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The (Mis)understanding of Scientific Uncertainty? How Experts View Policy-Makers, the Media and Publics

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ABSTRACT
Frequent claims that publics 'misunderstand' science ignore the contested definition of scientific uncertainty itself. Scientific uncertainty means different things in the natural sciences, social sciences and the humanities, while public controversies show that these interpretations of scientific uncertainty have different implications for policy and decision-making. This prompts analysis of the ways that experts view scientific uncertainty and how they characterise the (mis)understandings of this uncertainty by policy-makers, media and publics. Experts from diverse academic fields define scientific uncertainty differently depending on their disciplinary background. For example, mathematics provides experts from the natural sciences with a practice language that facilitates communication with those sharing this cultural competence, but it does not suffice for engaging with wider audiences. Further, experts' views of diverse publics come across as folk theories, in Arie Rip's terms, which, compiled from disparate pieces of information, can be used to fill a gap in the knowledge about publics.

KEY WORDS: Scientific Uncertainty, Policy-Makers, Media Representations, Public Understanding

Introduction

> Extraordinary steps were taken by the British Government last night to head off a proposed EU ban on neonicotinoid pesticides, which have been widely blamed for bee deaths around the world. The Environment Secretary, Owen Paterson, circulated a note to all 27 EU member states saying there was not enough evidence yet for a ban, which environmental campaigners have increasingly called for and is already supported by 13 EU countries. (MacCarthy, 2013)

Scientific uncertainty often figures in public controversies about environmental problems. The aforementioned quote originates in a debate about whether the scientific research identifying neonicotinoid pesticides as the major cause for the observed decline in bee populations warranted a two-year moratorium on their use in the European Union (McGrath, 2013). A UK government scientist explained the scientific disagreement:

> Neonicotinoids will kill bees, let me be absolutely clear about that. It is what numbers do they kill and whether it affects populations—the question is whether banning them in any way would be proportional and at the moment the balance of evidence suggests it wouldn't be. (McGrath, 2013)

'Balance of evidence' here points to a scientific debate about how the research ought to be done. For example, UK government scientists argue that studies demonstrating the detrimental effects of neonicotinoids on bee populations are laboratory based and not reflecting real-life conditions. Other scientists respond that since neonicotinoids are currently widely used, it is impossible to construct the pesticide-free controls needed for randomised field trials outside of the laboratory. This scientific uncertainty cannot be reduced by more research of the same type, but rather requires that scientists reach an agreement on how to produce conclusive evidence.

The example illustrates the variability of the implications of scientific uncertainty for decision-making, as the UK viewed it as an argument against a moratorium, while 13 EU countries took the opposite view. The controversy over neonicotinoids also shows how scientific uncertainty acquires different meanings in different parts of society. For scientists uncertainties arise in the research process, debates about them are common in all scientific fields and are usually resolved by reaching an agreement on how to handle them. It is too early to say how the scientific uncertainty over neonicotinoids and bees will be resolved, but we can assume that it will be. We can also assume that such an agreement about how to manage the scientific uncertainty in the scientific community will have different impacts on political decision-making depending upon the specific context. The ability of scientists to agree on how to differentiate between types and degrees of scientific uncertainty in order to establish new knowledge is not unidirectional or uncontested as it is incorporated into public debates or political decision-making.

The meanings of scientific uncertainty in society arise in cultural processes involving more than science and scientists; it is a phenomenon with different meanings depending on the context. In this sense it is similar to climate change, which Hulme (2009) understands as having two manifestations, one physical, described and analysed by science, the other cultural, debated and valued by the whole of society. If we understand scientific uncertainty as having multiple meanings, it is interesting to look at whose definitions get communicated and used in which contexts. We find that some scientific communities try to disseminate scientific approaches to scientific uncertainty in society. One example is the Intergovernmental Panel on Climate Change (IPCC) construction of scales to express different aspects and degrees of uncertainty, in order to communicate climate change science accurately to policy-makers and the general public (IPCC, 2007). In contrast to this attempt at communicating the complexity of scientific uncertainty, other experts argue that scientific uncertainty is too complicated for the general public and that it is better to talk about 'risk', for example, in relation to climate change (Pidgeon, 2012). These two ideas on what scientific uncertainty ought to mean in society indicate different views among experts on what wider audiences are able to comprehend.

Faced with different meanings of scientific uncertainty and contrasting ideas of how to handle it in society, we came to ask: How do science-based experts view the understanding of scientific uncertainty among other actors in society? We addressed this question in an interview study with experts in the public understanding of science from different disciplinary backgrounds. Before presenting the findings in the article, we introduce the analytical perspectives used to interpret the interviews. We then present the interview findings in four steps: examining first how the interviewees defined scientific uncertainty, and then moving on to their views on how policy-makers, media and the general public understand it.

Science and Technology Studies Perspectives on Scientific Uncertainty

Controversies involving scientific uncertainty, such as the one about bees and neonicotinoids presented earlier, have been a topic for science and technology studies (STS) analysis for decades. From the literature we learn that while underpinning environmentalist arguments for precautionary regulation of new chemicals in the 1970s (Nelkin, 1971), scientific uncertainty was later used by tobacco companies and the oil industry in the USA to resist government policies restricting cigarette advertisements and greenhouse gas emissions (Oreskes and Conway, 2010). The meanings of scientific uncertainty in public controversies are obviously context specific and contested. However, the roles played by scientific uncertainty in public controversies contrast starkly with the ways in which scientists develop techniques to manage the uncertainties arising in their field, which is necessary for achieving agreement within research communities (Parker, 2010).

