Speech at Victoria University of Wellington - *Integrity in Science: Implications from and for the Climate Change Debate*

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First I'd like to thank the School of Government at Victoria University and the Institute of Policy Studies for inviting me to speak here today. Let me start with two caveats and an apology:

The first caveat: of necessity I will be talking in broad generalities about the nature of science and scientists and of community attitudes and lobbyists. In doing so it is inevitable that there will always be exceptions to the rather broad statements that I shall make.

Secondly, I will be analysing matters that have engendered heat from multiple quarters and where intense, and not always polite, debate is ongoing. It is not my intention to exacerbate that heat, rather to explore why it exists and understand its implications for the public understanding of science and policy formation. Only then can the public understand what is happening.

Now the apology – this will be a relatively long lecture – the topic is too important to trivialise.

The nature of science

The interaction between science and society has always been complex. Special knowledge of the natural world was what gave shamans and spiritual leaders their special authority. But what we now call science emerged in the 16th century with the rise of empiricism, supplementing if not replacing the teleological and deductive thought which had prevailed since the time of Plato and Aristotle.

Science, as we now know it, is an iterative process of observation, experimentation and concept formation whose purpose is to understand the natural world. Perhaps the most succinct definition is that of Jonathon Marks, a philosopher of science who recently defined science as "the production of convincing knowledge in modern society". The key word in this definition is "process" – science is not just about facts, it is the process by which the validity or otherwise of knowledge about the natural world and the universe is established – that is becomes convincing. In the absence of science, knowledge about the natural world can only be acquired via anecdote, belief or dogma.

For many years science was dominated by the physical sciences with their focus on the discovery of natural laws, whereby science, mechanics and mathematics combined to produce a rather Pythagorean view of science – one in which science was about achieving certainty. This was about gravity, about the laws of physics, about determining the speed of light, and at the other end of the scale, determination of molecular structure. Most of this

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science was relatively linear – push the system in one way and it would respond in a given and proportional way. But even these sciences were to fall foul of complexity and uncertainty with the advent of concepts such as quantum physics, relativity and string theory.

But it was particularly with the explosive emergence of the biological sciences in the early 20th century, and more recently the environmental and ecological sciences, that science has had to develop ways to handle complex systems. Deterministic science has been augmented with ways to handle probabilities and understand the confidence limits around uncertainty. Models become more important. And importantly, a feature of many of these systems is that they are non-linear – that is, the response may involve thresholds and complex interactions and feedback loops.

There are two general approaches to the study of complex systems. The first is a top-down approach which tries to describe the system as a whole and then dissect the components at various levels. Evolutionary arguments as first detailed by Darwin and Wallace fit in this category. The alternative is a bottom up approach whereby the individual parts are studied in detail so as to build up a model of the whole system; molecular genetics is an example of this latter. Reconciling these two approaches is not easy – often the scientists involved in these two approaches effectively do not speak the same languages and the assumptions and nature of evidence used in the two approaches can be very different.

The modern synthesis of the 1940s which reconciled Darwinian evolution with classical genetics is an example of a successful fusion, but one which still leaves conceptual gaps. But the evolutionary story reinforces my earlier point – observation leads to hypothesis that leads to observation that leads to refinement of the hypothesis and so on. From the time of the modern synthesis on, observation after observation supported the general Darwinian model as it was gradually refined to incorporate what were earlier judged problematic observations.

Sometimes, data can come along that makes a past concepts untenable and then new models need to be developed to explain the observed facts. A good example of this was the discovery of *Helicobacter* by the Australian Nobel laureates Barry Marshall and Robin Warren. This is a bacterium that causes peptic ulcers. This completely replaced the earlier idea that such ulcers were due to psychosomatic stress. Antibiotics replaced earlier ineffective forms of therapy and even surgery. Such are the paradigm shifts that Thomas Kuhn wrote about.

This tells us something else about science: while scientists are often highly individualistic and egotistical, ultimately science is a group activity – essentially it is a community who in a variety of formal and informal ways assess the body of evidence for the most plausible explanation, which is then tested iteratively in various ways until that explanation is either accepted as knowledge or a new explanation is sought.

