Imperial College London

Institute of Infection

THE ROYAL SOCIETY

Navigating Degrees of Certainty:

A guide to providing science advice

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Contents

About this report

The following report provides a summary of a workshop on science advice to Government, held on 21st February 2022 under the Chatham House rule. The meeting was organized by the Institute of Infection of Imperial College London in partnership with the Royal Society. The report also summarises a series of interviews conducted between 11th February and 1st March.

Many of the speakers who contributed to the workshop had a background in the life sciences. However, the report attempts to draw broadly applicable conclusions about science advice, and so may be of interest to a wider audience. Similarly, although the speakers at the workshop were chiefly involved in advising the UK Government, certain lessons are likely to be more widely applicable, regardless of the advisory system.

The report is a synthesis of the conversations which took place during the workshop and interviews and should not be interpreted as representing the views of Imperial College, The Royal Society, the speakers or interviewees.

It should be noted that this report focuses only on the provision of science advice from the perspective of science advisers. From the perspective of policymakers there are structural and cultural factors that can limit the ability of government to make best use of science advice. These factors include the fact that the vertical hierarchy of departments creates accountability challenges when dealing with issues that cut across departments, and that the small research budgets of some departments limits the engagement of staff with science and their familiarity with how science is done. Whilst these and other parameters can limit the capabilities of government to request, receive, and act on scientific advice, exploration of these issues is beyond the scope of this report.

Acknowledgements

We thank the participants of both the workshop and interviews, without whom this report would not have been possible.

Workshop speakers: Professor Dame Sally C. Davies (Trinity College, Cambridge), Professor Neil Ferguson (Imperial College London), Dr Rupert Lewis (The Royal Society), Professor Wendy Barclay (Imperial College London), Sir David Spiegelhalter (University of Cambridge), Professor Peter Openshaw (Imperial College London), Amanda Wolthuizen (Imperial College London), Professor Christl Donnelly (Imperial College London; University of Oxford), Dr Fiona Lethbridge (Science Media Centre), Professor David Nabarro (Imperial College London), Professor Sir John Bell (University of Oxford).

Interviewees: Professor Roger Pielke Jr. (University of Colorado Boulder), Professor Andrew Stirling (University of Sussex), Professor Paul Cairney (University of Stirling), Professor James Wilsdon (University of Sheffield) and Dr Kathryn Oliver (Government Office for Science, The London School of Hygiene and Tropical Medicine)

Institute of Infection organisers: Professor Charles Bangham and Dr Melanie Bradnam

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Executive summary

The COVID-19 pandemic is not a typical case study of science advice. It is rare that science advisory systems are required to respond so urgently yet in such a sustained manner, working with so little conclusive information about societal impacts, despite the certain knowledge that these impacts will be both highly significant and highly diverse. This is a policy environment where new evidence accumulates daily, sometimes reducing uncertainty regarding which course of action to take, but sometimes increasing it. By generating an environment of extreme uncertainty and ambiguity on the one hand, and urgency and pressure on the other, the pandemic has proved a severe test of the UK's science advisory systems. Early indications suggest some components of the system have performed better than others,[1] though it will be necessary to analyse their performance before drawing robust conclusions. Such an analysis is not the aim of this report. Instead, we explore some lessons provided by the pandemic which may be of interest to the scientific community.

Imperial academics and the Royal Society amongst many others have played a significant part in the national and international response to the pandemic by advising governmental and other public health bodies. Owing to their interdisciplinary nature, the Institute of Infection and the Royal Society are well placed to act as a bridge between academics from many disciplines who have such experience.

This report compiles insights from a workshop organized by the Institute and the Royal Society on 21st February 2022 that brought together senior scientists, and a series of interviews with senior policy academics. Both the workshop and the interviews focused on two themes: communicating uncertainty, and science advice to Government before and during the pandemic. The purpose of this report is to present both experiential and systematic accounts of the science advisory process. It aims to introduce the subject to future science advisers. In particular, it gives guidance on navigating the relationship between the adviser and their counterparts in Government.

The key findings are summarised below:

- The practices and cultures of scientific research and policymaking are very different – mutual understanding between these worlds is not a given. To be effective, science advisers must appreciate the complexity of political decision-making, have a realistic idea of the role that science advice plays in those decisions, and understand the cultures of the political institutions with which they interact.

- To make the most of science advisory systems, it is vital that science advisers engage in dialogue with policymakers to understand the motivation for their questions and to work with them to explore how issues are framed.
- To engage in dialogue effectively, advisers must demonstrate their trustworthiness. Showing trustworthiness as an adviser requires refraining from commenting on areas beyond one's expertise and openly acknowledging the limitations of scientific knowledge.
- The communication of uncertainty is of key importance for science advisers. There are different types of scientific uncertainty, and different ways of communicating each type. It is of crucial importance to convey the degree of certainty or uncertainty of scientific evidence.
- The line between science and policy can become blurred, particularly in a climate of uncertainty. Explicit terms of reference that define what is expected of advisers and the conditional nature of the advice (e.g. conditional on the level of uncertainty) are crucial to maintaining lines of accountability between advisers and policymakers.

