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5 Strong uncertainty

Ignorance and indeterminacy

A repeatedly stated aim of the scientific community addressing the enhanced Greenhouse Effect is to reduce, evaluate and quantify uncertainties. This is reflected in calls for risk–benefit analysis and similar deterministic quantitative approaches. However, contradictory messages appear across reports and within single documents. Such approaches sit uneasily with the recognition that: 'Because of the uncertainties associated with regional projections, of climate change, the report necessarily takes the approach of assessing sensitivities and vulnerabilities of each region, rather than attempting to provide quantitative predictions of the impacts of climate change' (Watson *et al*., 1997: vii). The scenarios which informed the IPCC work under the TAR were explicitly stated to be 'equally valid with no assigned probabilities of occurrence' (Nakicenovic *et al*., 2000: 4). However, the TAR then used a classification of 'subjective' probabilities with precisely defined quantitative confidence levels (see IPCC Working Group I, 2001: 2). There is an obvious discrepancy between the different approaches to uncertainty, resulting in inconsistent statements.

In the last chapter the way in which uncertainty pervades the issue of predicting climate change was explored from the perspective of weak uncertainty. That approach concentrates upon a specific characterisation of missing knowledge as 'objective risk'. The idea of strong uncertainty was also introduced and discussed as being relevant to both scientific and economic modelling and prediction. The aim in the current chapter is to further elucidate the distinction between different types of uncertainty, their relevance to climate change and implications for research and policy. This requires a more in-depth explanation of the classification already introduced before moving on to the issues raised by strong uncertainty.

Risk can be defined as the case where the set of all future events are known but the occurrence of any one event is only a potential. Thus, tossing a fair (evenly weighted) coin would be regarded as leading to two events, either heads or tails, with a known probability of 50:50. In common use risk is associated with harm or negative outcomes, but under environmental risk assessment or economic decision analysis the outcomes could all be beneficial, neutral or harmful or any mixture of the three.

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The standard theory of decision-making under uncertainty modifies the normal economic assumption of perfect knowledge to account for risk. That is, rather than being certain as to the outcome of their choices, the decision-maker (e.g. consumer, producer, civil servant or politician) still knows all future possible outcomes but only the probability (density function or distribution) of their occurrence. This allows the calculation of every possible outcome and the expected value (or utility) of each choice, also called the probability weighted average. Additional weightings can be added to account for the attitude of the decision-maker towards risk, i.e. risk neutral, risk averse or risk taker. The original economic decision model can be maintained by using the expected values instead of the known ones. This theory assumes that 'objective' probabilities are associated with events or outcomes.

Empirically observable and repeatable events, such as a coin toss, allow the construction of what are termed 'objective' probabilities or risks of an event occurring. That is, anybody could repeatedly toss the coin and count the number of heads and tails and would find the same probability of their occurrence. However, as Loasby (1976: 8) states, 'the notion of an objective probability distribution carries a strong (but unstated) implication about the nature of the world, namely that it generates all the necessary (and quite unambiguous) frequency distributions from a stable population of events'. As already shown in chapter 4, this is not the case for global climate change and, as Loasby notes, is indeed a generally implausible requirement. As also explained in the last chapter, the past provides no assurance of the future.

Accepting that 'objective' probabilities are absent means moving to what economists term 'uncertainty', which is in fact still only a limited, although problematic, adjustment. In the absence of an ability to estimate a probability distribution from observation (i.e. 'objective' probabilities) an appeal may be made to 'subjective' probabilities as an alternative. The assumption is now that probability functions are undefined although all states of the world or future outcomes are still known. The solution to this problem for mainstream economists is to allow the use of probabilities placed by the decision-makers themselves upon the likelihood of an event. In practice various methods are employed to obtain such 'subjective' probabilities. This new adjustment makes the move from 'objective risk' to 'subjective risk', but neither has addressed what is commonly understood as uncertainty. Thus, economists (and scientists) tend to restrict themselves to discussions of weak uncertainty.

Keynes (1988), amongst others, argued that the terms risk and uncertainty should be regarded as strictly separate.[1] However, in common use the terms are often interchanged so that employing the term 'uncertainty' in such an unusually restrictive way (i.e. excluding risk) can create confusion; the temptation is always to slip back into common usage. Therefore, here, risk is included under weak uncertainty while the term strong uncertainty is applied to the more Keynesian concepts, as shown in table 5.1.

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Table 5.1 Classifications of uncertainty, risk and ignorance

	Sub-categories	*Explanation*
Weak uncertainty	Objective risk	Known outcomes and their probabilities; termed 'risk' by mainstream economists; probabilities given by natural world
	Subjective risk	Known outcomes only; termed 'uncertainty' by mainstream economists; probabilities assessed from human preferences
Strong uncertainty	Partial ignorance	Unknown outcomes
	Indeterminacy	Unpredictable outcomes

Strong uncertainty then refers to the admission of a lack of knowledge about potential outcomes. The coin may land on its edge or disappear between the floor boards. Such strong uncertainties are often excluded from calculation because they are regarded as so unlikely as to be of negligible significance, in which case, we are truly surprised when they occur. They often relate to events which have been excluded by assumption. Thus, partial ignorance is an inevitable part of modelling where situations are simplified and vision restricted in order to aid understanding. Strong uncertainty requires that allowing for surprise events and admitting knowledge about future possible events is always incomplete. This is particularly relevant to complex systems (such as those forming climate, or economies) where choice cannot be assumed to be fully informed (contrary to the simple coin toss, and assumptions of positive economics).

As Loasby (1976) has explained, choice within complex systems provides the basic subject matter of economics. Thus, what he terms 'partial ignorance' becomes central to economics because the subject concerns the study of the unintended social repercussions of human actions. As a result the problem of how to describe and deal with a lack of knowledge in the sense of ignorance opens up a much wider debate. The concept of ignorance raises the idea of an irreducible lack of knowledge which is never removed by research and is in fact endemic to scientific knowledge. As a result ignorance is revealed due to events external to an individual's or group's models, disciplinary focus or world view and this can force a changed of perspective.

In addition, the concept of an 'indeterminacy' of outcomes is also relevant. While the concept of an indeterminate future may appear similar to a state of partial ignorance there are additional distinct features. Indeterminacy will arise due to a lack of knowledge and an inability to comprehend all existing knowledge, but also because of the social context within which knowledge is applied. Social context varies and involves customs, culture, institutions and socio-economic systems. The importance of indeterminacy is explained later in this chapter.

