., data vs. expert) and level of uncertainty (i.e., lower vs. higher) were manipulated by varying the content of these statements.

In the data uncertainty condition, uncertainty about the impacts was expressed by presenting the likelihood of specific impacts occurring. In the low uncertainty condition, this likelihood was estimated by a single figure (e.g., "There is 80% chance that global warming may make more than a quarter of all species extinct"). In the high uncertainty condition, the likelihood was estimated by a percentage range (e.g., "There is 70–90% chance that global warming may make more than a quarter of all species extinct"; for a similar manipulation of uncertainty, see Ref. 4). The single-figure likelihood in the low uncertainty condition always matched the mean of the likelihood interval in a corresponding sentence of the high uncertainty condition and the statements included impacts that were both high likelihood and low likelihood.

In the expert uncertainty condition, uncertainty was expressed via a percentage of experts that agree that a particular impact of climate change may occur (e.g., "nine out of ten experts agree that global warming may make more than a quarter of all species extinct"). In the low uncertainty condition, the proportion of experts in agreement was high (i.e., nine out of ten or ten out of ten for all statements). In the high uncertainty condition, this proportion was lower (i.e., six out of ten or five out of ten).

After reading the climate change statements, participants were asked about their own intentions in relation to the issue of climate change. Specifically, they were asked to report how likely they were to perform a number of environmental behaviors during the following month (e.g., decrease non-green energy consumption, reduce water use, change behavior in any way because of environmental concern) plus how willing they were to support the introduction of household carbon budgets (overall seven items, $\alpha = 0.73$). Participants responded to all items on a seven-point scale from 1 "very unlikely" to 7 "very likely." After completing the questionnaire participants were thanked and debriefed.

2.2. Results

We conducted a regression analysis with level of uncertainty (lower = 0; higher = 1), type of uncertainty (data = 0; expert = 1), and beliefs about science (centered) as predictors and environmental intentions as the dependent measure. All main effects were tested at the first step, and all two- and three-way interactions were tested at the second and third steps, respectively. There were no significant main effects at Step 1. At Step 2, the only significant interaction was between level of uncertainty and beliefs about science: $\beta = 0.29$, $p = 0.037$; see Fig. 1. The three-way interaction introduced at the next step was not statistically significant.

To decompose the two-way interaction, we explored the relationship between beliefs about science and willingness to act on climate change as a function of degree of uncertainty in the message. This analysis demonstrated that participants who faced the higher level of uncertainty responded with significantly stronger intentions when they believed that debate is an integral part of science rather than when they believed that science should provide unequivocal answers: $\beta = 0.29$, $p = 0.035$. However, beliefs about science played a lesser role in guiding individual responses among those presented with a message containing lower uncertainty: $\beta = -0.16$, $p = 0.260$. Said differently, participants who believed that debate is part of science responded to the higher level of uncertainty with stronger environmental intentions than to the lower level uncertainty: $\beta = 0.34$, $p = 0.013$. In contrast, participants who believed that science should provide certain answers were not significantly affected by the level of uncertainty they were exposed to: $\beta = -0.10$, $p = 0.453$.

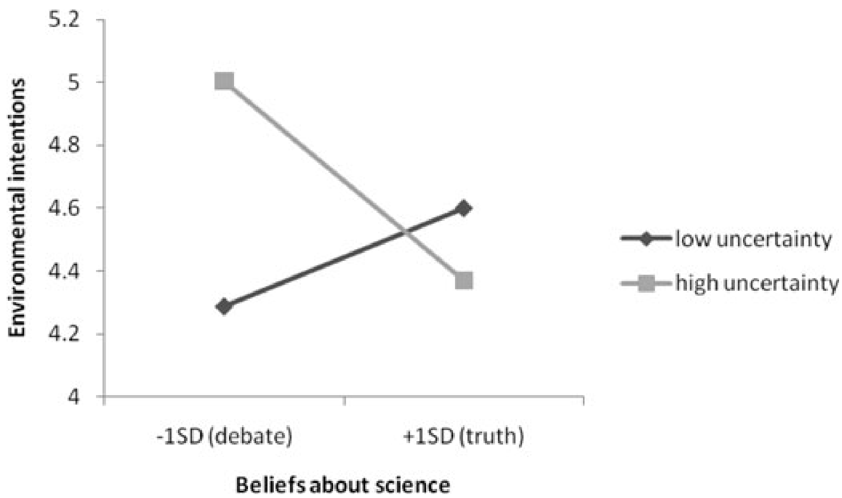

Fig. 1. Mean level of environmental intentions as a function of beliefs about science and message uncertainty (Study 1).