The idea that scientists manage scientific uncertainty was introduced by Shackley and Wynne (1996) in a study of the IPCC's communication of climate change science to policy-makers in the first Assessment Report (AR) from 1990. Shackley and Wynne (1996, p. 281) found that 'the potentially damaging effects of uncertainty can be limited if certainty about uncertainty can be achieved' and used to manage uncertainty rhetorically in communication with policy-makers and publics. Shackley and Wynne's study shows how the IPCC formulated scientific uncertainty in four distinct ways—as

ignorance, risk, indeterminacy and uncertainty. Risk is when the probabilities of a known event occurring were not known; indeterminacy is when not all parameters of a system and their interactions were fully known; ignorance applies when scientists do not know what is not known and uncertainty is when enough is known to make qualitative, but not quantitative judgements. In Shackley and Wynne's typology, the question about the amount of damage neonicotionoids cause to bee populations would qualify as uncertainty.

The IPCC has continued to work with uncertainty since Shackley and Wynne's study. The Fourth AR (IPCC, 2007) introduced a twofold scale representing scientific uncertainty as, on the one hand, the quantitative likelihood of the occurrence of projected events and, on the other hand, a qualitative assessment of the level of confidence in the scientific community about specific knowledge claims (IPCC, 2007). This representation is further refined in the Fifth AR, by relating the two scales to each other and clarifying the methodologies used to assess confidence (Mastrandea et al., 2012). The IPCC's ongoing uncertainty management has been undertaken in a context of academic debate, involving climate scientists, policy researchers and philosophers (Baer and Risbey, 2009; Swart et al., 2009). However, the increasing terminological sophistication has not prevented public controversies about climate change science pivoting on contestations of scientific uncertainty (Pearce, 2010).

The IPCC's effort to manage scientific uncertainty in their communication draws attention to the importance of language. To understand the failure of the IPCC vocabulary to defuse public controversy about the scientific uncertainty of climate science, Collins' (2011) discussion of the link between practice and language in science is illuminating. Collins explains that scientific research communities—in which participants share tools and procedures, work in the same way and address the same questions—develop languages defined by the domains of practice. Such practice languages arise in sub-fields rather than disciplines and share many, but not all, linguistic repertoires with the wider discipline. Collins (2011, p. 274) identifies an important difference between individual and collective practice languages as 'for the individual, language dominates practice, at the collective level, where language is formed and maintained, practice is a vitally important driver of the language'. The link between practice and language suggested by Collins indicates that while it is possible to develop a vocabulary that conveys the intent of the IPCC, the recipient of the communication is likely to belong to another practice community and, thus, not use the terminology as intended.

The difference between individual and collective relationships to practice languages may play a part in the tendency of scientists to reduce scientific uncertainty to questions of risk, something Stirling and Gee (2002) identified in policy advice. The challenge of conveying scientific uncertainty to policy-makers, unfamiliar with the scientist's practice language, could prompt over-simplification. Stirling and Gee (2002) clarify the reduction of scientific uncertainty to risk in a grid capturing the relationships between knowledge of outcomes and knowledge of likelihoods. In this typology, uncertainty means that the possible outcomes of a process are known, while the likelihood of occurrence is poorly defined. In contrast, risk means that both outcomes and likelihoods are known. Ambiguity pertains to situations where possible outcomes are poorly understood, but the likelihood of occurrence is clear. Ignorance is a state in which neither possible outcomes, nor their likelihoods, are known. Stirling (2010, p. 1029) warns that the misapplication of probabilistic risk appraisal in situations when uncertainty, ambiguity or ignorance is at hand is 'an inadequate response to inadequate knowledge' that 'leaves science advice vulnerable to the social dynamics of groups—and to manipulation by political pressures seeking legitimacy, justification and blame management'.

The communication of science to policy-makers is recognised as an important site for the construction of the meanings of scientific uncertainty in society, but it is not the only one. Another site is the media, which play a critical role for the dissemination of scientific knowledge in society. There are several studies analysing scientific uncertainty in the media in relation to specific scientific knowledge claims (e.g. climate change). A well-known study of climate change science and its uncertainties in the US media between 1985 and 1995, for example, found that uncertainty was represented as a problem in need of resolution relating to 'controversy, new research topics, and an

expanding problem domain' (Zehr, 2000, p. 98). The US media also represented scientific uncertainty as something that scientists could manage, but that was too difficult for the public to understand. Hence 'even though scientists themselves were uncertain, their knowledge was deemed superior to public viewpoints' (Zehr, 2000). Later studies have criticised the media's reporting of climate science and its uncertainties. For example, Boykoff and Boykoff (2004) argue that media attempts at impartiality in the face of scientific uncertainty become 'balance as bias'. Boykoff (2008) also found that the media tended to present climate science as being more uncertain than indicated by scientific reports. Recently, Nerlich et al. (2012) found that while the US news media tend to continue reporting climate change as a scientific challenge, emphasising uncertainty, UK reporting has shifted to focus on how climate change might be addressed. The ongoing STS examination of how media contributes to the construction of the meanings of scientific uncertainty in society is an important backdrop for our interpretation of the interviews.

The STS literature also makes clear that it is important to distinguish between media discourses and public understanding, because it is difficult to determine the influence of media representations on the people who access them. Zia and Todd (2010) found that media coverage of scientific controversies rarely changed people's views. Readers tended to interpret new information in relation to their existing opinions and assimilate what was consonant with their existing views.