This report is not intended to be a comprehensive review. There are many excellent academic papers and reports on the topic of science advice, some of which we refer to here. In addition, there are several organisations which provide support and guidance to science advisers, such as the European Commission's Joint Research Centre (JRC) and the International Network for Government Science Advice (INGSA).

Report structure

We first discuss potential sources of misunderstanding between science advisers and policymakers. These include a lack of appreciation of each other's priorities, and the report provides suggestions on how to overcome such misunderstandings (Science-policy cultural barrier). We then highlight the importance of dialogue and trust between policymakers and advisers, particularly emphasising the need for advisers to demonstrate their trustworthiness (Framing and dialogue, and Trust). In addressing the complex links between science and policy we examine the role of science advisers in policymaking, and we emphasise the need to acknowledge the limitations of scientific knowledge and maintain clear lines of accountability between advisers and policymakers (Communicating degrees of certainty and ambiguity and Maintaining lines of accountability). It is through those lines of accountability that the different roles of science and policy within society can be better understood. Finally, we outline some guidance for academics interested in engaging in science advice (Getting involved).

Introduction

In this report, "science advice" is taken to mean any communication between scientists and policymakers regarding the use of scientific evidence for the purpose of informing policy. "Policymakers" here includes any individual within the Government, Parliament or Civil Service involved in influencing and shaping policy measures.

It is beyond the scope of this report to enumerate the many interfaces between scientists and policymakers in the UK: this has been done elsewhere.[2] Instead, we draw some general conclusions as to how to navigate the process of science advice.

At best, when properly applied, science advice can help policymakers to identify and analyse societal problems, highlight potential interventions, predict and measure the impact of those interventions, and mitigate any side-effects they might cause. At worst, policymakers can choose the scientific evidence to justify preconceived policy positions or to avoid legitimate value-based debate.[3–5]

Because of the potential for the misuse of scientific evidence, the need for science advisers to remain free of political interference has been recognised since the Second World War.[2] The UK science advisory system combines independent science advice with many science advisory roles within the civil service, the most senior of which is Government Chief Scientific Adviser.[2(p15)] As participants of the workshop noted, the role of science advisers within the central civil service is less to offer deep expertise in a certain area, more to act as a bridge between Government and independent academics. These advisers are tasked with both promoting mutual understanding and providing access to networks of experts.

In theory, science advisory systems that are not subject to political pressures provide non-partisan information to inform policies, leading to effective policymaking. However, two key problems arise from the use of independent science advice in government.

First, independent science advisers often have little experience of policymaking, while policymakers have little understanding of academia.[3] The resulting mutual misunderstandings must be overcome for science advice to be effective. Second, policymakers may use a misperception of perfect scientific objectivity in independent advice as a means to diminish debate and accountability. Some suggest that the Government's insistence early in the pandemic that its policy measures were "following the science" can be seen as an example of ministers attributing to science and scientists the responsibility for decisions for which they themselves were responsible.[6]

Prospective science advisers need to be aware of these issues, which are important for an understanding of the science-policy interface. Because of their centrality we have used them to structure this report.

Science-policy cultural barrier

"The most brilliant advice may go wholly unheeded if it's not fitted to the social context of decision makers, the psychology of people making decisions in a hurry and under pressure, and the economics of organisations often strapped for cash. What works for whom and in what circumstances are crucial factors; and evidence and advice have to make themselves useful if they are to be used."

Geoff Mulgan[7]

The conduct of science and politics differs in a number of ways that can create a cultural barrier between scientists and policymakers. In a crisis, this barrier must be overcome under intense pressure and scrutiny. When negotiated well, the result is accountable, well-informed policies that balance scientific and other expertise. One contributor explained how the UK's COVID-19 lateral flow self-testing capacity resulted from the effective combination of the Government's aim for self-testing to predominate and the necessary scientific expertise to make it a reality. However, negotiating the barrier poorly can result in an inefficient compromise or, in rare cases, friction between advisers and policymakers.

In some cases, the conduct of science conflicts with politics. For example, science operates on principles of international collaboration and universalism,[8] whereas participants noted that elected politicians are more constrained to act in the interests of the nation. This has contributed, for example, to the serious inequity in the international response to the COVID-19 pandemic.

In other cases, a lack of appreciation of policymakers' priorities can lead to avoidable misunderstandings between policymakers and their scientific advisers.

Different backgrounds

Science advisers and policymakers often come from different educational and professional backgrounds. As several speakers at the workshop highlighted, relatively few people involved in policymaking in the UK have a background in STEM subjects.[9,10] Many agreed that this can make it more difficult for policymakers to use scientific advice appropriately and effectively in policymaking. The recognition of this has led to initiatives to improve the use of science advice within government and the civil service.

Similarly, scientists often lack experience of working in political institutions. As a result, they may not fully understand the culture or process of policymaking, and may not appreciate exactly what is expected of advisers, making it difficult to relate their evidence and expertise to policy.[11] Initiatives which second scientists into science advisory roles are important efforts to redress this lack of experience.