First in the following section five events are used to characterise the range and type of uncertainty confronting society due to the enhanced Greenhouse Effect. This draws upon chapter 3 but aims to focus the reader's mind on how some of the

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issues have been debated, judged or neglected. The way in which weak uncertainty has been used to address such issues is then discussed with specific focus on the insurance risk model. This shows flaws in the economic approach which are then explained in greater detail. The need to move away from the weak uncertainty characterisation is explained and the alternative explanation using strong uncertainty described. The current conception of scientific and technological research as removed from social processes is highlighted as false. Knowledge about natural and socio-economic systems is then placed within a common context of choice where humans simplify, assume and guess.

Characterising future events

This section considers how relatively near, future generations could be affected by global warming.[2] Below, five events caused by the enhanced Greenhouse Effect are identified from the literature presented in chapter 3 so as to characterise the type and range of impacts which might occur around the year 2100. Such events form the basis for economic cost–benefit analysis, which is discussed in the next chapter, as well as the case for concern over distant future people. The resulting ethical issues, which will be discussed in chapter 9, include questions over compensating future generations for harm due to enhancing the Greenhouse Effect. The framing and characterisation of impacts is therefore central to the entire debate over policy responses.

Agricultural impacts

Researchers have estimated that doubling carbon dioxide equivalent levels will cause annual welfare losses of $33 thousand million due to lost US crop production.

This compares to a $40 thousand million loss in the US mainly to agriculture from the drought in 1988 (Wilhite, 1990). Nordhaus (1991) associates a double CO_2 equivalent world with much lower losses of $9.7 thousand million and possibly gains of $10.6 thousand million (1982 prices); his figures were selected from amongst those of an EPA study which gave a much wider variety of scenarios and outcomes under a double CO_2 equivalent. The original research was done for the EPA by Adams *et al*. (1988), as discussed in chapter 3. They reported losses of $5.9 thousand million using the GISS global circulation model and $33 thousand million under the GFDL model, without a CO_2 fertilisation effect; with fertilisation these figures became those selected by Nordhaus. However, Adams *et al*. also reported losses of up to $44.6 thousand million if increasing demand was included with technological progress but without a fertilisation effect. The IPCC has noted the failure of studies to account for changes in agricultural pests and climatic variability (Watson *et al*., 1996: 9). For this and other reasons faith in the extent to which fertilisation benefits will actually occur has been brought into question (see: Daily *et al*., 1991; Erickson, 1993; Wolfe and Erickson, 1993).

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Even accepting full fertilisation, Cline (1992) has recognised errors in the fertilisation calculations as employed by Nordhaus and adjusted the EPA figures for a $2\times CO_2$ equivalent scenario accordingly. This requires recognising that rather than 600 ppm (double CO_2) the appropriate concentration of CO_2 is 442 ppm (double CO_2 equivalent); as a result central estimate losses with the fertilisation effect are \$17.5 thousand million (1990 prices) or \$13 thousand million (1982 prices); this excludes any demand increase. In addition, Cline (1992: 32) gives the figure of \$95 thousand million for the long-run annual loss, i.e. a beyond $2\times CO_2$ equivalent figure. Note that, according to Cline (1992: 74), a $2\times CO_2$ equivalent warming of 2.5°C is exceeded before 2050, by when temperature is predicted to have risen by 3.1°C. On this basis losses of \$33 thousand million per annum by 2100 seem conservative.

However, the process of estimating cause–effect relationships between agricultural crops and an enhanced Greenhouse Effect is fraught with difficulties. Erickson (1993) has pointed out a series of problems with the research being used to predict increased agricultural yields from CO_2.

- The results from experiments measure changes in crop dry matter which ignores the difference between economic yield and plant growth.
- Negative feedback mechanisms are ignored, such as greater stomata resistance increasing leaf temperature and so impairing radiation use.
- The experimental conditions rather than field conditions are idealised; this ignores the normal limiting factors to growth. For example, phosphorous deficiency can prevent any CO_2 fertilisation effect.
- Water stress is a key factor determining plant response and is inadequately taken into account. For example, water stress at key times can affect the marketability of products, flooding can damage crops directly, and a greater frequency of extreme events cause ongoing stress.
- Research into combined impacts is lacking. For example, there are no studies on increased CO_2 in association with water stress and higher temperatures, although this is a typical scenario under climate change.
- The need for increased fertiliser applications and other complementary inputs in order to benefit from CO_2 fertilisation is neglected.
- Managerial ability to grow crops in the field under new conditions diverges from that of expert plant scientists in an experimental situation.
- The role of non-CO_2 gases in changing climate parameters is ignored, e.g. temperature and water stress will then increase faster than predicted.
- CFCs are depleting the stratospheric ozone layer and UV-B damage is therefore expected, but models have yet to take this into account in association with climate change.
- The role of other air pollutants on crops is neglected, but is known to be important, e.g. crop losses due to tropospheric ozone.

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- Pests, diseases and weeds are predicted to have a greater impact on crops in a warmer world. Erickson cites work showing 32–4 per cent losses in North America and 45–6 per cent in Africa.

In summary, a standard experimental approach to developing dose-response functions grows plants under ideal environmental circumstances excepting the one factor being studied (e.g. CO_2 levels). Thus, the simultaneous impact of multiple factors is ignored (e.g. nutrient deficiency, precipitation, pollutants, pests). Transferring results to actual farm conditions results in numerous variations. Extrapolation from limited experimental data on a small range of crop species creates considerable room for error and potential inaccuracy when estimating aggregate environmental impacts on agriculture across large regions, let alone nationally or globally (for a detailed discussion see Spash, 1997). As the IPCC note:

> 'Major uncertainties result from the lack of reliable geographic resolution in future climate predictions, difficulties in integrating and scaling-up basic physiological responses and relationships, and difficulty in estimating farm sector response and adaptation to changing climate as it varies across the world. Thus, while there will be winners and losers stemming from climate impacts on agricultural production, it is not possible to distinguish reliably and precisely those areas that will benefit and those that will lose.
>
> (Reilly, 1996: 429)

Sea level rise

The Maldives are a group of islands off the coast of Africa. They are only a few metres above sea level and will be totally submerged due to rising sea levels, forcing the 177,000 inhabitants to lose their homes and be relocated.

As Gribbin (1990: 176) points out the 2,000 atolls which constitute the Maldives at no point rise more than 2 m above current sea levels. The upper bound of IPCC estimates for sea level rise are around 1 m by 2100, but storm surges at this level could easily inundate such low-lying islands. As shown in a previous chapter, table 3.8, other studies place the upper range at 3.5 m in 100 years.

Bangladesh currently suffers from severe annual floods. As sea level rises and monsoon rains increase, 11 per cent of Bangladesh will be flooded all year affecting 8.5 million people.