Although there is limited scholarship on how the general public understands scientific uncertainty as such, there is research focusing on climate change showing that comprehension of the science and its uncertainties has not changed as people have become aware of climate change (Ryghaug et al., 2010). We also found that studies discussing the public understanding of scientific uncertainty in relation to climate change tend to transform the meaning of it. For example, Morton et al. (2011, p. 6) begin by stating that 'scientists are increasingly explicit about the uncertainties around their predictions in order to conform to scientific standards and to be transparent about what they do, and do not, know'. Approaching the issue of how the public understands this message, they focus on how the communication of uncertainty affects an individual's willingness to take action. They consider it to be likely that communication of scientific uncertainty could 'further undermine responsiveness among a public that has been characterised as generally averse to uncertainty' (Morton et al., 2011, p. 6). So, Morton and collaborators do not ask how the public understands scientific uncertainty, but whether it can be communicated in ways that inspire action. Other studies ask respondents if they think that scientists are uncertain about an issue, for example climate change (Whitmarsh, 2011), not about how they understand scientific uncertainty as such.

While there is limited scholarship on the general public's understanding of scientific uncertainty, there is research on how experts view the public. This research shows that scientists and experts tend to view other groups' comprehension of their fields as deficient (Frewer et al., 2003; Petts and Brook, 2006). In a recent survey, Besley and Nisbet (2013) found that scientists both in the USA and the UK thought that the media misrepresented their field, that policy-makers were poorly informed about science and that the public lacked adequate understanding to participate in decision-making. Rip (2006) found that nanoscientists developed their ideas about the public by drawing on common beliefs and anecdotes rather than any form of systematic inquiry. He defined the expert community's views about the public as 'folk theory', that is, articulated elements of 'folk sociology' that, in the same manner as 'folk biology', 'folk physics' and 'folk chemistry', are 'part and parcel of the repertoires of everyday life' (Rip, 2006, p. 349). Folk theories 'are a form of expectations, based in some experience, but not necessarily systematically checked' (Rip, 2006). Such folk theories may, or may not, be explicit and may, or may not, be challenged or checked. Folk theories can be used as frames through which the world is interpreted and thus as self-perpetuating justifications of particular behaviours. Rip argues that folk theories could potentially offer natural scientists an 'entry point for further interaction with social scientists because claims are being made about what is the case' (Rip, 2006, p. 362). Hence, critical interdisciplinary analysis of folk theories and the social phenomena they represent could increase reflexivity among natural scientists.

The Interview Study

We were prompted to undertake the research in this paper by the 'Climategate' controversy. It erupted in the media in 2009 and brought scientific uncertainty into public view. We initially identified and contacted climate scientists who, we thought, would have had reason to consider and reflect upon the uncertainty of climate science independently of our questions. Using a snowballing approach—asking interviewees to recommend other people to talk to—we progressively widened the scope to include other experts from the social sciences and humanities, NGOs, media and research policy. For the purposes of this study, we defined an expert as a person with an academic background, recognised by their peers as having knowledge relevant to the issues under consideration.[1]

The over-arching question concerned how experts view the understanding of scientific uncertainty among other actors in society. We explore this by asking questions on four themes in the interviews. Firstly, we asked about the interviewees' views on scientific uncertainty and with whom they communicated. Secondly, we probed the experts' views on how policy-makers understand scientific uncertainty. Thirdly, we enquired about their views on media representations of scientific uncertainty. Finally, we asked what they thought about the public's understanding of scientific uncertainty. In the following we present the findings in four corresponding sections.

Experts' Views on Scientific Uncertainty

We began the interviews by asking the experts to share their views on scientific uncertainty. They all conceptualised scientific uncertainty as an inevitable aspect of research. For example, one interviewee explained that:

> Scientific uncertainty is a constant of science, science and scientists very rarely know things for absolute certain, they can do some studies and report the results of their studies and reach conclusions from those, but they're usually quite hard conclusions or relate to some specific circumstance. (Science journalism 07.09.10)

This view of uncertainty as intrinsic to scientific research corresponds with the understanding of it in the STS literature. That it was offered by an interviewee not based in STS suggests that the view of uncertainty as a permanent feature of science, subject to management rather than reduction, has become more widely established, superseding some of the findings of Shackley and Wynne (1996) in the 1990s.

While all the interviewees agreed on the inevitability of scientific uncertainty, there was considerable diversity in the way they conceptualised it. Some interviewees viewed scientific uncertainty as a quantifiable phenomenon best addressed with statistical methods and discussed in probabilistic terms:

> …you've got a known probability distribution or an assumed distribution of events and you sample from it and if you know the shape of that distribution you can work out what the chances are of getting certain results when you sample it and that probably relates closely to uncertainty in climate change predictions in terms of what the effect of natural variability would be... (Climate science 20.08.10)

Such quantification of uncertainty has been analysed in STS literature discussing the role of statistical techniques in creating agreement within a research community on the uncertainty of, for example, climate modelling results (Parker, 2010). Other interviewees used qualitative terms to talk about scientific uncertainty in a manner more critical of the way natural scientists (e.g. climate scientists) addressed the topic:

> …there is a tendency particularly among scientists to reduce any kind of contentiousness around science and technology to an issue of uncertainty and it doesn't take into account indeterminacy, it doesn't take into account alternative framings of issues, you know, what kind

> of a problem is climate change? Is it an environmental problem, is it a technical problem, is it an energy problem, is it a development problem, is it a social welfare problem, you know, and the answer is it is all of the above. (Social science 05.10.10)

This interviewee, with an STS background, was the only expert who used STS terminology. In this case the term 'indeterminacy', introduced by Shackley and Wynne (1996), was used to refer to a rhetorical displacement of uncertainty from a scientific knowledge claim to the unpredictability of society.