Factors influencing policy

Inexperienced science advisers may overestimate the role that science advice plays in decision-making. While scientific evidence plays a crucial role in providing systematic knowledge,[3] participants emphasised that policymakers must balance science advice against a number of other inputs.

One of the key factors that policymakers consider is public acceptability: how will the public react? This is important for three reasons. First, practicality: policies that the public find unacceptable may simply fail if compliance is low. Second, for democratic accountability: elected officials should take account of the views of the public that voted for them. Politicians can therefore legitimately ignore scientific advice if they believe that public acceptability is low or that another policy is in the public's best interests, provided the reasoning behind such decisions is made clear. Thirdly, politicians often consider public acceptability as an important factor influencing voting behaviour.

The decision of the Advisory Council on the Misuse of Drugs to go against the publicly stated view of David Nutt, then a science adviser on the Council, is an example where politicians advocated a policy outcome that was framed not by the scientific advice alone, but also took account of other factors, including their assessment of public opinion. The banning of smoking in public places is a further example of the impact on policy of a judgment on public acceptability. The science advice on the harms of smoking had been clear for decades, but the timing of the ban resulted from a judgement of public acceptability.

Policy measures must also be cost-effective to be considered. Voluntary measures and guidelines, such as those introduced at the beginning of the pandemic, are popular with policymakers because the cost to government can be minimal, although the cost to the public may be considerable. Since policymakers have finite resources, the public value of a given policy must also be carefully weighed against other policies. Science advisers need to understand that not acting may be the best option for policymakers, and that resource-intensive and costly new regulation is often a last resort, unless the public benefits clearly outweigh the costs.

Finally, Rupert Lewis noted that the assumption that it is necessary to intervene in response to science advice may be unfounded. The first test for policymakers is whether market forces will resolve the issue: certain problems will resolve themselves. The threshold for intervention depends on a number of factors, including ideology, with left-leaning parties being historically more inclined to intervene – particularly in social policy – than right-leaning parties in a given situation.

Bandwidth, resources and turnover

Advisers must also be aware of limitations to policymaker bandwidth – limited resources and little time. Particularly during a crisis, windows of opportunity for science advice may therefore be narrow. For example, one participant reported that the answer to one question posed to SAGE was required at two hours' notice. This urgency creates a tension between expediency and the strength of the evidence informing decision-making. Roger Pielke Jr. summarised the tension, "I can do a study of epidemiological trajectories of the pandemic, and I'll get back to you in three years. That might be good research, but that's not going to help."

In addition, many policymakers lack technical expertise for a given problem, to the extent that they may not be able to identify relevant academics to advise them. Policymakers often have small teams and consequently limited capacity to maintain networks, which is exacerbated by the frequent turnover of staff in the civil service. These limitations can make it difficult to reach the right adviser at the right time.

Although science advice can do little to address the roots of these problems, several participants emphasised the crucial importance of establishing and maintaining multidisciplinary networks representing a breadth of expertise to ensure that rapid, relevant and high-quality advice is readily accessible, particularly when it is needed at short notice.

Maintaining large personal networks was cited as a desirable quality for science advisers for this reason. Several contributors noted that intermediaries play a vital role in building and maintaining these networks. An intermediary in this context is anyone who bridges the worlds of academia and policy, including Chief Scientific Advisers within government, members of policy offices within universities, such as The Forum of Imperial College and the Centre for Science and Policy (CSaP) of the University of Cambridge, and organisations such as the University Policy Engagement Network (UPEN).

Framing and dialogue

"Science and policymaking are different realms characterised by very different cultures, styles of reasoning, methods and epistemologies."[3]

Many of the science advisory committees in the UK, including SAGE, are commissioned to respond to specific questions posed to them by policymakers.

How questions are asked can affect the framing of a policy problem, and vice versa. "Framing" refers to how issues are defined, and therefore which evidence and disciplines are deemed relevant and which policy options are included or excluded. In short, framing "delimit[s] what is 'thinkable'" for a given problem.[3]

The need for framing can be understood through the concept of "bounded rationality".[12] Due to the limitations on their time, and on human cognition, policymakers cannot focus on all facets of a question simultaneously, but must judge which to prioritise.[13] This is particularly apparent in complex issues.[3]

How policymakers and scientists frame problems can contribute to a cultural barrier between them. As described in the *Factors influencing policy* section (above), policymakers often adopt a "market failure" paradigm or approach when framing a question: they may not take any action until they are convinced that the situation (the market) will not be able to fix itself, and the threshold for intervention may legitimately vary based on a policymaker's ideology. Scientists are less likely to be cognisant of the "market failure" paradigm, so may assume that policymakers will act based on a particular piece of evidence, despite there being no evidence to suggest the situation will not fix itself (i.e., no market failure).

Framing helps to explain the change in the UK's response to the pandemic. Initially, policymakers framed the pandemic solely in epidemiological terms, as shown by their focus on the national healthcare service's intensive care capacity. As the country came out of the first nationwide lockdown, policymakers adopted a more economic framing of the pandemic. This resulted in policies such as the "Eat Out to Help Out" scheme, which would probably have clashed with advice given solely on epidemiological grounds, as it increased rather than decreased infection risk.