The estimate given here is based upon Broadus *et al.* (1986) for a 1 m or less average sea level rise. The UNEP has estimated that 15 million Bangladeshis are threatened by total inundation from a primary rise of 1.5 m, and a secondary increase up to 3 m would flood 20 per cent of the land area dislocating a further 8 million people (Jacobson, 1990). These estimates are calculated on the basis of a static population size and density, both of which are growing. These displacements would

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be part of a more general shift in population due to sea level rise during the next century. Asduzzaman (cited by Hayes, 1993: 129) estimates 80 million refugees from sea level rise alone.

Forced migration and droughts in arid zones

As global warming becomes a predominant trend 50 million people living in the arid areas of the Third World will be forced off their land by persistent droughts.

This kind of outcome is more speculative and is normally mentioned in general terms. As discussed by Keyfitz (1992) the poor are set to suffer most, be least able to adapt, and the problem of forced migration will be exacerbated by population growth. Where agricultural zones shift, the migratory pressures will increase on the rural poor. The impacts of changing climate will be severest for industrially developing countries which have half or more of their population engaged in agriculture and population density which is closely linked with soil fertility. Barbier (1989) has discussed such dislocations without quantification. Woodwell (1990: 128–9) mentions hundreds of millions of people being displaced by sea level rise in the next century and additional countless millions becoming migrants due to aridity and biotic impoverishment.

Human migration in response to chronic crop failures, regional flooding or drought is cited by the 1995 IPCC report as ‘difficult to quantify or value in monetary terms’ (Watson, Zinyowera and Moss, 1996: 36). However, Adger and Fankhauser (1993) produced a highly speculative figure of $4.3 thousand million for a doubling of CO_2 (based upon Fankhauser, 1995). These numbers from Fankhauser are meant to largely exclude impacts from sea level rise as coastal populations are assumed to be protected. In order to produce the financial number Fankhauser (1995: 49–51) borrows money estimates, only covering relocation costs, from Cline (1992) and Ayres and Walter (1991). He admits costs of hardship and stress are ‘almost impossible to assess’, but speculates they are a larger amount than the ‘pure economic losses’; although they too are welfare impacts and no less pure in economic terms. The borrowed migration numbers of 2.7 million per year are based on a percentage ‘guesstimates’ for the US, also from Cline, which is then applied globally. How the 2.7 million per year becomes the figure for all impacts under double CO_2 is unclear, i.e. the 2.7 million is a flow rather than a stock. If this is meant to be a constant flow then after about 18.5 years the 50 million migration mark would be reached.

Catastrophic surprise

The West Antarctic ice sheet could totally melt causing an average sea level rise of 6 m.

During the last interglacial 132,000 years ago the temperature was 1°C warmer and sea level approximately 6 m higher (Goodess, Palutikof and Davies, 1992: 109). The melting of the West Antarctic ice sheet is discussed by Revelle (1983) and Schneider and Chen (1980). The latter estimate an 8 m sea level rise. The IPCC has

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reported that this event is unlikely under typical scenarios (Warrick and Oerlemans, 1990: 261). As Warrick *et al*. state (1996: 364):

> Concern has been expressed that the West Antarctic Ice Sheet might 'surge', causing a rapid rise in sea level. The current lack of knowledge regarding the specific circumstances under which this might occur, either in total or in part, limits the ability to quantify the risk. Nonetheless, the likelihood of a major sea level rise by the year 2100 due to the collapse of the West Antarctic Ice Sheet is considered low.

Such a catastrophe is seen to represent a positive and increasing risk of occurrence with continued warming. This is a characteristic treatment of an unquantifiable irreversible event as a low positive risk (weak uncertainty) rather than a case of strong uncertainty, i.e. partial ignorance or indeterminacy.

Collapse of the West Antarctic Ice Sheet would initially release about two million cubic km of ice causing a 5–6 m sea level rise prior to the remaining half of the ice sheet, which is below sea level, beginning to float (Revelle, 1983: 442). This is estimated to take a minimum of 300 years, starting from the middle of the next century, giving a 2 m rise per 100 years, or perhaps 500 years with a 1.1 m rise per 100 years. However, warming might thin the Ross and Filcher-Ronne ice shelves enough in the next 100 years to make the process irreversible (Titus, 1989: 188). The implications are dramatic, systems appear to have non-linear characteristics and knowledge is extremely limited. As Warrick *et al*. (1996: 396) state:

> Of all the terms that enter the sea level change equation the largest uncertainties pertain to the Earth's major ice sheets. Relatively small changes in these ice sheets could have major effects on global sea level, yet we are not even certain of the sign of their present contribution.

As discussed in chapter 3, the understanding of ice shelves and sheets and their disintegration is poor and rapid collapses of ice shelves in the late 1990s raised some alarm while bringing into question scientific knowledge of the issue.

Judgement in assessment

A central issue in trying to assess the probability of future events is determining what is at risk and when in the future it will be at risk. These five events indicate how different experts attribute varying likelihoods to the occurrence and characteristics (i.e. magnitude, speed and timing) of future events related to the enhanced Greenhouse Effect. Thus, even given a particular set of outcomes or states of the world, assessing the unknown probability of a state being realised as a subjective risk will result in widely varying responses depending upon who is asked for their opinion. The way in which knowledge is collected and used to form such opinions is crucial

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to how the issue is perceived. In addition, how the issue is framed in terms of which aspects are regarded as relevant and how different information is considered will determine the scope of perceived dangers.

Economic use of weak uncertainty

Attractions of the risk analogy

The essence of wanting to limit trace gas emissions is to avoid a state of the world in which an uncontrollable threat to human life support systems is created. The potential outcomes involved in the case of global climate change have been perceived by the international community to include extremely large damages, such as outlined by the five events above. This is also evidenced by the final statement of the 1988 Toronto conference on the issue which included representatives of 46 countries and 15 international organisations: 'Humanity is conducting an unintended, uncontrolled, globally pervasive experiment whose ultimate consequences could be second only to a global nuclear war' (Environment Canada, 1988: 1).

The military analogy has also been used by Daily *et al*. (1991) to compare the policies required to reduce the risk of damages due to global climate change to those implemented over the last 40 years to protect the world from a third world war. In the decade of the 1980s, the US alone is estimated to have spent $1,500 thousand million to protect against an enemy whose probability of attack in the previous quarter of a century was given as less than 3 per cent. In contrast, climatologists in the 1980s were cited as giving the chances of unprecedented climate change as 50 per cent.

Introducing risk in this way can appear attractive because it allows for the inclusion of risk aversion. This can lead to the conclusion that reducing GHG emissions is desirable even if the expected costs of doing so are known to exceed the expected benefits. The reasoning is based upon social decision-making being risk averse. For example, assume the costs of reducing GHG emissions by 75 per cent are known to be $1 trillion. The benefits of reducing GHG emissions might range from $0.25 trillion to $10 trillion, with an expected value of $0.8 trillion. If risk aversion is operating there can be a logical preference for incurring the certain loss of $1 trillion (the 'certainty equivalent') rather than the expected loss of $0.8 trillion, with the potential for higher losses.