2.3. Discussion

Study 1 provided some initial support for our hypothesis that beliefs about the nature of science guide responses to uncertainty in scientific statements. Specifically, we found that among participants who believed that scientific questions can have multiple answers (i.e., who adopted a Kuhnian model of science) communicating uncertainty in scientific messages did not undermine relevant action. In fact, these participants responded to high uncertainty about impacts of climate change by increasing their willingness to act in a sustainable way. This contrasted from participants who adopted a more classical model of science. Contrary to predictions, however, rather than being motivated by scientific certainty, these participants were relatively unresponsive to the level of communicated uncertainty. This may partly reflect that although the experimental conditions did differ in their degree of uncertainty, some level of uncertainty was present in both conditions (i.e., we never present participants with a set of statements of 100% certainty or agreement). This could suggest that people who adopt a model of science as truth search for *absolute* certainty before deciding how to act, rather than being influenced incrementally by degrees of uncertainty. Given the unpredicted nature of this finding, however, we will return to this issue after considering the results of Study 2. Finally, although we anticipated that the interplay between beliefs about science and communicated uncertainty might further depend on the specific source of uncertainty (data vs. expert disagreement) there was no evidence for this in our study. Instead, the data suggest that one's model of science (as measured in this study) is relevant to interpretation of uncertainty irrespective of its source.

Although these patterns do provide some support for our predictions, a fully experimental design would provide stronger support for the causal role of beliefs about science in guiding responses to uncertainty. As such, a goal of the second study was to replicate the observed interaction using an experimental manipulation designed to affect individual beliefs about science. In addition to replicating the interaction, a manipulation of models of science might allow a fuller comparison between classical and Kuhnian frameworks. In Study 1, participants scored around the midpoint of the beliefs measure. This suggests that although some were Kuhnian and others classical in their approach to science, in general participants were ambivalent about these specific models of science. Amplifying the distinction between these two models might allow for the predicted effect of certainty in motivating action among people with a classical model, in addition to demonstrating the effect of uncertainty in motivating action among those with a more Kuhnian approach. Given the absence of source of uncertainty effects in Study 1, we no longer considered this factor in the second study.

3. STUDY 2

3.1. Method

3.1.1. Participants and Design

One-hundred-six adults participated in the study (43 males and 63 females, mean age 30.7 years). Participants were recruited via various online fora. A 2 (uncertainty level: high vs. low) $\times$ 2 (perception of science: debate vs. search for absolute truth) between-subject design was used. The type of uncertainty was held constant in this study (data uncertainty). Participants were randomly allocated to one of the four conditions. The dependent variable was participants' willingness to engage in environmentally sustainable behavior.

3.1.2. Materials and Procedure

Participants completed the study online. On the first page, participants' beliefs about science were experimentally manipulated. Participants in all conditions read a short text about the "nature of science" that they believed to be an excerpt from a book *What* Is *Science*? written "to communicate the idea of science widely accepted within the scientific community." In the "debate" condition, the text suggested that the purpose of science is to debate different versions of truth, not to uncover absolute truth. It highlighted that scientists' function is not to generate truth, but to propose and test theories, and that most scientific questions have more than one plausible answer. The text concluded that all scientific findings are inherently uncertain and good science is explicit about uncertainties involved. In the "absolute truth" condition, the text suggested that the purpose of science is to uncover unquestionable truth. It stressed that for most scientific questions there is only one correct answer, and the purpose of science is to find it. It concluded by saying that uncertainty is a sign of imperfect knowledge and as science progresses it is able to offer clear answers that do not allow alternative interpretations.

After reading the text, participants responded to four manipulation check items: "The role of science is to uncover truth," "The role of science is to debate different versions of truth," "There may be more than one correct answer to most scientific questions," and "For most scientific questions there is only one correct answer." Participants responded to all items on a seven-point scale from 1 (strongly disagree) to 7 (strongly agree). The second and third items were recoded, and the single manipulation check score was computed ($\alpha = 0.72$).