Although epidemiological modelling predicted that the absence of restrictions would result in a significant impact on healthcare capacity and mortality, the reintroduction of restrictions was contested by some because of their potential impact on the economy, which itself has significant health impacts. Many contributors emphasised that this was, in fact, a false dichotomy, because locking down rapidly was likely to benefit both public health and the economy in the longer term. However, this debate demonstrates how framing can focus attention on a single facet of a complex subject, and how this in turn can preclude helpful analysis. The absence of an analytical approach that combined epidemiology with economics meant that there was no straightforward way of reconciling these competing frames. The importance of competing frames to science advice is discussed in *Communicating degrees of uncertainty and ambiguity*, below.

Exploring the frame: the role of dialogue

Approaches that encourage scientists to pursue careers in the civil service, or that second civil servants into the government, are valuable exercises in improving understanding of how each tends to frame issues. Participants again emphasised the vital role of intermediaries in organising these efforts and in providing support to both scientists and policymakers while they transition.

Even scientific advisers with an intimate understanding of policymaking need to engage in dialogue with policymakers in order to advise them effectively. Dialogue allows advisers to understand the rationale and the motivation behind a policymaker's question. This requires the policymaker to have clear policy goals for advisers to work towards (something which was reportedly lacking early in the pandemic[11,14]) and to be transparent about their priorities. Wendy Barclay added that this was particularly important before embarking on intensive evidence synthesis. Dialogue also allows the policymaker to interrogate the reasoning behind the advice that they receive. This requires the science adviser to set out their rationale, to listen to the policymaker's feedback and concerns, and to create an environment where the policymaker feels comfortable asking for clarification of points they do not understand.

> "Some back and forth at that interface is incredibly valuable and generates insights on both sides that can lead to a refined and better question."
>
> Rupert Lewis

Such dialogue is vital to maximising the effectiveness of the science advisory process. It promotes a mutual understanding of priorities and helps to elucidate how a topic is being framed, which prevents advisers and policymakers from talking at cross purposes, and produces more focussed questions and more useful answers.

The Intergovernmental Panel on Climate Change (IPCC), and the Data Evaluation and Learning for Viral Epidemics (DELVE) each provide examples where dialogue between scientists and policymakers before reports are published helps to maximise their comprehension and impact.[3,15]

Some participants expressed concerns that negotiating the question being asked by policymakers may blur the line between science and policy and may interfere with perceptions of the objectivity of the science advisory process. The importance of maintaining lines of accountability in decision-making is discussed in *Maintaining lines of accountability*, below. However, it is important to note that policymakers and their advisers may not agree even when framing does align. Baruch Fischhoff summarised the aim of effective communication of scientific evidence as "not agreement, but fewer, better disagreements".[16] Put differently, even when people agree on what the evidence means, they may disagree on what action should follow. Policy options informed by evidence can legitimately be contested on a number of grounds, such as cost, feasibility, risks, and public acceptability.[3] Working together to define a scientific question is therefore unlikely to interfere with scientific objectivity or democratic accountability, though how appropriate it is may depend on the agreed role of the adviser (see Box 2, below).

Trust

"Building trust is a central task for senior science advisers. Trust is central to many of the tasks of science advice: to the personal relationships through which advice is transmitted, to bridging research and policy communities, and to leadership at times of emergency."[2]

Dialogue between policymakers and their advisers is likely to be fruitless without mutual trust. Several participants suggested trust was the most important single factor in determining whether or not advisers were effective.

Building trust is neither a trivial task, nor a simple concept. David Spiegelhalter cited the work of Onora O'Neill as foundational to his thinking in this regard. O'Neill distinguishes between the act of trusting and the notion of being trustworthy.[17] The aim of dialogue in this regard would, according to O'Neill, not to be to ask the other person to trust you, but rather to *demonstrate your trustworthiness to them*. David Nabarro summarised this approach as "being authentic", and outline outlined four concepts as useful rules of thumb for building trust as an adviser: see Box 1.

Box 1. The 4 Cs

- **Connecting** with a policymaker via dialogue is key to establishing trust. Accordingly, Sally Davies suggested that emotional intelligence was a key quality for a science adviser. A science adviser who has direct contact with policymakers must be able to quickly read a situation and know how to frame the subject, for example. In addition, Charles Bangham quoted the advice given to a journalist: “never underestimate your readers’ intelligence, but never overestimate their knowledge”. David Nabarro pointed to the usefulness of incorporating scientific evidence into a coherent narrative that refers to matters of importance and relevance to policymakers as a highly effective means to connect with them.
- Being **Consistent**, not in terms of maintaining a certain opinion, but in terms of your approach to advising, is also a key facet of trustworthiness. This might mean maintaining a consistent threshold for evidence past which you might change your advice.
- **Credibility**, demonstrated through competence, honesty, and not straying from your area of expertise, is also vital. Being honest when you don’t know the answer to a policymaker’s question was cited as particularly important. This means “staying in your lane” regarding your expertise, and not being drawn to speculate.
- **Cadence** refers to the need for advisers to *regularly* provide good science to policymakers. This was highlighted by several contributors as an important part of building trust.