Thus, GHG control could be regarded as an insurance premium against known but only potential future states of the world, where the probability of those states occurring is known or knowable. This would be consistent with an expected utility framework, and could justify a safe minimum standard approach. That is, once a threshold with a safe margin has been chosen, the economy could be 'safely' allowed to emit GHGs. So even environmentalists might wish to welcome the insurance analogy and the weak uncertainty characterisation of the enhanced Greenhouse Effect.

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Greenhouse Effect insurance

Manne and Richels (1992: 1) conduct a more detailed analysis of the enhanced Greenhouse Effect as if it were a case of deterministic risk where policymakers can act 'as though they were purchasers of greenhouse insurance'. The extent to which the policy outcome is removed from an 'objective' scientific approach to economic analysis is apparent in the role of belief in their following statement:

> Depending on one's views of control costs, a case can be made either for or against emission cuts. The issue is similar to purchasing an insurance policy. If one believes that there are great risks from global warming and that the insurance premium is negligible, there is little reason to delay. This is the attractiveness of 'no regrets' strategies, such as costless conservation. The problem becomes more complex when there are price tags attached to limiting the emission of greenhouse gases. If the insurance premium is expensive, it may be worthwhile to pursue alternatives to immediate cutbacks on emissions.
>
> (Manne and Richels, 1992: x)

In fact, Manne and Richels, and others, are wrong in this analogy because insurance does nothing to prevent the chances of damage, but merely arranges for compensation after a harmful event has occurred. The error here is to regard endogenous risk as exogenous, a point discussed further below; but for now another aspect of this approach is relevant.

In a fragmented world, risk aversion leads to a risk externality; that is, the risk is placed upon 'others' who are often unable to respond (e.g. future generations, the resource poor, non-humans), rather than leading to GHG control. Action at a global government level is implied to correct both an international and intergenerational pollution and risk externality. Interestingly, Chichilnisky and Heal (1993) claim that insurance markets (rather than GHG control) can cope with climate change risks. Their explanation neglects missing future markets (e.g. inability to communicate with future generations) and is limited to the geographical distribution of damages. They argue that there are efficiency gains to be made by selling 'Arrow securities' and mutual insurance contracts when facing ignorance.

However, their argument depends upon ignorance being defined as weak uncertainty about the distribution of damages, so that a probability can be assigned to each frequency distribution. As they state:

> A typical probability distribution of this type might state for example that there is a 10 per cent chance that 90 per cent of the population will be harmed by global warming, a 25 per cent chance that 50 per cent of the population will be harmed, and so on.
>
> (Chichilnisky and Heal, 1993: 69)

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In effect they accept a wider concept of uncertainty (besides risk) and then reduce it to a 'secondary probability distribution'; the result is a probability of a probability of a damage. Individuals or communities then buy and sell securities which pay if the 'correct' secondary probability distribution occurs. Why this secondary probability is any easier to specify than the primary one is unclear. The authors themselves note some difficulties when they state that:

> In practice of course, probability distributions are not observable, and we cannot condition contracts on unobservable events. So conditioning on a probability distribution means conditioning on frequency distributions with that probability distribution in a sampling sense.
>
> (Chichilnisky and Heal, 1993: 71)

The method and meaning of the sampling sense and indeed this explanation remains unclear.

The distributional assumptions of this insurance risk model should also be noted. First, impacts are never mutually harmful; there is a gainer able to compensate the loser by transfers. Second, there is no consideration of the equity or ethics in asking, for example, Bangladeshis to buy insurance from the US to cover themselves against the threat of GHG emissions created historically by the US and other industrially developed economies. In fact, the position of the less industrially developed countries is carefully avoided by the authors giving the example of the US, as sceptic, trading securities with the EC, as concerned party. Third, the moral hazard issue is relegated to a footnote, but would be extremely important because, were such a market feasible and perfect, the insured have an incentive to increase their GHG emissions regardless of the consequences. Those who cannot afford the insurance premiums would be double losers. Fourth, the lower limits of insurance premiums, which allow entry into the market, are ignored and will depend upon the insurer's willingness to risk bankruptcy. Fifth, the possibility of insurer's bankruptcy is neglected.

Such an oversimplified characterisation of ignorance and catastrophic events using weak uncertainty is typical of the mainstream economic approach to modelling the enhanced Greenhouse Effect. This is also symptomatic of the general economic modelling approach under Pareto optimal resource allocation. For example, the model in Heal (1984), also used by Chichilnisky and Heal (1993), assumes two states of the world: economically favourable and unfavourable, where a future climate catastrophe occurs. The movement between these two states is from one equilibrium system to another with a positive probability of no change occurring. The probabilities sum to one so that all relevant outcomes are assumed known and included.

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How weak is weak uncertainty?

The mainstream economic approach to unknown aspects of the world has tried to emulate the natural sciences in as far as potential future states are reduced to probabilistic events. However, knowledge about climatic systems prevents either future states and/or their associated probabilities being defined. In this regard, there are several limitations to the weak uncertainty approach for dealing with the policy implications of the enhanced Greenhouse Effect. These shortcomings are more generally relevant to the economic theory of imperfect information and the treatment of uncertainty.

The range of issues affecting the applicability of weak uncertainty go from establishing systems behaviour through to the social psychology of the individual. The concept of a probability density function (as discussed in the last chapter) is often an inappropriate characterisation of uncertainty. The assumptions required to establish future states via cause–effect relationships mean systems behaviour can be excessively simplified. Simplification is an essential part of understanding but must be recognised as creating partial ignorance. In moving science and technology forward at a rapid pace modern society is creating new and unpredictable futures so that how partial ignorance is addressed becomes a central concern. An appeal to subjective probabilities to avoid some of these issues raises another set of issues including how these numbers are produced, by whom and what their value content is? Attitudes to risk vary and psychological research shows an extensive range of behaviour, much of which diverges from that under risk assessment models. The psychological importance of appealing to risk assessment as a decision support raises questions over their false precision, i.e. using a bad tool because that is the accepted method and fending off critiques with the quip that 'there are no better alternatives'. All these factors combine to make the characterisation of uncertainty as weak a highly misleading approach. Thus there should perhaps be little surprise that endogenous and exogenous risks are confused or treated as identical for analytical convenience. The following subsections give more attention to each of these points.