On the next page, the level of data uncertainty was manipulated in the same way as in Study 1. After being given a brief explanation of the Stern Review, participants were asked to read six statements that were said to be taken from the Stern Review that concerned the possible impacts of climate change. In the low uncertainty condition, this likelihood was estimated by a single figure (e.g., 80%) while in the high uncertainty condition, the likelihood was estimated by a percentage range around the likelihood estimate (e.g., 70–90%). Again, the statements included a mix of high and low probability events.

After reading the climate change likelihood statements, participants were asked to report how likely they were to perform a number of environmental behaviors during the following month (e.g., reduce water use, increase recycling, join an environmental organization; overall 12 items, $\alpha = 0.86$). Participants responded to all items on a seven-point scale from 1 "very unlikely" to 7 "very likely." After completing the questionnaire participants were thanked and directed to a debriefing page.

3.2. Results

3.2.1. Manipulation Check

An independent samples *t*-test conducted on the manipulation check measure demonstrated that the manipulation of beliefs about science was successful. Participants in the "absolute truth" condition agreed more strongly that science is about finding truth and giving definite answers ($M = 4.42$, $SD = 1.20$) than participants in the "debate" condition ($M = 3.57$, $SD = 1.10$): $t\ (105) = 3.78$, $p < 0.001$, $d = 0.74$.

3.2.2. Main Analysis

A 2 (level of uncertainty: high vs. low) × 2 (beliefs about science: debate vs. search for truth) ANOVA was performed on the environmental intentions measure. The analysis revealed the predicted interaction between level of uncertainty and beliefs about science: $F\ (1, 104) = 6.63$, $p = 0.011$, $\eta^2 = 0.06$, with no significant main effects of either variable (Fs < 0.47, ps > 0.49); see Fig. 2.

Follow-up comparisons revealed that participants in the high uncertainty condition responded with stronger environmental intentions when they were led to believe that science is about debate ($M = 4.23$, $SD = 1.05$) rather than search for absolute truth ($M = 3.59$, $SD = 1.20$): $F\ (1, 104) = 3.99$, $p = 0.048$, $\eta^2 = 0.04$. In contrast, participants in the low uncertainty condition were more motivated to behave sustainably when they believed that the purpose of science is to uncover truth ($M = 4.01$, $SD = 1.25$) rather than debate different versions of truth ($M = 3.49$, $SD = 1.13$), although this difference did not reach statistical significance: $F\ (1, 104) = 2.70$, $p = 0.104$, $\eta^2 = 0.03$.

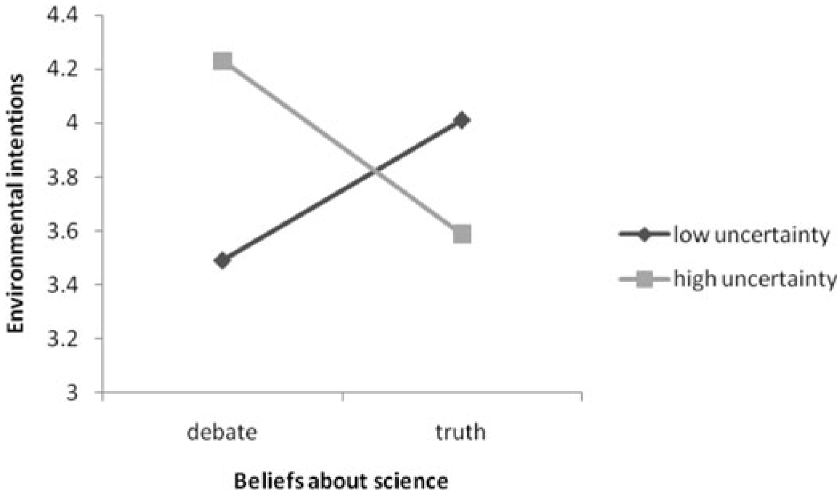

Fig. 2. Mean level of environmental intentions as a function of beliefs about science and message uncertainty (Study 2).