Confidentiality and criticism

Independent science advisers to the UK government are required to adhere to explicit rules of engagement, which state they are free to speak to the press as they wish, subject to confidentiality restrictions.[18]

Some participants exhorted those engaged in science advisory systems to speak openly to the press about science, citing the important benefits of having the best scientific minds in the country openly debating scientific evidence and improving the public scientific discourse.

Others were more hesitant about engaging with the press. Given their relationship to policymaking, science advisers' interactions with the press often carry more weight and are subject to much greater scrutiny than those of other scientists, which can make interacting with the media more difficult for them. One contributor said that they had become more reluctant to speak to the press lately because they disagreed with the government's current approach to the pandemic, suggesting a tension between freedom to engage with the press and maintaining policymakers' trust. Advisers may make their position untenable by repeatedly and publicly disagreeing with policymakers and undermining their trust.

Participants agreed that it was important for science advisers to avoid advocating a particular policy, noting that advisers should "stay in their lane". Advisers should understand the scope of their role: it is not to influence policy in a certain direction, but to facilitate policymakers to make informed decisions. Science advice is only one factor in decision-making, and science advisers may be unaware of the many other legitimate considerations of good policymaking (such as cost, risk, feasibility, and acceptability). The adviser should be aware of the importance of these other factors, and that advocacy can create friction and erode trust.

While advocacy can be inappropriate for formal advisers within government, it can be a legitimate and important function of external scientists. Criticising current policy can be an effective way of catalysing change and earning a seat at the table. Working with the media to call attention to issues can influence public opinion, and politicians pay close attention to the media. Policymakers often engage with critics who put across cogent and realistic arguments to which they are unable to provide good responses. Several academics who currently play important advisory roles began as vocal critics of current policy, such as Dieter Helm and Michael Marmot. In addition, influential advisers sometimes discuss the scientific aspects of government policy in the press in order to exert external influence on policymakers, although John Bell noted that it was important to attempt to communicate directly with policymakers first in order to maintain their trust. For example, the change in policy on mask-wearing during the UK's response to the COVID-19 pandemic was influenced by a concerted effort to publicise scientific evidence in the press.

Roger Pielke Jr's conceptualisation of the various roles that scientists can play in informing policy helps to resolve the potential conflict, for an adviser, between advocacy and impartial advice: see Box 2. Taking a more nuanced view of the scientist's role in policy suggests that advocacy can be legitimate. Scientists may adopt different roles depending on the topic at hand. A trusted government adviser may play an honest broker role in many cases but may adopt an advocacy role for more high risk or high impact issues. In Pielke's categorisation, advocacy is considered as a legitimate role for scientists in a democratic system, provided advisers are transparent about their intentions. For example, advisers on climate science may legitimately advocate for climate policy action, since their analysis would clearly indicate the high risks of inaction. The crucial point for Pielke is that for formal systems of science advice, policymakers, advisers, and the public must be clear on

Box 2. The multiple roles of scientists in informing policy

What might be an appropriate role for a scientist in one context may be inappropriate in another. Roger Pielke Jr. categorises the various roles that advisers can play in his book, *The Honest Broker.*[23] Scientists might occupy various roles depending on the type of issue and political setting.

"Pure scientist" is a largely hypothetical role. It describes scientists who do not aim for their research to have societal or political impact.

SAGE provides an example of "science arbitration", where science advisers use the tools of science to propose an answer to a given question. This is a common form of independent science advice. As outlined in *Exploring the frame: the role of dialogue*, above, some negotiation of this question is likely to maximise the effectiveness of this mode of advice.

"Honest brokers" understand the range of policy options available to policymakers and provide an explanation of the strengths and weaknesses of the body of knowledge which informs them. Whereas science arbitration addresses questions in a technical manner, honest brokers may be more engaged in framing a topic. Both science arbitration and honest broker functions are often carried out by committees.

Finally, "issue advocates" are responsible for identifying what they see as the key lines of scientific argument for a given policy problem. This role is likely to be filled by external scientists, although within government this can be coupled with a "red-team" function, which critically assesses the advocacy position to identify and mitigate any bias.

The key issue to look out for, according to Pielke, is "stealth advocacy", where scientists state they are providing an arbitration or pure scientist function, but are either secretly or inadvertently advocating a certain policy, something which is frequently seen in climate change policy.[23]

which role advisers are expected to play. Pielke advocates clear “terms of reference” that outline the function of advisers as a means of achieving this.

Humility and degrees of certainty

Two further factors are central in demonstrating trustworthiness. First, you must have the humility to admit when you do not know the answer. Second, it is important acknowledge the limitations regarding the evidence – i.e. to acknowledge uncertainty.