There was a marked difference between experts affiliated with the natural sciences and those who identified with other fields. The former referred to scientific uncertainty as quantifiable, while the latter discussed it in qualitative terms. Some interviewees mentioned the distinct character of scientific uncertainty in the natural sciences in comparison to the social sciences, and discussed scientific uncertainty as varying between research practices in the natural sciences.

In order to form an understanding of the development of the different vocabularies (quantitative or qualitative) used by the experts to talk about scientific uncertainty, we asked them with who they usually discussed the topic. The experts who were active in the natural sciences communicated extensively about scientific uncertainty with other members of their research community:

> Actually, we write whole, very, very detailed papers on, on ways of handling uncertainty, but those aren't the kind of papers that we would do a press release on and well, there's a relatively small community of people who are expert enough to be able to adjudicate on and help improve this, but I can tell people who are statisticians that you can talk to who, you know, are truly expert in this field… (Climate science 14.07.10)

Other interviewees also pointed to the existence of a practice language (Collins, 2011) that provides a research community with a vocabulary to talk about scientific uncertainty as this quote illustrates. Some talked about how easy it was to discuss scientific uncertainty with their peers:

> So I think if you're dealing with people who have any sort of mathematical statistical background then I think that makes life a lot easier because at least then they've some of the concepts of uncertainty. (Climate science 20.08.10)

This quote locates the practice language in the knowledge of mathematics shared by natural scientists across different fields. Experts with a background in the natural sciences have learned to use mathematics to approach natural phenomena and to address the uncertainty of scientific knowledge. The notion of practice languages as fractal (Collins, 2011), as nested within ever-widening communities, captures the way in which the interviewees identifying with the natural sciences described their communication about scientific uncertainty. This sense of being part of a wider community, using the same language, reflects the self-identification by interviewees with the natural sciences, regardless of their discipline or current job.

One of the interviewees quoted earlier expressed awareness that the practice language used to discuss scientific uncertainty within the expert community does not work with other audiences. Some interviewees affiliated with the natural sciences with experience in communicating with more diverse audiences had learned to use different styles in their presentations to different people:

> I mean if it's a scientific paper then you would, you know, have lots of graphs and numbers and probabilities and all those sorts of things. When you're trying to actually turn that into something that is more meaningful to people in everyday life, obviously you have to describe it, use more descriptive language and avoid using graphs so the way that you describe the uncertainty is different I think and the trick is not to, you know, to describe it in a way that still engages people without losing sight of the fact that it's, you know, of the complexity. (Science communication 15.09.10)

Shifting from communicating with one's peers to talking to a wider audience takes effort and calls for consideration. This expert's strategy reminds us of the efforts made by agencies such as the IPCC to design vocabularies specifically to communicate scientific uncertainty to wider audiences. The quote also expresses an ambition not to reduce the complexity of scientific uncertainty by transforming it into risk, as Stirling and Gee (2002) found happened in formal communications of science to policy-makers.

Some interviewees found it challenging to convey the meaning of scientific uncertainty without being misunderstood and emphasised the need for caution when communicating with non-scientists:

> I think amongst the scientific community it's part of our training in the physical sciences, which I know most about to be pretty precise about… and have a common understanding of what we mean by uncertainty and the sources of uncertainty. I think where, where there's interpretation is when one's using that kind of language with the public and with non-scientific audiences where perhaps one has to be a bit careful that their level of knowledge about what is technically meant by uncertainty may not be at the same level as one's own. So I think you have to be careful in that sense (Research funder 24.08.10)

The caution expressed by this interviewee signals awareness of the difference between scientific uncertainty as constructed within scientific communities and its potentially contentious meanings in public debates. It also implies that for users of a mathematical practice language, it may be difficult to use other vocabularies to convey what they regard as a correct understanding of scientific uncertainty.

In contrast to the interviewees with a natural science background, the experts from the social sciences or humanities appeared not to share a common language for addressing scientific uncertainty in their everyday research, nor did they seem to discuss it much among themselves. One interviewee elaborated, when prompted:

> …there is an exchange, if you like, that goes on in the review process for papers that are submitted to journals and so on, where there is a to-and-fro between the author, or authors, the reviewers and the editor of the journal and very often a component of that will be around issues of reliability and transparency in terms of the kind of deliberations that have been made and modifications that have been made and so on and so forth /…/ the other, which is a bit more discursive in the straight forward sense of that term is at conferences. So, the kinds of questions that you get to handle, having presented a paper, and/or in discussion sessions around somebody else's paper, I think often dwell quite specifically on those on those sorts of issues about the handling of uncertainties, or indeed the non-handling of uncertainties, the kind of denial of there being any uncertainties can often come up as a subject for debate in that kind of context too. And I guess the third area, and I don't…yeah, I would guess there would be some commonalities anyway between social and natural science, would be more in terms of what I'd call the kind of pedagogical mentoring role within laboratory groups or just groups of social scientists working on the same project, or in a kind of supervisory relationship where one tries to instil through workshops or discussions or whatever, the significance of questions around issues of uncertainty. (Social science 13.09.10)