Most science fits into one of two categories – experimental or observational. Experimental science involves active manipulation to see what happens to a system. The randomised clinical trial is an obvious example. While most domains of science have an important experimental component, some are almost entirely observational – and often that observation has to be historical rather than prospective. Geology, palaeontology, and astronomy fit in that category. In those sciences, progress occurs from looking at past data, formulating new hypotheses and thereafter exploring other data sets to test those hypotheses.

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Climate science

Climate change science is similar to those observational disciplines in that the data must by definition be retrospective or at best current, but there is one important difference – the models being developed are being used to predict the future rather than to develop a hypothesis to test against another retrospective data set. To a certain extent we use the same approach in some aspects of medicine – we treat mild hypertension largely because we can predict the dangers of raised blood pressure from observational studies at the population level and extrapolate from that to individual risk, but the key difference is that we can also perform experimental trials to test the validity of the prediction. This is simply not possible when examining global or regional climate change – we have no way of experimenting and we have only one planet.

It is this unique positioning of climate change science as a predictive science that causes discomfort for a few scientists, especially those from those components of disciplines such as engineering or physical sciences that do not deal with complex systems and uncertainty and who may regard climate science as a trivial application of basic physical science principles rather than appreciating that while based on physics, it involves particularly complex interactions including those with the biotic world.

The key to climate science is the application of model systems – that is mathematical models of future climate trends based on what has happened in the past. One of the challenges, given that instrument based readings are relatively recent, is how to extract information about past environments: proxy measures such as tree rings, sedimentary studies and ice cores are needed. The models that have evolved over the past 30 years originated primarily from those used to predict weather. There were also early contributions from those studying atmospheric behaviour in analysing the risks of nuclear winter during the cold war. The models were initially simplistic and have since then become increasingly complex in their endeavour to determine how the global climate changes over time and how it is affected by a multitude of factors including sunspots, reflection, pollution, volcanic activity and greenhouse gases. The relationship between rising greenhouse gas concentrations and global, let alone regional, temperatures is not linear and the technical issues have been rather substantial. Many unknowns have had to be addressed.

Early climate models in the early days showed considerable wobble in their predictions but as more and more factors were taken into account, they have become remarkably stable – the fit to past observations remains very good and it is this fit that gives the basis for greater confidence in future predictions. There are a variety of modelling approaches and the coherency reached between these is an important validation of the conclusions reached.

But let me be clear that the science will never be complete – it cannot be. While we may be able to be definite about the speed of light, no field of complex science can ever be considered complete. There are aspects of climate science we are very certain about, an increasing amount we are pretty certain about, and much we have yet to better understand. For example we have very clear records of changing greenhouse gas concentrations in the past 50 years, but we do not fully understand the lag between rising CO_2 concentrations and mean global temperature, the relationships between deep and superficial sea temperatures, the rate of methane release from warming tundra and so forth.

It is not my intention here to debate climate science; indeed, I cannot because I am not a climate scientist. Rather, I want to explore why there is a debate and its implications for science as a whole. But suffice to say that I accept the weight of evidence that anthropogenic climate change is real and at some time in the not too distant future there will be significant impacts. This is the consensus view reached by every credible scientific

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body that has examined the question. True, there remain uncertainties as to how fast warming will occur and to what degree and there remain many technical questions.

However the general consensus is that:

- The currently observed warming is different to that of past warming episodes and is caused by anthropogenic emission of greenhouse gases, such as carbon dioxide and methane.
- The world will continue to warm while we continue to emit high levels of greenhouse gases.
- Because of the latency in the forcing effects of greenhouse gases, the world will continue to warm for some time even if we ceased all greenhouse gas emissions tomorrow.
- There is a risk of dramatic and non-linear change – for example large scale ice sheet melts, or release of methane from thawing tundra that could cause large and particularly rapid climate shifts.