Scientific uncertainty can be defined as "the limitedness or even absence of scientific knowledge (data, information) that makes it difficult to assess exactly the probability or likelihood and the range and intensity of possible outcomes".[3] Importantly, there is no widely accepted definition. Nor is there a consensus on how to categorise or communicate degrees of certainty. There are many different typologies of certainty, which are often incompatible with one another.[3,19]

Van der Bles *et al.* categorise uncertainty into direct and indirect uncertainty. Direct uncertainty expresses uncertainty relating to the measurement of a phenomenon and can be expressed in terms of a confidence interval, for example.[19] Indirect uncertainty concerns the quality of that measurement and may rely on an expert’s qualitative assessment of the quality of the underlying evidence.[19] This categorisation was conceived with communication in mind, and so is useful in the present context.

Direct and indirect uncertainty are relevant when focussing on a single quantity of interest that might inform decision-making, whether from the past (e.g., vaccine effectiveness rates) or the future (e.g., COVID-19 cases next month). But this “narrow” uncertainty concerns only a few measures, whereas advisers and policymakers are interested in a much bigger picture that is not fully quantifiable.

The limitation of metrics to describe a situation in which the potential impact of an action or phenomenon cannot be fully specified can be termed “epistemological uncertainty”, “radical uncertainty”, “ontological uncertainty” or “indeterminacy”.[3,20–22] Whereas direct and indirect uncertainty refer to our inability to answer questions accurately and confidently, indeterminacy encapsulates our inability to conceptualise a problem and so to identify relevant questions and analyses.

Indeterminacy opens up the possibility of multiple ways of framing an issue, as in the example of how the framing of the pandemic by UK policymakers changed over time in *Framing and dialogue,* above. This example shows that experts from different disciplines are also likely to frame problems differently, generating ambiguity regarding which course of action to take. “Ambiguity" here describes situations where multiple interpretations of an issue are valid.[3] As one contributor summarised, ambiguity is a case of “comparing apples and oranges” – there is no definitive right answer.[23]

Communicating degrees of certainty and ambiguity

"It is recommended that attention is always given to identifying and assessing uncertainties when the scientific advice is given. Scientific advisors need to provide clarity about what is known, partially known, unknown, and unknowable."[24]

Distinguishing between types of uncertainty can be useful, because different methods for generating and communicating science advice are appropriate for each type.[23] The critical point is to understand that there are different degrees of certainty in scientific evidence: this degree can often be quantified and can be used explicitly in formulating policy. Formalised methods exist for the communication of different types of uncertainty and ambiguity: for a detailed description of these methods, see the *Science Advice for Policy by European Academies* report.[3]

Direct certainty

David Spiegelhalter provided an example of good practice in communicating direct uncertainty. Fan plots are used by the Bank of England to project future economic trends. Unlike line graphs, fan plots do not have a central line on which people can fixate. Instead, the chart depicts a “fan” of continuously varying colour density, the density indicating the confidence interval. This is a more useful way of representing direct uncertainty than the commonly used error bars. He noted, however, that people may not warm to this initially, because the absence of an exactly identified central estimate makes it difficult to quote precise statistics.

Indirect uncertainty

One effective means of communicating indirect uncertainty mentioned by several contributors to the workshop was the use of “low”, “medium” and “high” categories of confidence in evidence. For example, Wendy Barclay said that this method was used to communicate confidence to policymakers in the effectiveness of vaccines against variants of COVID-19, based on the number of sources of data on which the estimates were based. The IPCC was also cited as a body that distinguishes between direct and indirect certainty.

The GRADE scale of evidence as used in medicine was noted as another method for communicating indirect uncertainty. The GRADE system categorises separately two quantities: the strength of evidence for a given conclusion, and the strength of a recommendation resulting from that conclusion.

Box 3. The importance of communicating indirect uncertainty

The UKHSA is responsible for producing information on outcomes following COVID-19 vaccinations given in the UK. To calculate the percentage of people who experienced a certain outcome, an estimate of the size of the UK population is required. There are a number of such estimates, for example, from national healthcare databases and the census.

By basing their figures on national healthcare databases, which assume the UK has a larger population than does the census, the UKHSA produced figures that suggested a *greater* proportion of vaccinated 40–49-year-olds were dying from COVID-19 than those who were unvaccinated.

Using a more realistic reflection of the UK's population resolves this issue, however, the UKHSA continued to publish their estimates, although with additional caveats.

The resulting misinterpretation fuelled a number of online debates and theories, including being part of an argument made by President Bolsonaro of Brazil suggesting that COVID vaccines caused AIDS,[19] which contributed to the misinformation around the safety of COVID-19 vaccination.

David Spiegelhalter demonstrated the importance of communicating indirect uncertainty clearly.[25] In particular, he discussed the controversy generated by the UKHSA's mortality and morbidity figures: see Box 3. Christl Donnelly said that best practice in communicating indirect uncertainty therefore includes, in addition to quantifying the degree of confidence in data or conclusions, a critical analysis of the evidence and an explicit statement of the assumptions made in calculating figures. David Spiegelhalter agreed that it was crucial to list the limitations as an integral part of an analysis. Speaking about graphs in particular, he suggested that the limitations should be included as "part of the JPEG." Empirical evidence has shown that when information regarding the quality of evidence is absent, people tend to assume that it is of high quality, providing strong reason to communicate this information.