The probability density function

There are difficulties in adopting probability density functions to characterise climate change uncertainty. The variable of concern, say temperature or rainfall, might have a probability density function which is different from the normal distribution, and may be non-random. Climate shows periodic and quasi-periodic cycles which describe non-random behaviour (Hare, 1979). More generally, the probability of many events under the enhanced Greenhouse Effect is unobservable because the events are unique and cannot be evaluated as frequency events, e.g. the melting of the West Antarctic Ice Sheet, sea level rise, disruption of El Niño or the Gulf Stream.

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Cause–effect relationships

A cause and effect relationship is required to determine both the actions relevant to a decision and the outcomes to be included in the set of possible future states. This is a difficult task for global climate change, even if climate and socio-economic systems were deterministic with regular, and therefore predictable, behaviour. A search for a single specific cause of a climatic event can be futile. Small disturbances can result in large effects, e.g. from positive feedback amplification, while every link in the loop is both cause and effect (Berger, 1990). Note, this difficulty applies to even the apparently most scientifically tractable problem of crop response to GHGs.

Excluding alternatives

Uncertainty is always reduced to weak uncertainty as if there were no case of a simple lack of knowledge nor a danger of the exclusion of relevant alternatives (the two of which may interact). For example, the developers of CFCs had no idea that their product would deplete the stratospheric ozone layer; this was an unknown potential which was never remotely considered or relevant to them. Similarly, the detection of the stratospheric ozone hole was hampered by the programming of software which rejected what was regarded as satellite data so far from expected models as to be in error. Partial ignorance is a design feature of the way in which technology and science proceed.

Subjective probabilities as concepts of value

In order to make exclusive use of the weak uncertainty model, probabilities are required in association with all future states of the world. As explained earlier, an action leading to an event may be recognised as a possible (uncertain) state but without a probability being attached to the outcome. The probability itself may be unknown or non-existent. This may be because the event of concern is unique and therefore no frequency distribution can be estimated, e.g. the melting of the West Antarctic Ice Sheet.

An appeal to subjective probabilities means that individuals could be asked to give their estimates of the probability of an event and this information would then form the basis of a probability density function (or an expected frequency distribution). These density functions are then taken to form the prior belief of individuals before additional information is gathered allowing revision. This framework is that of Bayesian analysis and rejects the notion that strong uncertainty exists.

The underlying intuition is that rational individuals act as if they knew a probability distribution. The individual need only make rough subjective judgements about the likelihood of damages to enable their attitude to risk to be described as a loss of

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utility associated with damage-causing events. Subjective probabilities can, for example, be inferred from the willingness to pay for insurance. This ability to create probability density functions neglects their meaning and worth as concepts of value.

The derivation of a subjective probability function begs the question: whose subjective probabilities? For example, the general public might be argued to be the relevant constituency in a democracy, but asked the probability of, say, sea level rise flooding the Maldives by 2100 would draw a blank. The appeal to the general public might seem rather pointless given their presumably ill-informed background on such specialist topics. If some group of experts were convened this would still leave room for disagreement while forcing a consensus might exclude divergent viewpoints. The information conveyed by such expert-derived probabilities is very different from the frequency observed probability, as explained next.

Divergent perceptions of risk

The problems of using subjective probabilities then relate to the meaning of risk as a concept and the divergence of perceptions of risk amongst different groups. The general public has been observed to reject very low-probability, high-loss risks which experts judge to be acceptable (Freeman, 1993: 260). Thus, experts could vastly underestimate the potential welfare costs that these risks impose upon people. The public is worried by the potential meltdown of nuclear power stations despite continuous reassurance from the power industry and nuclear experts of the low risk. Here the concept of weak uncertainty which the nuclear industry is talking about diverges from the concept of strong uncertainty perceived as relevant by the general public.

Jaeger (1996) makes a related point concerning risk paradoxes, of which he gives two examples. First, probabilities close to zero are treated in practice in different ways despite appearing identical in expected utility terms, i.e. when the outcomes are weighted by their probability and utility. So in some cases probabilities close to zero are treated as zero, e.g. as train accidents have historically been viewed, and in others create extreme concern, e.g. nuclear power station meltdown. Context and culture will also play a role in such divergence, and the mix of attitudes can also change over time for various reasons, e.g. public perception of train accidents in the UK since privatisation. Second, Kahneman and Tversky (1979) have shown that choices with identical outcomes and probabilities are treated differently if they are losses as opposed to gains. Amongst other implications this affects the economic use of willingness to pay and accept as welfare measures (Knetsch and Sinden, 1984; Knetsch, 1997).

False precision and 'objective facts'

The use of probability estimates can give a false sense of precision and the results of illustrative examples may be misinterpreted as conveying scientific 'facts'. Thus,

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probabilities may be given to two or more decimal places despite their speculative character. Probability density functions make the production of such precision straightforward although the meaning may be lacking, e.g. specifying the subjective probability of the West Antarctic Ice Sheet melting as 1.34 per cent. The highly uncertain and unpredictable is apparently converted to a precise prediction.

More generally, the conception of 'facts' as central to an issue can give a false sense of objectivity to decision-making where the 'facts' are taken to 'speak for themselves'. That is, a belief is engendered in an underlying objectivity which can be discovered and which should direct environmental management and, indeed, society. Whether ecological or technological such 'facts' result in social regulation which should be openly debate rather than dictated. As noted in chapter 4, and will be seen again in chapter 6, economists call for further research to obtain 'true' costs and benefits while the search for scientific facts is meant to resolve uncertainty. These points are addressed again in the context of the meaning and implications of strong uncertainty.

Exogenous and endogenous risk

Related to the conception of 'objectivity' is the discussion of climate change risk as if it were exogenous. The extent to which the Greenhouse Effect is enhanced is driven by the release of GHGs, and the extent to which these releases occur is a human choice. The risk is endogenous and therefore fundamentally different from observing the frequency of events beyond our control. As Chichilnisky and Heal (1993) point out, but without much analytical consequence, this is in contrast with most economic models of resource allocation under uncertainty. Probabilities may be subjective and modified in a Bayesian sense in an Arrow–Debreu model, but the frequency of harmful events is assumed to be beyond control. Similarly, classical insurance risk models assume such events are exogenous. Once the risks are taken to be endogenous (i.e. within the control of the decision-maker) the entire range of social perspectives on responsible action becomes relevant. The type of uncertainty no longer fits neatly into the weak uncertainty characterisation and the role of economists and scientists seems less clearly divided upon value versus fact specialisms.