There are many uncertainties, particularly about this last point and this had led some climate scientists to take a point of view seen as potentially extreme by others. But the issue is not that the scenarios are possible, only what is their probability on top of the baseline increase about which there is no real debate.

One problem in public understanding of what we are dealing with is that weather and climate are different and global warming will not be uniform and for a variety of reasons, regional and even extreme seasonal cooling may be observed.

Some recent analyses suggest that it is more likely than not that global average climate will warm at least 3 °C relative to pre-industrial conditions by 2100. A rise of 2 °C is generally accepted as being associated with significant change in numerous physical and biological systems on the planet which will impact on our lives. This is seen as likely to occur between 2050 and 2070 even on a medium mitigation model – that is where the communities of the world do take some reasonable steps to reduce greenhouse gases. And it is important to note that the origin of the 2 °C threshold is rather arbitrary and relates to the reality that even with the most aggressive mitigation efforts, because of the latency phenomenon, this is the inevitable degree of rise predicted.

Indeed there is ample evidence of the consequences of warming already being observed from studies of the Arctic ice sheets, to the rising temperature of Lake Tanganyika, to studies of the changing distribution of many animals and plants and the timing of their reproductive behaviours. The changing incidence of fires and extreme weather events is compatible with the warming trend. Even in New Zealand, whose temperature is buffered by the surrounding ocean, native beech trees are already producing more seed at higher altitudes and welcome swallows are breeding noticeably earlier.

Despite the recent cold UK winter which was due to the shift in the flow of the northern jet-stream, recent assessments by US agencies based on global temperature measurements suggest that 2010 could be the warmest year ever – the Arctic ice is at its lowest recorded limit for this time of year. Recent studies also confirm global sea temperature rises continue, with deeper layers which previously were not warming, now starting to show a warming trend. There is also clear acknowledgement that natural factors such as the El Nino – La Nina cycle and the sunspot cycles play a role, but these are well factored into the models that lead to the strong consensus conclusions about anthropogenic warming.

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Different world views

But these conclusions are not universally accepted – despite the strong scientific consensus from those experts in the subject there has been considerable scepticism and frank rejection of these conclusions. This discord has been well reported in the media and as a result the public is confused with a significant and perhaps increasing percentage now appearing to reject the scientific consensus.

The reasons for this confusion are the major focus of this presentation. Before getting to the specifics, it is worth noting that climate science is but one example where the interface between science and society exposes different agendas and worldviews and these latter differences, rather than the science itself, becomes the point of focus.

Evolutionary biology is a classic example. The science of evolution has come into direct conflict with particularly fundamental beliefs held by some people. For example, there are young earth creationists who hold the sincere belief that what is written in their Bible is fact – the world was created 6000 years ago and all species came into being in 6 days. Nothing based on scientific observation will convince them otherwise. For the scientist, on the other hand, there are hypothetical observations that would lead them to having to revise their evolutionary models. For example, finding a mammalian fossil in a Precambrian rock formation would overturn all current understandings, and I apologise to the great JBS Haldane for stealing his famous example of what would lead him to change his mind about evolution. But over the last 150 years biological and paleontological observations have only continued to reinforce the basic paradigm. Indeed, in the last 20 years modern molecular tools have allowed many aspects of evolutionary biology to be prospectively confirmed. While the science will never be complete, evolutionary biology is now as firmly based as our understandings of gravity. And yet even within evolutionary science, there will be a variety of emphases held by different scientists – some will give greater weight to selection, some to drift, others think the developmental component has been not fully considered and so forth. Similarly within climate science there will be a variety of emphases.

In both, there may be maverick scientists who, for reasons we will discuss later, stay outside the consensus. The scientific processes however, will over time, addresses these mavericks provided that their positioning is strictly scientifically based. If their objections appear to have some validity, then further observations will lead to either confirmation or rejection. Where the idea has merit the scientific process eventually incorporates their ideas – Wegener's idea of continental drift, Barbara McClintock's concept of jumping genes; indeed we see examples of novel ideas and concepts entering science continuously. But we need to distinguish such scientific mavericks who have novel and challenging ideas from those who are driven by other motives I will shortly discuss.