Indeterminacy and ambiguity

Science advisory committees such as SAGE aim to distil the available evidence into a consensus scientific view.[2] SAGE generally aims to present a "single view of the science", [14] however, a consensus does not necessarily comprise a single view. Reaching consensus on the diversity of legitimate interpretations (ambiguity) and explaining exactly why they diverge can be a more useful way of advising on complex issues which cannot usefully be reduced to questions of certainty.[3] Such approaches to describing uncertainty and diversity of view can help policy makers frame the decisions they can make on the basis of the evidence. For example, framing decisions in terms of the least bad option, or what "no regrets" measures – measures that are useful in all circumstances - might be available, helps decision-makers in the absence of clear or certain evidence.

There are techniques which allow the simultaneous representation of multiple viewpoints, such as "multicriteria mapping".[23] It is less straightforward to represent ambiguity in numerical or graphical terms, although counterfactual modelling can represent multiple viewpoints through techniques such as sensitivity analysis, for example.[23]

Some participants expressed concerns about the even representation of multiple viewpoints, because it can give rise to false balance – that is, a false impression of the balance of views. An example of false balance is one-on-one debates on climate change, where a "for" and an "against" commentator are chosen, giving the false impression of a 50/50 split in the scientific community, rather than the reality of an overwhelming scientific consensus on anthropogenic global warming. Concern was also expressed that simple communication of uncertainty and ambiguity, without any measure of the degree of uncertainty, can be used to make scientific knowledge appear seem less certain than it is, as in the example of the fossil fuel and tobacco industries.[26] David Spiegelhalter pointed to empirical data which indicate that accurate and honest representation of uncertainty does not generate mistrust, and noted that public trust in science had increased during the pandemic, despite open disagreement amongst scientists.

In fact, failing to communicate uncertainty and ambiguity was an important source of public distrust generated by the BSE crisis in the UK.[27] The government tried to downplay the uncertainty inherent in their advisers' judgements, famously promising British beef was safe to eat.[28] When it transpired that eating contaminated meat could indeed cause variant Creutzfeldt-Jakob disease (vCJD), public trust in the government and scientific advisory systems plummeted.[29]

Faithfully representing both uncertainty and ambiguity is therefore crucial to creating authentic dialogue and trustworthy communication. They are also integral to creating clear lines of accountability: see *Maintaining lines of accountability*, below.

The importance of trust to science advice can create problems for the inclusion of multiple, diverse viewpoints,[2] and therefore for the communication of ambiguity. As Amanda Wolthuizen said, in a crisis, policymakers tend to reach for "the usual suspects". While intermediaries play an important role in broadening those networks, trust still plays a role; Paul Cairney noted that intermediaries themselves may also be prone to the "usual suspects" approach.

Maintaining lines of accountability

> "The point of an honest brokering committee is... to provide the policymaker with a range of choices, because it's really the policymakers, the elected officials, whose job it is to represent societal values and make those trade-offs. We don't do that very well. And the reason for that is it clearly locates democratic accountability with the policymaker."
>
> Professor Roger Pielke Jr.

It has been suggested that some policymakers may expect too much certainty from scientific evidence.[3,7] Although much emphasis is often placed on ensuring policymakers understand uncertainty, participants noted that policymakers are used to making decisions under significant pressure with only partial information. Aside from creating authentic and trustworthy dialogue, another reason to communicate uncertainty and ambiguity clearly was put forward: to maintain clear lines of accountability between science advisers and policymakers.

Early during the pandemic, policymakers in the UK adopted the mantra that they were "following the science". As a number of participants pointed out, this was a misrepresentation of science, given the uncertainty surrounding the impacts of the pandemic and the unknown consequences of various policy measures aimed to mitigate these impacts. Representing science as a single entity which can be followed can give policymakers a spurious means of escaping accountability.[6]

An important method of clarifying the role of science advice in this regard is using explicit "terms of reference", which clearly delineate the role of advisers and policymakers. Communicating widely via the media the role that advisers play in relation to policymakers is important both to clarify that it is the politicians who are responsible for decision-making, and to maintain public trust in science advisers.

Andrew Stirling suggested that advisers should avoid expressing scientific advice as a singular voice, to ensure that accountability for decision-making remains with politicians. His advice was "always say 'it depends'", which might mean expressing a range of advisory positions given a number of different scenarios: "if a, then x, if b, then y," where the conditions (a and b) are as important as the recommendations (x and y). This approach makes it clear that the relative strengths and assumptions underlying each possible outcome must be discussed, and clearly locates the responsibility for decision-making.

This approach can be at odds with what policymakers may want from science advisers, however. Chris Whitty and Patrick Vallance have noted previously that policymakers were unlikely to warm to highly conditional advice representing multiple viewpoints.[14] Although offering contingent advice may be at odds with what policymakers want, scientists should resist providing simplistic answers where the evidence is more ambiguous.