Said differently, participants who believed that the purpose of science is to debate different versions of truth reported stronger intentions after reading information with the higher rather than lower level of uncertainty: F (1, 104) $= 5.95$, $p = 0.016$, $\eta^2 = 0.06$. In contrast, participants who believed that science is about searching for absolute truth were more motivated by information with the lower level of uncertainty, although this difference did not reach statistical significance: $F\,(1, 104) = 1.61, p = 0.207, \eta^2 = 0.02$.

3.3. Discussion

The results of Study 2 again supported our hypothesis regarding the role of different models of science in guiding responses to scientific uncertainty. Importantly, participants' models of science were manipulated (rather than measured) and as such this study provides evidence for the causal role of these in responses to uncertainty. As predicted, participants who were led to believe that science is a debate (rather than search for absolute truth) were more motivated to act in response to messages that contained a higher level of uncertainty than by less uncertain messages. In contrast, participants who were led to believe in the classical model of science demonstrated the opposite effect. Thus, scientific information with a higher level of uncertainty about the risks was more motivating when it corresponded to participants' beliefs about science. As in the previous study, however, although the pattern of means was in the predicted direction, the effect of uncertainty was significant in the "debate" condition, but not in the "truth" condition. We return to this issue in the general discussion.

4. GENERAL DISCUSSION

In this article we aimed to explore the role of beliefs about science in responses to scientific uncertainty. Specifically, we focused on the contrast between the classical model of science (believing that most scientific questions have a single true answer) and the Kuhnian model of science as debate (believing that scientific questions may have multiple answers that could be negotiated and debated). Our results demonstrated that people do hold beliefs of this kind, and that these beliefs guide responses to uncertainty in risk communications. Across both studies, participants who held beliefs consistent with the Kuhnian model of science (whether measured or manipulated) seemed more accepting of scientific uncertainty and more willing to act in response to risk messages that communicated uncertainty rather than certainty. Although the opposite effect was apparent among participants who held beliefs consistent with the classical model of science as a search for absolute truth, this difference did not reach significance. One explanation for this could be that the studies lacked statistical power to reveal this comparatively weak effect. A more important question, however, is why the effect of uncertainty was weaker in the latter case. One reason for this might be that some degree of uncertainty was present in all experimental conditions. Participants whose beliefs were consistent with the classical model of science may be looking for absolute certainty from science rather than relative certainty. In other words, the very presence of uncertainty may signal to such participants that the information provided is not consistent with their view of what good science should be. As there was always some degree of uncertainty present in our experimental stimuli, the difference between the conditions may not have been strong enough to elicit motivations to act among this group. To resolve this, future research could explore whether people who believe in science as a search for truth respond differently to information that contains no uncertainty (as opposed to information with some degree of uncertainty).

Another possible explanation is that proponents of the classical model of science may acknowledge that uncertainty is inevitable (and acceptable) at the early stages of science development. Some of them may realize that climate science is exactly at such an early stage at the moment (and thus respond more positively to higher levels of uncertainty), although others may not make this concession (and thus be stricter in their judgments of credibility). The uncontrolled differences in participants' understanding of the stage of development of climate science could have diluted the effect of uncertainty in the classical model of science condition. To eliminate this ambiguity, future research could experimentally manipulate participants' understanding of the stage of development of the science in question.

The present findings qualify some previous research on the role of uncertainty in understanding and responding to scientific statements. Unlike this previous research,[11,17,20,23] our data suggest that uncertainty in science does not always undermine willingness to act in line with scientific messages. In fact, uncertainty can be motivating for those who share the concept of science as debate. Although our data demonstrate that uncertainty in science is not demotivating in an absolute sense, it is important to note that our measure of intentions did not directly juxtapose participants' individual interests against collective benefit (like some previous studies on the role of uncertainty[22]). Although uncertainty does not necessarily undermine the meaningfulness and motivational pull of scientific information,[5,7] it may still be used to justify one's self-serving actions.