Scientists are true sceptics

Sceptics ask questions and all good scientists are sceptics. Indeed science is nothing more than organised scepticism. More than once, I have revised my understandings of the very biology I am considered to be expert in, as my own experiments and those of others have produced data that destroyed a past hypothesis that I had developed and argued for. Data indeed moves one in mysterious ways. Indeed, the scientific process critically relies on constructive scepticism, both by the individual and by other scientists. At the heart of the scientific method is the unique self-correcting process of expert criticism, review and repetition. While the peer review process is never perfect, it is a process by which the reliability of observation and hypothesis formation is filtered. Parenthetically there are other aspects of the peer review processes, such as committee bias, that can cause concern

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particularly in funding systems within a small country or a small field, but they are not the focus of today's discussion.

Scientists may speculate, but cannot interpret beyond their data. A single observation is an anecdote and is not conclusive; proper experimental design and sampling, repetition and independent expert review are required. Over time, observational or interpretative errors are corrected, bias is addressed and the relatively rare episodes of fraud are exposed, and hypotheses are either discarded or reinforced.

I mention bias and fraud because we need to acknowledge that science is a human process. Scientists are not robots; the scientific method acknowledges the potential for bias and errors. The processes of repetition and confirmation, good experimental design and peer review are largely used to prevent bad science. Bad science can take many forms: improper or biased review, failure to disclose conflict of interest, fraudulent data, sloppy science where the observations are unreliable or the experimental design biased or the statistics improper or where outliers are inappropriately excluded.

A frequent error is muddling association with causation – this underlies in no small part the promotion of a clearly false link between autism and immunisation in which Andrew Wakefield argued that because autism rose in incidence at the time children were getting the measles vaccination, the vaccination and syndrome must be causally related. He could have equally argued that autism was caused by children growing taller. His observational study was flawed on many counts, including the small number of subjects and it now appears there were undisclosed conflicts of interest and other motives in play. But despite the data being well refuted and his co-authors withdrawing, many children have suffered measles and its consequences because parents were frightened to have their children immunised. This fear is still maintained by many individuals and still promoted totally irresponsibly by our celebrity culture – since when have film stars become authorities on childhood disease? I must applaud *North and South* for their editorial this month entitled Good Science, which is one of the first times the popular media has acknowledged their responsibility in this sad affair.

Science and policy

In the climate change debate, there are some scientists who, while not doubting the fundamental conclusions and observations, worry about non-absolute science being use to predict the future. These contrarians would rather that science stays remote from policy. They would rather only act on concluded science, which in the case of climate change is simply not possible. But science cannot stay remote from policy. Science is the way we gather knowledge about the natural world and governments rely on science every day in making policy – whether it be in managing the health system, setting aside areas for conservation or deciding on what industries to support. But an important principle that I must remind myself constantly as the Prime Minister's science advisor is that science does not make policy; rather, it must establish to the best of its ability the information on which the public through its politicians chooses its priorities after taking other factors into account and then makes policy.

In climate change, as in other areas, this separation of roles is important, but at times has been conflated by both scientists and politicians. Some scientists have become overzealous in their arguments and have taken extreme positions to push for aggressive mitigation. They are now sometimes called alarmists, not a term I like. When scientists go beyond their data and reasonable extrapolation they are effectively also responding to a personal agenda. The origin of that agenda is understandable, that is to induce a policy response, but ultimately

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their behaviour has analogies to those who deny climate change because of their own agenda. The irony here is obvious – scientists may have overstated their case to persuade the population that something is happening and in doing so may have undermined their own credibility. But the problem here is that what might have been seen as extreme is not totally implausible.

On the other hand, rather than leaving the scientific process free from other agendas, the IPCC process did allow for a political dimension. It required a validation loop that led inevitably to a more conservative consensus and added to the confusion.