This interviewee conveys a clear sense of a social science community, but not of any practice language for discussing the uncertainty of social science knowledge claims with much precision. Other interviews also indicated that experts in the social sciences and humanities draw on a variety of ideas to engage in critical reflection on scientific uncertainty in both science and society. For example, one social scientist commented on climate science:

> …one of the issues I think that climate change science raises is, it kind of calls into question those whole notions of scientific truth, and even some of the kind of methodologies that are used to validate kind of scientific knowledge. Which I think is a good thing but, I think what

> the difficulty has been, is because climate change itself is so complex, those uncertainties have made it even more difficult to kind, for climate change consensus to be achieved, but also for that consensus to be communicated. (Media and communication studies 10.08.10)

This quote reveals a reflexive perspective on scientific uncertainty as an aspect of knowledge in society, concerning scientific research, decision-making and publics. This view on scientific uncertainty is more comprehensive, but less well defined than the quantitative approach of natural scientists.

One of the social science experts disagreed with the other interviewees on the importance of scientific uncertainty for political decision-making:

> …it [climate science] has for over 18 years been sufficiently robust as to be comparable to the technical inputs into a wide variety of decision making processes, government decision making about say economic policy or trade policy or employment policy or decisions to invade Middle Eastern countries. It's been quite as good as the kind of information that firms will regularly use to decide whether to launch new products or to do mergers and acquisitions and yet it is apparently being held to some bizarre standard of certainty and accuracy reflected in this question about the uncertainty /…/ what is essentially a policy dispute about different policy alternatives to climate change, that's been displaced into a surrogate argument framed as a scientific argument which it isn't really. (Social science 05.10.10)

This critical view of the relationship between scientific uncertainty and climate change policy was unique among the interviewees. The quote highlights the thought that the public debate is not primarily about knowledge and that certainty would not make a difference because the disagreement is about political values. This view accords with studies showing how scientific uncertainty has been used to deflect debate about the political interests and values of actors involved in public controversies (Nelkin, 1971; Oreskes and Conway, 2010).

The ways in which the interviewees talked about scientific uncertainty confirm the diversity described in the literature reviewed earlier. Our interviews also showed a clear distinction between experts based in the natural sciences and others. Using a practice language based in mathematics, the former constructed scientific uncertainty as a feature of scientific research, open to mathematical analysis. In contrast the social science and humanities experts talked about scientific uncertainty in ways echoing discussions about what uncertainty means for science in society.

Experts' Views on Policy-Makers' Handling of Scientific Uncertainty

The literature suggests that the communication of science to policy-makers is a context for active translation of scientific uncertainty to an audience of non-scientists (Shackley and Wynne, 1996; Stirling and Gee, 2002). Besley and Nisbet (2013) noted that scientists, in both the USA and the UK, regarded policymakers to be the most important group in society to engage with. However, there are few detailed studies of how scientists and experts view the ability of policy-makers to grasp scientific content, or features such as scientific uncertainty. Among the interviewees we found two opposing views on the handling of scientific uncertainty by policy-makers. Some experts thought that policy-makers were unable to comprehend scientific uncertainty:

> I feel that they understand it very poorly /…/ it's always the first question that they ask, is how certain are you of this /…/ It seems to be very difficult to get policy makers who aren't…are not…you know, got a training in the scientific method to, you know, un…to get that perspective, in other words that the roots of the subject area are rather well placed, but there remain, you know, wide uncertainties on the detailed outcomes. (Climate science 14.09.10)

While this interviewee appears to view all policy-makers as being unable to understand scientific uncertainty, another expert argued that it was the expectations on science that thwarted policy-makers' ability to comprehend scientific uncertainty:

> …everybody understands uncertainty, absolutely everybody, what's the economy going to do tomorrow, will interest rates go up or down on the first Thursday, next month, when the Bank of England meets, you know, so everybody kind of understands variability and the unknowns, but there is some strange thing whereby, where it comes into the domain in science that that normal understanding of how the world works seems to get lost a bit and so the problem there is sometimes with the sort of the more policy communities and journalists, if they want an answer, and you say we can't give an answer, we can give the evidence base, we can give the best evidence base we've got that we think is independent and rigorous and things but that isn't necessarily what they settle policy on. So that is when it becomes more difficult, but in any other area they completely understand uncertainty. (Science communication 11.08.10)

This interviewee did not consider scientific uncertainty to be different from uncertainty in general, but insisted that it was the context of scientific advice that changed the policy-makers' perceptions of what was at stake. Another expert blamed the context of politics for the perceived failure of policy-makers to comprehend scientific uncertainty:

> …it's very difficult really to have a political debate about uncertainty, because politics doesn't do uncertainty very well, because it's hard to get the response from politicians if there's a modicum of doubt in what you're saying and uncertainty equates I guess with doubts rather than, you know, scientific uncertainty… (NGO 02.09.10)

Interviewees also distinguished between the comprehensions of people with different roles within the policy-making community:

> I think the government largely tries, particularly the civil servants in the departments advising ministers try to use uncertainty in the way that the scientists use it because they're really trying to reflect the scientific evidence. (Research funder 24.08.10)

This distinction between civil servants and ministers identifies the division of labour within government as a critical feature for the way in which scientific uncertainty is handled in policy-making, implying that politicians do not understand it as well as civil servants.