Our results are consistent with some previous research on the role of recipients' beliefs about communicators in responses to uncertainty in science. For example, Rabinovich *et al.*[7] found that people were more willing to accept scientific messages that conformed to their stylistic expectations of how such messages should be framed (as informative vs. persuasive). Consistent with this general idea, our results demonstrate that scientific information is motivating when the mode of its delivery meets recipients' expectations (either about the scientists' communicative motives, as in the previous research, or about the nature of science more generally, as in the present research). As such, uncertain information can stimulate behavior when it fits recipients' preexisting expectations about science and scientists, but may undermine action when it contradicts these beliefs.

4.1. Implications, Limitations, and Directions for Future Research

These findings have important implications for communicating scientific information in general, and climate change risks in particular, to the general public. First of all, they shift the focus from exploring parameters of the message as key to managing uncertainty (such as its content and framing[3,4]) to expectations about the communicative process itself. Our results suggest that preexisting beliefs about science are at least as important for stimulating action in line with scientific information as the message itself, and the fit between the two is crucial. In a practical sense this means that rather than shying away from communicating uncertainty altogether, (climate) science communicators should make an effort to understand beliefs held by the recipients of their messages. Although recent research suggests that it is important to manage public perceptions of expert uncertainty surrounding climate change,[23] we would argue that where uncertainty is compatible with public beliefs about the role of science (and reflects the actual state of knowledge), it may not need to be managed.

Where uncertainty is incompatible with audience beliefs, science communicators may need to consider their role in shaping those beliefs. In particular, Study 2 demonstrates that the audience's model of science is malleable and that a relatively subtle manipulation is sufficient to change one's ideas about the nature and purpose of science. This suggests an alternative approach to science communication. Rather than simplifying and reframing scientific messages in an attempt to make them acceptable for the general public, communicators might consider engaging with the public to shape their understanding of what science actually is. In this way, one could attempt to prepare the public for the levels of uncertainty prevalent in contemporary science, and present this uncertainty as a sign of a deeper understanding of the subject rather than a sign of falling short of the scientific ideal. It should be noted, however, that although the two studies presented here provide an unequivocal support for our hypotheses, they need to be replicated on wider samples before these ideas could be put into practice.

Although the present research demonstrates the robust effect of beliefs about science on responses to uncertainty, it does not identify the process that leads to the above effects. One possibility that follows from previous research on the role of expectations in perception of uncertainty[7] is that inconsistency between one's expectations and actual information results in reduced trust in the source of such information, while consistency increases trust. From this point of view, proponents of the model of "science as debate" may actually trust the source of scientific information more when it provides uncertainty estimates. In contrast, the same information may lead to mistrust among those who instead see science as a search for truth. These differences in experienced trust could then lead to different behavioral response to the communicated information.[38–41] Future research could explore the role of trust in the observed effect. It is also possible that higher uncertainty of negative consequences of climate change increases willingness to act by increasing self-efficacy associated with environmental action (i.e., participants could have decided that because negative outcomes are uncertain it is more likely that their action will be effective at averting them). It is important to note, however, that positive effect of uncertainty was only apparent among the proponents of the Kuhnian model of science. This suggests that establishing trust in the source of information may be a precondition for the positive effect of self-efficacy to take place.

Finally, the limitation of the present research is that we used sustainable intentions rather than actions as a dependent measure. Although intentions are a useful indicator of behavior, they should not be used to make conclusions about actual behavioral responses. Notwithstanding this, it is important to note that we used a wide variety of items measuring intentions that included not only easy, but also costly behaviors (such as helping to raise funds for an environmental cause). More importantly, our goal was to explore the extent to which scientific uncertainty was motivating versus demotivating, something that intentions seem adequate to assess. The fact that our simple manipulation led to robust shifts in responses to uncertainty suggests that this might be a fruitful avenue for future research and practice.

4.2. Conclusion

Uncertainty is an inherent aspect of scientific inquiry, and progress often means quantifying rather than eliminating it. Yet communicating uncertainty has become a central problem of translating scientific knowledge to the general public, sometimes resulting in public disengagement and mistrust. This article suggests a way of circumventing this negative effect. It demonstrates that uncertainty can be desirable and motivating when it fits people's beliefs about science as debate (as opposed to the classical model of science as a search for the absolute truth). Richard Feynman famously suggested that "philosophy of science is as useful to scientists as ornithology is to birds." We argue that this may not be true: communicators of science may strongly benefit from engaging with their audiences' lay philosophy of science.

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