From weak to strong uncertainty

Scientists, and engineers, have built up assumptions of well-defined and deterministic processes when dealing with the unknown on the basis of well structured mechanical problems (e.g. aircraft, aerospace, nuclear plants). In fact even '…these systems have often shown themselves to be less well-defined than analysts and designers thought, exhibiting surprising properties – such as exploding – which indicate that the system was less determined by controlling forces than the analyst recognised' (Wynne, 1992: 113). The approach has been extended to badly structured problems,

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non-mechanistic environmental systems and the global scale. For global environmental problems, such as the enhanced Greenhouse Effect, the limitations of available knowledge are more serious. Contrary to technological artefacts these systems cannot be designed, manipulated and reduced to within the boundaries of existing analytical knowledge. Thus, pragmatic factors, such as what can be measured, dictate the structure of resulting knowledge.

There is no surprise then in finding that the OECD (1995) publication on the economic appraisal of environmental projects and policies, which is subtitled 'A practical guide', concludes: 'The treatment of uncertain risk looms large in environmental appraisal. Converting uncertainty into risk is essential to make the problem tractable' (OECD, 1995: 150). Such apparent pragmatism ignores the theoretical straightjacket into which uncertainty is being squeezed. A warning then seems appropriate: 'Those who reject theory for pragmatism are liable to find themselves unwitting adherents of bad theory' (Loasby, 1976: 21).

Ignorance

Besides the design of limits to models merely to make them manageable, limitations arise for a number of reasons related to a basic lack of knowledge: ignorance about a particular system, ignorance about the behaviour of a class of systems, and the indeterminate nature of some complex systems (which can become chaotic at various points). This means that even where the behaviour of such systems might be modelled in probabilistic terms the relevance of this analysis is limited temporally and spatially.

All the models of the behaviour of complex systems, such as environmental and economic systems or their interactions, are imprecise and limited in their scope. The discussion in chapter 4 implied a stable equilibrium around the current mean of a climatic variable (e.g. temperature) and that the process of climatic change could be described by a shift to a new stable equilibrium. However, the process of human-induced climatic change could equally lead to a long path of alterations without creating the conditions for order and stability, which may in any case fail to represent climatic systems.

Ignorance also pertains to sources of utility which must be identified to assess economic impacts. Thus, there are elements, substances and organisms on the planet which have yet to be utilised directly by humans. This can be viewed as partial ignorance over future use patterns. For example, losses in biodiversity due to global climate change can cause future losses of which present humans are ill-equipped to guess; species properties may be unknown or presently of no economic value. In addition, many of the features of Nature that are directly utilised in economic processes are dependent on features of Nature that are indirectly utilised. Current biomass depends on an ecological infrastructure which enables flows into human systems but is ignored itself. For example, stratospheric ozone can be depleted by CFCs so allowing higher levels of UV-B radiation to reach the surface of the planet; this would in turn affect the

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marine biota at the base of the food chain on which harvested species of fish depend. Partial ignorance becomes particularly important when society builds commitments around the knowledge base.

Indeterminacy

The problem posed by complex systems cannot be avoided even by removing oneself to a desert island, a favourite economic example for clarifying basic principles. As Loasby (1976: 1–2) notes:

> Even Robinson Crusoe had to operate within a complex natural system, the future states of which could not be predicted with confidence; how much more difficult then to predict the future states of a system which is driven in part by the acts of other decision-makers similarly placed. Choice within a complex system cannot be fully informed; neither can the study of a complex system from outside. Partial ignorance is intrinsic to the problems of choice which economists claim to investigate.

Yet here Loasby is combining a lack of knowledge about the future with the indeterminate nature of complex natural and social systems, i.e. where the behaviour of others is a determining factor. While the two may be connected a distinction is also worthwhile.

An important aspect of indeterminacy is recognised by Loasby as being linked to choice, a matter at the heart of economics, e.g. consumer choice, decision-making, choices under weak uncertainty. ‘If knowledge is perfect, and the logic of choice complete and compelling, then choice disappears; nothing is left but stimulus and response’ (Loasby, 1976: 5). In order to be meaningful in terms of a reasoned action choice must be neither random nor predetermined, and be able to make a difference (if there is no difference choosing is meaningless). Choice and determinacy are incompatible and the future unpredictable. As Loasby (1976: 5) summarises: ‘If choice is real, the future cannot be certain; if the future is certain, there can be no choice’. Thus, indeterminacy is at the heart of economics.

The importance of treating indeterminacy as a distinct concept from ignorance is emphasised by Wynne. Thus, he argues that when trying to draw causal links the difficulties that arise have less to do with lack of problem definition (unknown states) and more to do with ‘… a combination of genuine constraints laid down in a determinate fashion, and real open-endedness in the sense that outcomes depend on how intermediate actors will behave’ (Wynne, 1992: 117). This social indeterminacy is readily apparent from the discussion of choice, and has serious implications for the implementation of policy. For example, technical solutions determined to solve a problem only do so under specific social conditions, i.e. if actors make the ‘right’ choices.

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There is always an element of indeterminacy in classifying empirical evidence under one theory or model or another. Concepts of sameness and difference in Natural relations are never fully determined solely by Nature but open to social commitment. This social commitment is part of the scientific culture of a discipline and often operates subconsciously on choices. As Wynne (1992: 123) states:

> scientific knowledge is not fully determined by 'the facts' – what 'the facts' are has to be actively read into nature to some extent. In other words, social mechanisms of closure around particular logical constructions have to occur in order to complete the otherwise incomplete logical construction. This is a further, more subtle and pervasive sense in which indeterminacies exist in the basis of authoritative natural knowledge about environmental risks.

Thus, normative choices which are meant to be 'external' to the scientific process actually influence 'internal' choices about inferences, sameness and difference relations in theoretical models and what is then regarded as problematic.

Models in science and economics: revisited

As discussed with regard to economic and scientific models in chapter 4, the understanding of the enhanced Greenhouse Effect clearly shows choices about what is to be included and excluded. Here this process of judgement has been argued to be a normal part of the process of learning and understanding. However, this process also means 'facts' are dependent upon the theory by which they are classified, judged, measured and selected.

Thus, for example, the form of experimental research on crop responses depends upon accepted scientific theory and, as has been explained, can influence or even determine the result. Experimental design, in aiming to achieve the desired scientific requirements of a controlled experiment, holds other factors constant which are then by assumption excluded from consideration. Testing one hypothesis requires accepting others and there is no definable end to this process of testing hypotheses, i.e. the assumptions in one hypothesis test are the hypothesis in the next, so new assumptions are required (Loasby, 1976: 19). If results are theoretically inconvenient the lack of a definitive test soon becomes apparent as a range of standard arguments appear: the experimental results were unreliable, discrepancies between empirical results and theory are only assertions and empirical anomalies will disappear if understanding or measurement methods were improved. The standard of evidence required for accepting and rejecting evidence depends upon the associated theory and how well the results conform with scientific or economic opinion.