Many of the interviewees who perceived policy-makers as failing to understand scientific uncertainty supported this view by referring to personal experience. Interestingly, personal experience was also used to support other interviewees' positive views on policy-makers' comprehension of scientific uncertainty. One interviewee explained that:

> The climate change committee that I serve on /…/ we phrase it all in probability terms, we said with current understanding we don't think 2 degrees is an absolute. We want, with the current understanding, the 50% probability point to be near 2 degrees and the chances of going 4 degrees to be negligible with current understanding. Now we phrase the whole thing in probability terms because of the uncertainty, the inherent uncertainty and also the uncertainty given our current knowledge and that has been, that was accepted by DECC [Department of Energy and Climate Change] and by government and by parliament and we have… I don't think we compromised our uncertainty, we embraced it and presented it in those terms… (Climate scientist 19.08.10)

Although this interviewee appears to have been able to communicate scientific uncertainty quantitatively in deliberations with policy-makers, the two opposing views on policy-makers' ability to comprehend scientific uncertainty did not map on to the distinction between natural scientists and others; instead on the differences in views on policy-makers' handling of scientific uncertainty related to different personal experiences. The interviewees who had engaged in longer term collaborations with policy-makers viewed them as able to understand scientific uncertainty, while the experts who had no such experiences viewed policymakers as failing to comprehend the topic.

The detailed reflections provided by the interviewees add to the STS literature identifying a tendency to reduce scientific uncertainty to risk in the communication of science to policy-makers (Stirling and Gee, 2002; Stirling, 2010), or to use it rhetorically to promote more research (Shackley and Wynne, 1996). The interviewees talked about social interaction with policy-makers, not written communication. Their perceptions of the science–policy relationship were founded on individual experience. Because we did not ask the experts to reflect on policy-makers' ability to handle scientific uncertainty in relation to formal communication, the interviews do not provide information about whether the experts would ever use, for example, the terminologies introduced by the IPCC (2007), or if they would present scientific uncertainty in terms of risk (Stirling and Gee, 2002) in things like policy briefing notes. However, we note that the interviewees did not make such a connection spontaneously, which suggests that there was no obvious link between their personal views on policymakers' comprehension and the strategy they would employ in formal communication.

Experts' Dissatisfaction with Media Representations of Scientific Uncertainty
The interviewees had strong and similar critical opinions of media representations of scientific uncertainty:

> I think the worst example of that is actually the media, who want things to be black and white and to have one big story line and I think that they entirely, almost always entirely miss the subtleties of the conditionality of scientific knowledge claims. (Social science 13.09.10)

This quote from a social scientist is typical; it was echoed by interviewees from the natural sciences:

> Well, again I think they're [the media] … that overall they're very poor and they … because they always want to make a story, so they want a particular line, preferably as controversial as possible that they / … / push, so this doesn't help assist in understanding scientific uncertainty at all, it does the precise opposite. (Climate science 14.09.10)

These negative views of media representations of scientific uncertainty reflect the opinions found in surveys of scientists in both the UK and the USA (Besley and Nisbet, 2013).

While all interviewees thought that the media failed to represent scientific uncertainty accurately, they explained this in different ways. Some thought that the media simply failed to grasp the issue:

> …I think the media has problems with it. /…/ if we get floods or something I will get the media call up and say can we say this is because of climate change and when I start presenting my uncertainties and we can't say this but we can say such things are, may become more likely, they will often switch off and go to someone else who will give them their headline or they will just write it themselves. (Climate science 19.08.10)

In contrast, another interviewee distinguished between how the media generally represent scientific uncertainty and the understanding of it held by different journalists.

> If you're talking to an established environmental or technical correspondent /… / they know about uncertainties and, you know, indeed some of them have written / … / stuff of considerable significance, well, I say considerable significance, at some depth I should say, on the subject of scientific uncertainties and, you know, the uncertainties around climate science. If you talk to someone who's new on the beat then, you know, it's much less clear and, yeah, I suppose that's true if you're dealing with political correspondents, when stories get big then that's definitely true. (NGO 31.08.10)

The distinction made in this quote, between knowledgeable journalists and the media establishment, might reconcile a positive relationship with one and a negative view of the other. This resonates with the findings of Besley and Nisbet (2013), indicating that although scientists dislike the representation

of science in the news media, they still consider media interviews to be an effective way to communicate their knowledge to the wider public.

Some interviewees elaborated the issue further, echoing media studies research suggesting that the media's need to generate drama to get the attention of an audience results in an over-emphasis of scientific uncertainty and conflict within the scientific community (Ryghaug et al., 2010):

> … if one thinks about the imperatives for the media, particularly the news media or news and current affairs media, the raison d'être is to have more people reading their paper or watching their channel than the competition / ... / there seem to be certain standard conventions of the craft of producing, of translating scientific knowledge claims into stories that are whatever the … whether it's a public policy broadcaster or a red top that are going to get them onto the front page in competition with, I don't know, stories about what some celebrity has been doing or whatever and that those standard practices or aspects of the craft seem to be to want to convey stories about science or about the interface between science and public policy in either apocalyptic terms to attract attention or in terms that are about an argument or an controversy ... (Social science 13.09.10)

Some interviewees made explicit reference to critical academic analyses of media practices; for example, the argument that the preference for balanced reporting can lead to misrepresentation of climate change science (Boykoff and Boykoff, 2004).