Rejection of the scientific evidence

While science is a truly sceptical process, the term sceptic has paradoxically applied somewhat differently in the climate change debate. Many people who call themselves sceptics are in fact more than that – they already have a fixed position. It is one they have reached for one or more of several motives. Some may reject or deny the scientific consensus for a philosophical or other reason and for them there is no set of data that is likely to change their public position. Others might even accept the world is warming but do not think there is any need for immediate action to mitigate it, at least action that might affect them, and they justify this position by appearing to deny the science. We need to explore the origins of such denialism which is at the heart of the so-called debate over anthropogenic climate change.

Such active rejection of the scientific consensus has also been seen in other controversies, including the causal relationship between tobacco smoking and lung cancer, the alleged but non-existent relationship between measles immunisation and autism, and in the denial of the causative relationship between the HIV virus and AIDS.

For some, rejection of the scientific consensus is based initially on genuine conclusions about uncertain evidence. That is healthy but often this gets displaced by a conviction that is unreasonable. This is what appears to have happened in the South African HIV denial episode. For those who are not aware of the story, for a large part of the Mbeki presidency in South Africa it was not accepted that HIV causes AIDS and anti-retrovirals were not funded, leading to many deaths – by one estimate an additional 330,000 cases. The political rationale was that the drugs were unnecessary and were being foisted on the population by western pharmaceutical companies to exploit poor South Africa. Garlic and herbs would be adequate treatment.

The scientific rationale was reinforced by the arguments of Peter Duesberg – the most prominent of AIDs deniers. Duesberg had had a distinguished career as a virologist, but some early observation in the HIV story led him to doubt the viral origin of AIDS which he published in a non-peer reviewed journal. He continued to deny the overwhelming evidence to the contrary. Thereafter he appeared to be caught up in the process of denial and its accompanying celebrity-like reinforcement.

The climate change debate

At the heart of the climate change issue are three questions:

- What is the rate of change in global temperature and what will be its local effects?
- What is the level of certainty about these predictions and the assumptions made in reaching these predictions?
- What is the nature of response that the world community must make?

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The bulk of climate science and indeed the IPCC consensus approach has been an effort to deal with the first two questions. It is important to note that the IPCC is forced by its inbuilt political process to be conservative and not alarmist. Within the tens of thousands of observations in the current report, and given the immense and microscopic inspection, surprisingly few errors have been found and none that are substantive in the conclusions reached. Perhaps the worst error was the very sloppy statement over the rate of Himalayan glacier melt: this was unscientific and poorly sourced, but it had no impact on the fundamental conclusions reached.

It is however the third issue – the nature of the response that the community must make – that is the primary driver of current controversy. Acceptance of anthropogenic global warming brings with it the acknowledgement that both mitigation and adaptation are necessary. Most predictive models suggest that without mitigation efforts, temperatures will rise in the foreseeable future to a level that will be harmful because of sea level rises, food and water security issues, ocean acidification and so forth. However it is also clear from the models that mitigation effects have a long latency – climate prediction models show little effect of mitigation for another generation and this raises important philosophical issues. Hence governments since Kyoto have been moving gingerly towards accepting the need for mitigation approaches.

While there is hope in the long-term for technological solutions such as carbon sequestration or other forms of geoengineering, it is clear that immediate mitigation requires regulatory approaches including the use of incentives that shift people towards reducing fossil fuel use and reducing emissions through the setting of carbon prices through cap and trade and ETS schemes. Many of the same measures are equally important in reducing other pressures created by our species' impact on the planet – in reducing energy usage and promoting food and water security.

New Zealand's response

New Zealand is following both a technological approach through its investment in research to reduce pastoral greenhouse gases and by way of a regulatory and incentive approach through the ETS. But why have we done it? All said and done our actual release of greenhouse gases is small in absolute terms though surprisingly large in per capita terms. Any mitigation will have a negligible effect on global warming and climate models suggest that New Zealand will be relatively less affected than most countries. But we are not unaffected – ask the people of Tokelau – and there can be little doubt that there will be in time major changes in our farming profile with some areas being much wetter and others much drier. Will we suffer from major mosquito-borne diseases like dengue fever in the year 2100?