In, for example, the work of Callendar (1938) presented to the Royal Society his evidence on climatic warming excluded the higher temperatures observed in the arctic. A commentator remarked that these temperatures were ten times those

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at middle and low latitudes and were inexplicable in terms of CO_2 releases. In his reported response, Callendar agreed 'that the recent rise in arctic temperatures were far too large to be attributed to change of CO_2' and that '[o]n account of their large rise he had not included the arctic stations in the world temperature curve' (Callendar, 1938: 239). He undoubtedly believed he was erring on the side of caution in reporting his results. Today higher than global average arctic temperatures are seen as a key signal of the impact CO_2 has on climate via the enhance Greenhouse Effect.

This is not a particular criticism of Callendar; scientific knowledge proceeds by externalising some of the significant uncertainties. Thus, 'scientists, like wise examination candidates, are careful not to attempt certain questions' (Loasby, 1976: 3). As Wynne (1992: 115) states:

> The conventional view is that scientific knowledge and method enthusiastically *embrace* uncertainties and exhaustively pursue them. This is seriously misleading. It is more accurate to say that scientific knowledge gives prominence to a *restricted agenda of defined uncertainties* – ones that are tractable – leaving aside a range of other uncertainties, especially about boundary conditions of applicability of the existing framework of knowledge to new situations.

Of course economics is no less guilty of ignoring the way in which it operates and selecting only the evidence which proves compatible with theory.

A major concern in this regard has been the gap between economics and ecology, see Dale and Rauscher (1994: 79–81). Holling *et al*. (1995) suspect many economists ignore ecological information despite the accumulated body of evidence from natural, disturbed and managed ecosystems. In particular they identify four key features, common to the function and structure of many ecosystems, which they believe economists should bring into their subject. Their points can be summarised as follows:

- Ecosystem change is episodic rather than continuous and gradual. For example, uncommon events (e.g. hurricanes) can unpredictably reshape structure at critical times or in vulnerable locations.
- Scaling up from small to large is a non-linear process. Thus, spatial attributes vary with scale rather than being uniform.
- Ecosystems exhibit multiple equilibria, an absence of equilibria and are destabilised by forces far from equilibria. The movement between such states maintains structure and diversity. This contrasts with the conception of ecosystems as single equilibrium systems with functions operating to maintain the stable state.
- Recognising that ecosystems have multiple features, which are uncertain and unpredictable, requires management and policies to be flexible, adaptive and experimental at scales compatible with those of critical ecosystem functions.

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A belief in the near equilibrium definition of ecological resilience, as found in mainstream economics, focuses upon efficiency of function with emphasis upon resistance to disturbance and speed of return to equilibrium. This contrasts with ecological case studies and the inductive formation of ecological theory which focus attention upon the 'existence of function' where instabilities can flip a system from one domain of stability to another. In this case the resilience of a system is determined by the ability to absorb disturbance before the system changes its structure by changing the variables and processes that control behaviour (Holling *et al.*, 1995: 48–51).

Implicit social regulation and control

Social and behavioural control is intertwined with the way risk is analysed and standardised. That is, social behaviour must be reorganised in order to conform to the implicit assumptions of social behaviour embedded in standardised models. For example, nuclear power stations are built upon the premise of human controllers acting in response to certain signals in a given order and within a given amount of time. In order to operate such a power station humans must conform to the requirements of the system. A nuclear power station may be regarded as having an objective risk of meltdown, but whether this is sited in Afghanistan, China, France, Germany, Indonesia, Iraq or Russia would generally be accepted as making a difference due to institutional, social and cultural differences, i.e. the assessment of performance is indeterminate and requires assumptions about specific types of social control. 'Thus an inherent contradiction exists between such standardising tendencies and the realistic appreciation of the diverse and more open-ended situational forces and factors which defy such reductionist and deterministic treatment' (Wynne, 1992: 119). If social systems fail to conform to the definition of risk, and related regulations, then greater flexibility is necessary. The possible paths Wynne identifies for social control include following the determinate discourse from technology (as is current), following one from Nature, or finding 'socially flexible technologies'.

One response to ecological complexity and the interactions between components is the imposition of constraints upon economic systems to avoid undue environmental stress. This requires policy decisions at the scale of the function being considered, e.g. global atmospheric regulation. The process of setting such constraints will, however, mean that specialists have a central role in the formation of information inputs to any decision. Thus, the premises upon which a specialist decides what is important, where research time and effort should be expended and how modelling should proceed all have implications which go far beyond the perception of research as increasing confidence by refining the probabilities of given outcomes, i.e. risk analysis under weak uncertainty. That is, the conception that research on the enhanced Greenhouse Effect is fundamentally based upon the need to fill agreed-upon factual

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gaps in understanding is itself only a belief, as are the choice of gaps upon which research ends up focusing.

The belief in such a foundational truth may also imply social norms because acknowledging boundary conditions can be used to require human behavioural change to avoid passing thresholds. For example, Friends of the Earth Scotland (1995) has argued for the concept of 'environmental space', which calls for the definition of physical constraints required for the region to be sustainable (based upon input–output type analysis), which then implies limits on individuals (e.g. per capita carbon dioxide emissions allowed) but is presented as a scientific fact. Martinez-Alier (1994) has raised a similar concern related to the limitations of ecological planning and gives the example of prescriptions on carrying capacity. As he states (Martinez-Alier, 1994: 29):

> precisely because of uncertainties about the future and the inevitability of choices being made between differing social, species, and ecosystem options, a so-called ecological rationality is not an indisputably better base for policy decisions than the usual economic rationality.

The danger here is that the decision process is removed to the realm of the objective 'scientific' manager who reveals the truth and conveys the 'facts' as uncontestable commandments.

Norgaard (1994: 66–7) critically explains such a scientific approach as the acquisition of knowledge whereby individual minds investigate the parts and processes of Nature, which he refers to as an atomistic-mechanistic view. This view is seen to be premised upon unchanging parts and relations allowing knowledge to be regarded as universal over space and time. Variations in natural and social systems are then regarded as due to differences in the proportions of parts and the strength of relations, rather than being an indication of fundamental differences. 'Thus, the idea of underlying universal truths could be maintained across diverse environments and cultures' (Norgaard, 1994: 67). This methodology leads in turn to the separation of facts from values and what is termed logical positivism (see Gordon, 1993). While the logical positivist approach is flawed (e.g. in rejecting non-empirical knowledge) it still remains dominant in public beliefs and institutional structures. Thus, the 'professional' natural scientist and neo-classical economist participate in public decision-making through this dominant belief pattern, which they then reinforce.