We also found that interviewees were concerned that what they perceived as media misrepresentations of scientists' views were causing confusion among the public:

> ... you know, there was a headline in The Independent newspaper two days ago, based on some of the presentations that have taken place in Bonn for the last UN negotiation, you know, saying that current pledges within the Copenhagen Accord would lead to / ... / 3.58 warmer by the end of the century. Now, you know, that's fine and it makes a good headline / ... / but even so I think that the proliferation of that kind of story telling about climate change leads to sense of, you know, that the science is much more certain than it is and I know that, you know, that's just not the case. (NGO 02.09.10)

However, the connection between media representations and the public understanding of scientific uncertainty, made explicit in this quote and mentioned by several interviewees, does not show awareness of the complexity of the relationship between the two indicated in the literature.

Experts' Views on the Public's Understanding of Scientific Uncertainty

We found that all interviewees, except one, were of the opinion that the general public has a poor understanding of scientific uncertainty. Many thought that 'people' expect scientists to present certainty:

> Well, people are still not very good at understanding / ... / people are still inclined to think that science, scientists should always be able to give absolutely firm answers / ... / So, you know, there are still, you know, expectations of scientists, that scientists can't always deliver and I think scientists need to be honest about that. But I think the public also needs to be accepting about what science can and can't do. (Science journalism 07.09.10)

There was no discernible difference between the natural and social scientists with regard to this issue. A common notion was that to 'the general public' uncertainty equals ignorance:

> The way that the general public understand uncertainty / . . . / is as a synonym for ignorance. So when you say I'm uncertain about whatever it is, x parameter, the conclusion they draw is that you don't know, and that is the biggest hurdle. / . . . / Now, to say that there's a bit of

> uncertainty around it, doesn't, is not to say that you're ignorant about it. (Government policy 15.09.10)

Of the 17 interviewees, 16 agreed that the public does not understand scientific uncertainty. One expert was of a different opinion:

> I mean people understand life is uncertain. People deal with uncertainty all the time. People deal with probabilities all the time. My goodness gracious, I mean you see some ordinary people with virtually no education who deal with probabilities when it comes to betting on horse races and things like that or knowing, you know, this kind of thing. The idea that somehow or other the public is terribly naïve and is constrained from acting in rational policy ways because they don't have a full appreciation of scientific uncertainty once again I just think is nonsense. (Social science 05.10.10)

This minority view conveys a very different perspective and prompts us to examine the basis of the majority view among the interviewees. None of the interviewees were doing research on the public understanding of science, although some were involved with the communication of natural science. In contrast to the earlier conversation about media representations, in which the experts made references to published research to support their opinions, they did not appear to base the views on the public's understanding of scientific uncertainty on any established body of knowledge. Nor did they talk about personal experiences of interacting with the public, as they did with regard to their views on policymakers' comprehension of scientific uncertainty.

The lack of substantiation, with experience or research, of the view that the public fails to understand scientific uncertainty points to its character as what Rip (2006) identifies as 'folk theory', that is, views about society widely accepted within an expert community, but not underpinned by evidence. Rip (2006) found that nanoscientists shared views about the public, unrelated to their experience and to established academic knowledge, upon which they drew when acting outside of their particular field, for example, as experts. Other studies of scientists and experts suggest that a folk theory about the public's failure to understand scientific uncertainty persists across time and space. A decade ago Frewer and Collaborators (2003) found that experts on food safety considered the public to be unable to understand scientific uncertainty with regard to food risks. Another qualitative study found that experts considered publics, whom they were obliged to consult, to be too poorly informed to be trusted with making rational decisions (Petts and Brook, 2006). Besley and Nisbet's (2013) survey material also reflects the view that the public lacks an understanding of science and its uncertainties to be widespread among both UK and US scientists. Before criticising the interviewees for promoting a folk theory about the public's failure to understand scientific uncertainty, we must recognise that we failed to find any literature specifically addressing the issue. It is possible that the scarcity of knowledge about how the general public understands scientific uncertainty as such leaves a gap that the interviewees filled with a folk theory.

Since several interviewees provided explanations for the perceived failure of publics to understand scientific uncertainty, we are able to examine how they constructed this folk theory. The factor most commonly used to explain the perceived poor public understanding of scientific uncertainty was the media's flawed representations of it. This indicates that the interviewees combined their opinion of media representations as deficient with a view of the public gaining knowledge about scientific uncertainty from the media. However, that there is a linear causal connection between media representations and public comprehension has been problematised in empirical research. Zia and Todd (2010), for example, found that media audiences interpreted new information in ways that agreed with their pre-existing views, indicating that the impact of media representations of scientific uncertainty on the public's understanding will be limited, regardless of the perceived quality of the representations. This complexity of the relationship between media representations and public understanding was not recognised by the interviewees.