But despite this, New Zealand has been relatively proactive in trying to do something to alleviate its greenhouse gas emissions although some are currently rather vocal in their opposition to the introduction of mitigation strategies and in particular the ETS. So why should New Zealand take this position? In part this is to protect our environmental brand, but in part it is because this issue is not local, it is global. If the "tragedy of the commons" is to be avoided, every nation must play its part and sometimes it is the smaller countries that have to lead – as we did over nuclear weapons. Whether we like it or not, for this is a global issue and we can see in the Copenhagen meeting the difficulties of getting countries to get beyond national or sectoral interest.

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The motives and actions of denialism

In understanding those who reject the scientific consensus it is important to distinguish between those who are questioning the science and those who really debating the response to it. Although to advance their position the latter often focus on creating scientific confusion through a wide variety of strategies.

Mitigation through regulation will change economic settings and thus affect the interests of powerful groups. It is no accident that the most powerful supporter of the so-called climate change sceptic movement has been the fossil fuel industry. Just as was the case in the tobacco saga where many so-called experts in the pay of cigarette companies provided so-called evidence against the restrictions on tobacco marketing, industry will pay for 'experts' – who may be scientifically qualified but are not experts in the area in question – to generate superficially plausible scientific positions. This is little different to the hired gun approach often used in medico-legal affairs in the USA where one can find an expert opinion for any position.

We need to be aware of these interests which are in play globally. Imagine if climate change brought with it evidence of dramatic economic growth for the pastoral sector far outweighing the effect of the ETS, would farmers be questioning the science? No, they would be demanding research to further its exploitation.

But beyond these obvious, if always apparent, vested interests, there are others who have trouble accepting climate change. In particular, many with a libertarian ideology do not accept that the state should control how they live their lives, particularly when the actions required will not impact for a generation or so. The economic libertarian believes growth is paramount and if there is a problem then technology will eventually solve it. There seems to be some irony in accepting that science may solve a problem but that it cannot correctly identify the problem.

In America there has been a degree of conflation between the libertarian and anti-evolution movements – both are active in denying science and there has been quite a crossover of activity - perhaps reflecting a faith-driven view of some particularly in the USA that the world was created for humans to exploit.

So there are basically three groups – a small group of scientists who sustain a contrary view for a variety of reasons, some scientific and some not, those who have a vested interest in promoting denial and those who for a variety of reasons, largely philosophical, will reject the evidence.

While the motives of those who reject the science are variable, the responses within climate change, evolution, HIV, smoking, ozone holes, immunisation and so forth have been remarkably stereotypic, so much so that they been the subject of study – the field has been given the general name of denialism. It is not a term I like very much as it conflates people with a variety of motivations but I will use it through the rest of this talk. In general, denialism involves vocal rejection of the consensus reached and to do so some denialists actively confuse or convince the public and the media that the consensus is not based on sound science.

Such rejectionists, when they have some form of scientific qualification, can provide strong voices as alternative authorities who appear credible but in general their credentials are not the same as those of active researchers in the field. Sometimes special interest groups will establish institutions with pseudo-scientific credibility such as the Discovery Institute in the

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USA to bolster their position. A frequent tool is an excessive focus on outlier extreme papers or irrelevant observations. Other tools are misrepresentation, selective use of the literature and the use of false analogies. The use of false experts is common and serious attempts are made to harass and denigrate real experts.

Harassment through use of freedom of information legislation is not new and the independent reports into the so-called Climate-gate affair show that the understandable but inappropriate actions of the Climate Unit at the University of East Anglia were in no small part due to that harassment. The allegations of bad science, now rejected by independent inquiry, arose when some admittedly fairly robust discussions among research groups were quoted out of context and used by many denialists to persuade the public that scientists will withhold data when it does not suit their hypotheses, will try to suppress alternative hypotheses, and will manipulate the peer review process to prevent dissent. As I have already explained the scientific process does not and cannot work like that. The media thrived on this but were much less vocal when those allegations were discounted by two separate and independent enquiries in the UK.