The L'Aquila earthquake in Italy provides a striking example of the importance of having clear lines of accountability in climates of uncertainty.[30,31] Box 4 explains the L'Aquila case study in greater depth. The IPCC was highlighted by Roger Pielke as an exemplar, as they have clear terms of reference. However, James Wilsdon noted that terms of reference can't

Box 4. The importance of clear terms of reference in climates of uncertainty

On 31st March 2009, six scientists attended a meeting with local politicians to advise on the likelihood of a serious earthquake impacting the inhabitants of L'Aquila, a city in central Italy. There, they suggested that an earthquake of sufficient magnitude to put the inhabitants' lives at risk was unlikely, but did not rule out the possibility.

Local politicians, however, assured the city's population that they were not at risk, and recommended they stay inside during the earthquake, rather than evacuating.

This misrepresentation of uncertainty led to over 300 people losing their lives, and to six science advisers receiving custodial sentences. The verdict was eventually overturned, but L'Aquila exemplifies the importance of drawing clear lines of accountability.

formalise how advisers should act in every possible scenario. Wilsdon therefore suggested that the onus is on advisers to be honest, to be clear about their intentions, and to avoid oversimplifying, while Kathryn Oliver noted that maintaining strong ethical principles as an adviser was key for this reason

A conditional approach also avoids the framing of changes in advice as “U-turns”, a matter on which several participants commented. Because science advice may change as new evidence appears, it is important to shift the narrative to project changes in advice less as U-turns, more as evolving positions in the light of new knowledge. David Spiegelhalter quoted John Krebs’ method of communicating uncertainty in response to the BSE crisis: “First of all, you say what you know, and then you say what you don't know. Then you say what you are doing about it to improve your knowledge, then you say what the consumers can do… but the crucial thing to finish off with is saying we will come back when things change – and things will change.”

Getting involved

Finally, participants shared their advice on getting involved in policy as a scientist. It is important to note that there is no one-size-fits-all approach to influencing policy, but some key factors were noted.

Having significant networks within academia is a desirable trait as a science adviser, as it gives you ready access to a wider group of experts who can contribute to policy discussions. Having contacts with those in government and Whitehall was seen as helpful in engaging in the advisory process; however, many early-career researchers will lack such contacts.

Many of the opportunities to give science advice encountered by the workshop participants resulted from their world-leading expertise in a particular area. Beyond expertise, this highlights the important role that “policy environments” play in the careers of science advisers. Unless an academic’s particular expertise is of relevance to policymakers, it is unlikely that they will be asked for advice. Academics can make their research more relevant to policymakers by listening to their needs, for example, government departments publish Areas of Research Interest.[32] However, it is important to note that this does not guarantee a policy impact.[33]

Applying to sit on science advisory committees and subcommittees offers another route into policy advice for established academics. Evidence synthesis for policy was suggested as a more accessible way of contributing to policy, as it often requires a larger group of people.

As discussed in *Confidentiality and criticism*, cogent criticism in the media can lead to opportunities to provide science advice. Communicating via the media, for example, working with the Science Media Centre, or writing articles in Nature or New Scientist, was suggested by participants.

Scientists were encouraged to practise defining the questions that they believe policymakers should be asking, which means considering the relevance of one's work for society. This was proposed as a key skill for scientists to practise if they are interested in policy, given the importance to policymaking of defining the question.

Participants exhorted those who believe that the government is insufficiently addressing questions within their area of expertise to raise their profile, although those in advisory positions must be wary of overstepping the mark. Beyond honing the skill of defining questions, communicating about your areas of concern with people around you as widely as possible was also seen as influential to influencing public opinion, which can indirectly influence policy. Alternative methods of swaying public opinion include activism and engaging with the media. Scientists are increasingly becoming politically engaged, for example in activism around COP26.[34]

University policy engagement programmes were put forward as an important resource for academics to gain other relevant skills, as well as a source of opportunities to learn about and get involved in science advice. Graduate school programmes that focus on the relationship between science and policy are also useful resources. Some participants suggested that school and undergraduate science curricula should also be reformed to include education on uncertainty and other factors that would help scientists understand the links between science, policy and society.

Any discussion of science advice would be disingenuous without mentioning equality. The gender and race disparities evident even in this workshop are symptomatic of the pressing need for more action on diversity and inclusion in science education and careers.

Conclusions

Policymakers and scientists inhabit different worlds, sometimes resulting in a cultural barrier that needs to be overcome for science advice to be effective. The importance of developing a mutual understanding between policymakers and scientists cannot be overstated: the two sides need to engage in dialogue to explore how issues are framed. An important factor in ensuring this dialogue is effective is trust. Trust cannot be built overnight; it requires advisers to demonstrate their trustworthiness. This report outlines several ways of achieving this, chief amongst which is the clear communication of uncertainty and ambiguity. The accurate and quantified representation of uncertainty and ambiguity also has important implications for ensuring that accountability for policy rests with policymakers, rather than advisers. Good science advice is nuanced, contextual, and requires the careful consideration of uncertainty and ambiguity.

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