The experts expressed particularly strong views on the publics' suggestibility to media messages in relation to climate change and considered climate scepticism to be a cause of public misunderstanding. Some argued that climate sceptics were actively spreading misinformation about scientific uncertainty in climate science, which was taken up by the general public:

> ... there's a lot of mixing up, in my opinion, political ideology with evidence. / ... / again let me use climate as the example, it's the prime … of the sceptics, some of them are absolutely ideological / … / on every single small uncertainty: "You don't understand that little bit of detail therefore why should I have any confidence in any of it?" It's really more of a political philosophy / ... / without any base in evidence. We need sceptics but we need sceptics using the evidence to challenge it. / . . . / total misuse of—for whatever reason, for whatever reason—of scientific information backed by a bunch of sceptics that are misusing it for whatever reason, ideologically, I've got no reason or understanding why they do it, they just do it basically. (Government policy 08.10.10)

This quote points to a curious phenomenon as the experts we interviewed were active in the UK at a time when all the major political parties agreed on the reality and importance of climate change, as did the mainstream media and a majority of the public (Poortinga et al., 2011). In this context, explicit climate scepticism was not politically prominent or promoted in traditional news media. At the time of study the view that climate sceptics caused the public to misunderstand scientific uncertainty, by questioning climate science (as the aforementioned quote suggests), relates more to events in the USA. In the USA, climate scepticism has been a strategy to oppose climate mitigation policies (Oreskes and Conway, 2010). US Republicans have also been found to agree with anti-environmentalist views and find climate scepticism to be convincing (Zia and Todd, 2010). In addition studies have indicated that individuals' political convictions and environmental values shape their opinions on climate change and climate change science (Whitmarsh, 2011). However, the folk theory expressed by the interviewed experts suggests an unquestioning extrapolation of nationally specific public debates across widely differing contexts.

Concluding Discussion

By addressing the question of how science-based experts view the understanding of scientific uncertainty among other actors in society, we found that experts from different disciplinary backgrounds perceive scientific uncertainty to be mostly misunderstood by other groups. This confirms findings by previous studies, showing that experts think that other actors fail to understand their fields (Frewer et al., 2003; Petts and Brook, 2006; Besley and Nisbet, 2013). However, a closer examination provides more nuance to this answer.

Firstly, the interviewed experts defined scientific uncertainty differently depending on their disciplinary affiliations. The experts with a natural science background discussed scientific uncertainty in quantitative mathematical terms, while the social scientists and humanities experts used qualitative vocabularies based in broader societal debates, and some even expressed criticism of the narrowness of quantitative approaches. We interpreted the quantitative vocabulary as a 'practice language' (Collins, 2011), even though the interviewees did not comprise a research community working together. Still, the good fit between this notion and the finding encouraged us to use 'practice language' in a slightly broader sense, encompassing familiarity with mathematics as a type of cultural competence. That interviewees who used this practice language found it challenging to communicate scientific uncertainty to people not familiar with mathematics agreed with Collins's (2011) idea that language dominates practice on the individual level. For natural scientists used to employing a well-developed and exact practice language to discuss scientific uncertainty, it may be difficult to use less precise vocabularies to communicate their understanding of it to a wider audience in a way they perceive as adequate.

Next we specified three societal areas in which previous research had indicated that scientific uncertainty manifested differently—policy, media and the public. We found that the interviewed experts' views on how policy-makers comprehend scientific uncertainty differed depending on personal experience. Interviewees who had collaborated with policy-makers over a longer time

considered their understanding of scientific uncertainty to be good, while brief encounters seem to have prompted the opposite view. Interviewees also expressed the ambition not to reduce the complexity of scientific uncertainty in communication with policy-makers. Our findings indicate a difference between the formal science– policy interaction analysed in the STS literature (Stirling and Gee, 2002) and the face-to-face engagements used as reference points by the interviewees.

All interviewees considered media representations of scientific uncertainty to be poor. None of the interviewees talked about personal experience of interacting with media. Published academic sources were invoked to support negative views, but the interviewees did not reference more complex findings reported in the media studies literature.

Finally, all but one of the interviewees viewed the public as lacking understanding of scientific uncertainty. None of the experts substantiated this view of the public with reference to personal experience or to published research, which suggested to us that this opinion is best understood as a folk theory as defined by Rip (2006). We found that the interviewees pieced together this folk theory by combining information from diverse sources and contexts, without regard to empirical specificity. In the literature overview we had seen that there were very few studies of how publics may understand scientific uncertainty as such, rather than the certainty of specific factual claims. We speculate that the paucity of empirical studies of how the general public understands scientific uncertainty may leave a gap that the interviewees filled with a folk theory.

While acknowledging the small number of participants in this study, the findings lead us to propose further STS research to address some gaps in knowledge. Firstly, the study of formal written communication between scientific experts and policy-makers could be supplemented with research on science–policy interaction as lived experience. This would add further depth to the understanding of the much analysed science–policy relationship. Secondly, more studies of how different publics understand scientific uncertainty and the ways in which it is represented to them in different forms of communication would contribute to the STS body of knowledge, and could provide resources for scientists interested in public engagement. We also think that more interdisciplinary deliberation, involving experts from the natural sciences, social science and the humanities, could contribute to the development of more diverse vocabularies to address different manifestations of scientific uncertainty in society, than what the practice language of mathematics offers.

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Note

[i]Of the 21 experts approached, 17 agreed to participate and interviews were carried out between July and October 2010 (see Appendix). We conducted the semi-structured interviews over the phone, following a series of prompts. Each interview lasted between 30 and 90 minutes; all were digitally recorded and professionally transcribed.

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Appendix: List of interviewees

Professional field	Interview date
Climate science	14.07.10
Climate science	19.08.10
Climate science	20.08.10
Climate science	31.08.10
Climate science	14.09.10
Social science	13.09.10
Social science	05.10.10
Science communication	10.08.10
Science communication	11.08.10
Science communication	15.09.10
Government policy	15.09.10
Government policy	08.10.10
NGO	31.08.10
NGO	02.09.10
Media and communication studies	10.08.10
Science journalism	07.09.10
Research funding	24.08.10

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