A common claim of the denialist is to suggest that the consensus has been reached by a giant conspiracy of scientists – so that the scientists can extract more grant support.
The complexity of the conspiracy needed defies belief.

While the conspiracy argument is silly, there is no doubt that science can be compromised by conflicts of interest. This has been well exposed in the relationship between the pharmaceutical industry and some clinical trials, and as a result medical journals have developed some very strong procedures to ensure that any potential conflicts of interest are exposed. Other scientific publications are learning from their experience.

Another approach of the denialist is to create impossible scientific challenges – for example it is common for climate change critics to demand the impossible - accurate thermometer readings from 500 years ago where only proxy measurements such as tree ring measures are possible.

The media

I want now to discuss the key role of the media. Not surprisingly they both are a part of the problem and essential to a way forward. The modern media like controversy – they feed off it. Entertainment is more important for most media outlets than information transfer. Furthermore, the modern media especially in the USA has been politicized and in many cases is closely linked to strong economic interests. They can give a platform to the celebrity denialist or, in their desire to appear balanced, give equivalency to each side of a scientific argument when there is in fact a broad consensus on one side and not much more than individual opinion on the other. If the smoking – lung cancer issue was only now to emerge, and even if there was strong scientific consensus, as strong as we have about the risk of climate change, would it be seen to be responsible television to give as much time to the denier likely paid by tobacco industry as to the public health expert?

The issue here that concerns me is that of how to communicate complex science. The public has a right to understand these issues and in the end they determine how society will respond. However without responsible media it is not clear how this can be achieved. Publishers, editors and journalists all have a role in ensuring quality in the information exchange. Some of the feature pieces in the Herald in recent months for example show what can be achieved.

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But if science is not better communicated, science cannot properly inform democratic decision making or policy formation and for many that would be seen as dangerous. But it is even more complex when it comes to the kind of science we have been discussing. In a recent paper in the American journal *Science*, one of the most distinguished philosophers of science, Professor Philip Kitcher of Columbia University, reminded us that one of the Greco-Roman suspicions about the viability of democracy was based on their elitist view that ordinary people would be susceptible to deception and exploitation and they argued that the ship of state should be entrusted to wise navigators. The contrasting perspective came later from those such as John Stuart Mill who argued that the free exchange of ideas is essential for intellectual and social health. The natural tendency of modern democracies would reject the former view, but the actions of rejectionists supported by the media show the difficulties of the democratic approach in the electronic era.

As Kitcher points out:

"It is an absurd fantasy to believe that citizens who have scant backgrounds in the pertinent field can make responsible decisions about complex technical matters on the basis of a few five minute exchanges amongst more or less articulate speakers..."

He goes on a few sentences later to say:

"Those covering the questions in the media, have the duty to convey the results so that citizens can cast their votes as an enlightened expression of freedom, justifiably aimed at the outcomes for which they hope. Staging a brief disagreement between speakers with supposedly equal credentials, especially when it is not disclosed that one of them is answering to the economic aspirations of a very small segment of society, is a cynical abnegation of that duty".

The response of the scientist

Scientists face a real challenge in dealing with these issues. To quote from a recent column by Leo Hickman in *The Guardian* discussing how to communicate ongoing evidence of global warming, the issue is how …

"… to present news such as this in a dispassionate, transparent, authoritative manner to a public that is also at the same time being aggressively courted by a noisy, anarchic blogosphere and a politicised media who are repeatedly urging them to shoot the messenger."

The responses of scientists to these social forces are human and we have seen some of them shoot themselves in the foot – we only have to look at the University of East Anglia affair. Most scientists are not well trained in public communication, some try and debate as if it is a scientific debate when the domains and responsibilities of the protagonists are almost always very different. Many scientists get angry and defensive in this situation and this raises suspicion.

Some scientists also worry that release of raw information will lead to greater harassment – this has been particularly the case over computer codes and models and raw data relating to climate change. They see in that an invitation for a wave of uninformed interrogation and harassment. This is a real conundrum – we live in an open society – information is now made widely available and should be. This moves into another issue – the validity of what is on the internet. Take any medical or scientific issue – there will be some source of contrary opinion somewhere on the web. Indeed, something to support every position and no real way for the public to judge which position is valid.

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Final comments

Climate change is unusual in that every person on the planet will be affected by the scientific conclusions reached – most other scientific controversies are more limited in their effects. The debate over climate change is twofold. The first is the genuine problem of how to predict and model the global climate. This is where there have been major advances. The models now have a good fit to past data although no doubt additional information will lead to refinement. Remember within these models there are aspects of climate science we are very certain about, aspects we are moderately certain about and other aspects we still understand very poorly. If we demand absolute confidence then all we can safely predict is that in 50 years time the world's average temperature will be somewhere between 1 degree cooler and 5 degrees warmer than it is now. But that is meaningless. What scientists have to do, and have done, is to refine their predictions as the models have become better and thus give tighter estimates of the range of temperatures that might occur.

Politicians then have had to judge what actions they should take to manage the risk, because in the end this is about risk management. Scientists are saying on the basis of what we know now that the risk of significant global warming is high – at least a 50% chance of the average global temperature in 2070, the lifetime of our children, being more than 2 °C higher than in pre-industrial times and a 33% chance this will be reached by 2050, which is within the lifetimes of many of you, and this is a level which has real problems associated with it. Would you get on a plane that had only a 90% chance of landing safely? Would you not take out insurance if you were told there is a 70% chance of an earthquake destroying your house in the next 30 years? Governments have to act in the same way.

The second debate is actually not a genuine debate about climate science – it is a debate about value systems and world views. The creationist and the evolutionary biologist cannot reach a consensus through debate or dialogue – they are talking different languages and the evolutionary biologist is not to become a creationist and vice versa. This is an asymmetric discussion. The advocates of genetically modified foods will not convince everyone that GMOs should be introduced, no matter how safe they might prove to be, because for some people their objection is philosophically based on not wanting to interfere with nature.

And in climate change much of the debate is really about economic interests.

The title of my talk linked climate change and integrity and science. There is a growing concern among those of us who have some role in marrying science and policy that the way the debate is being framed is undermining confidence in the science system. The media must bear some of the responsibility for this concern. The public is confused about what we know and what we do not know about the science, and is unsure whether governments are justified in making hard decisions despite the science not being certain. After all, it will take another 40 years for us to be 100% certain what the temperature will be in 2050.

I have tried to explain the scientific process, its internal and valid scepticism and the inherent self-correcting nature of that scepticism. But I have also suggested that in an electronically connected world the tactics of those who reject the consensus, whatever their motives, can undermine confidence in the entire science system. In a world that is increasingly dependent on science in many domains, I cannot regard it as helpful to actively promote distrust and suspicion of the scientific process for political ends.

The science on climate change is far from complete. However the consensus is strong – that the planet is degrading. The impacts of human activity are clear, and one of those impacts is

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rising greenhouse gas concentrations. The sensitivity of the planet to these rising concentrations is not linear, but there is no other credible explanation for the association between rising levels of gases and temperature changes. There is no way to test this experimentally – we only have one planet. Based on what we know now, there is a significant risk of an unacceptable rise in planetary temperatures. The most likely trajectories involve unacceptable temperature changes sometime in the next few decades. There are scientists who think that the rise will be faster and higher – some have focused on the most extreme scenario to try and get action. This is regrettable, and it is bad science irrespective of the intent – the appropriate response is to give ranges and probabilities. But to be over-optimistic about the future and minimally responsive is even more irresponsible, as the consequences of underestimation and overestimation are hugely asymmetrical. If we underestimate, then in 2050 our species might find itself facing an inhospitable future on an irreversibly degraded planet.

If we overestimate, then in 2050 we might find that we have over-invested in climate change mitigation, but most of those mitigation strategies, such as sustainable energy generation, will help to meet our other challenges. The equation is not equal.

Thank you.

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