A powerful lobby amongst economists has for some time been eager to treat economics as methodologically scientific with an emphasis upon empiricism to confirm an objective reality, i.e. following logical positivism (see Hutchinson, 1938). This view of economics as a science requires a belief in an objective truth and the ability of economists to reveal this truth. In the environmental economics literature this begins to appear in statements and approaches which suggest the 'correct' picture is being presented by the economic analysis. This lobby has tended to refuse to accept the idea of strong uncertainty and must logically do so if they wish to defend

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an absolute truth because there can be no absolute truth discoverable by research if we accept our own irreducible ignorance.

The changing perception of science

Knowledge and belief

There is a concern amongst some scientists that the type of media coverage given to issues such as global warming encourages 'bad science'. 'Bad' in this context refers to the lack of a notion of objectivity in the conduct of science. This objectivity might be seen as the conduct of repeatable experiments to test well-constructed hypotheses. For such a methodology issues of belief and subjectivity are non-scientific issues, and if such issues come to the fore the scientist is guilty of 'bad' science. Hence Harrison (1991: 4) has stated:

> A scientific community under financial siege has been all too eager to jump on a global warming bandwagon and there is a suspicion that objectivity has, in some cases, been sacrificed. Published conclusions have not always been supported by rigorous scientific arguments, but have degraded into conjecture.

Yet the notion that there is a rigorous scientific methodology of relevance to climate change is itself open to question. The extreme objectivity position seems to be closely associated with a belief in an ultimate truth (i.e. moral or theological), a concept which is again highly contestable. In the case of Christian scientists such as Harrison or Houghton this is clearly religious.

This leads the scientific community into a dilemma because 'good' scientists cannot admit they start from prior beliefs which are subject to their own personal experience and self-reflection and which influence their conduct of research. Idso (1984), a global warming sceptic, regards scenario development in relation to the enhanced Greenhouse Effect as being influenced more by the psychological disposition of the protagonists than science. Indeed, the preceding sections have shown how when modelling climatic systems, as well as their impacts on socio-economic systems, many apparently arbitrary restrictions are set in place by the analyst. This is recognised by climatologists as a problem when they make policy recommendations.

> So many other features of the system are excluded from examination that it becomes reasonable to suspect that the discussion – especially if it concludes that we must take action – is not an accurate forecast of the future but rather an artefact determined by the study's particular selection of which parts of the overall system to consider. Until this suspicion is overcome, no amount of warning about the need for early action is likely to be heeded.
>
> (Firor, 1990: 73)

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The problem here is that, outside of the objective science school of thought, overcoming this suspicion is impossible. There is, however, the potential for individuals to be persuaded and convinced of the dangers pointed out by the forecasts, through a process of open discussion and debate on the limitations of the models. Firor misunderstands the problems with the knowledge base, in which he has so much faith, and that this goes beyond converting everyone to belief in scientific objectivism. As Wynne notes:

> The very considerable amount of scientific work which has gone into the modelling of environmental risk systems over the past few decades cannot, therefore, be taken as reassurance that even the main dimensions of environmental harm from human activities have been comprehended. To understand this requires not only intense and open examination of the scientific evidence and competing interpretations in an area of interest; it also requires reflexive learning at a deeper level, about the nature and inherent limitations in principle of that knowledge, however competently produced.
>
> (Wynne, 1992: 113)

Yet when such debate is seen to be possible scientists are encouraged to disengage for fear of becoming advocates.

A notable exception to the 'good science' position is the case of Dr Hansen, Director of the Goddard Institute at NASA. Hansen created considerable controversy in the late 1980s and was regarded as being blunt and forthright in his statements concerning the enhanced Greenhouse Effect (Newton and Dillingham, 1994). In giving evidence at US government hearings he was seen to be acting as an advocate. Yet, on reading them, his remarks appear to be carefully worded judgements made on the basis of many years' work in the area of climate modelling (see Hansen, 1988). He was apparently being attacked for opening up a previously closed scientific debate for public scrutiny.

Much of the scientific community appears loath to see colleagues take such an open position, and try to avoid phrasing themselves in terms of their opinions or beliefs. Interestingly, the lead scientific author of the IPCC reports, John Houghton, was more open about the Christian beliefs underlying his concern for Nature and future generations when he published an introductory text on global warming. His open confessions of the importance of his beliefs in motivating his research and the values he associates with that work are highly unusual. Yet, according to the introduction to the second edition, while being 'surprised' or finding confessions of religious belief 'startling' in a scientific context, most peers accepted them as useful background information. That is, Houghton's beliefs were, he believes, accepted as arguments of why systems operate and seen as separable from the scientific quest for how they operate. Even with the apparent support of his colleagues, Houghton notes

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the need he felt to revise the specific chapter covering his Christian beliefs and, for the second edition, states that: ‘I have been somewhat more objective and less personal – which I felt was more appropriate for student readers from a wide range of disciplines, for whom the edition is particularly suited’ (Houghton, 1997: xv).

In general, economists can far more easily be identified with positions based on strong uncertainty resulting in advocacy, even though, as noted in chapter 4, some then try to disguise this in a veil of ‘objective’ modelling. The role and importance of personal belief is clear in statements by Crosson (1989), for example. When discussing impacts on agriculture he finds ‘no persuasive reason to believe that on balance they will be negative’ prior to a doubling of CO_2 equivalent. After that point:

> I think it is likely, although neither I nor anyone else can now prove it, that at some point the amount of warming and associated changes in climate would begin to sharply increase the economic and environmental costs of world production, not only in agriculture but in other sectors as well.
>
> (Crosson, 1989: 115)

Crosson is, however, guilty of a relevant methodological flaw in his statement. The hypothesis that warming due to the enhanced Greenhouse Effect will result in net damages to economic systems can never be proven. The evidence in favour of the hypothesis can increase so none may doubt its truth, but there will always be the possibility of an alternative hypothesis and counter-intuitive evidence. For example, accepting that all swans are white is held true only until a black swan is discovered on arrival in Australia. Only white swans may have been observed for hundreds or thousands of years by Europeans, but this cannot preclude the existence of the black swan. If we stop GHG emissions no climatic change may occur because the theory was incorrect, and if we go ahead and climatic change does occur the cause may be other factors of which we remain unaware.

In most daily life the world around us is accepted on the basis of beliefs (or social commitments) which are so common that to question them would make most people regard you as mad (pity the philosopher). Yet the point here is quite serious, because science plays a central role in the formation of those beliefs in modern society and especially so when confronting complexity and strong uncertainty. Scientific methodology has also been important in influencing economics. Thus, the basis upon which society is being formed and reformed, and information is accepted as valid, is intertwined with modern faith in science and technology. Where that faith is lacking the scientists or industrialists pushing technological solutions are seen as biased and their information suspect. Hence public concern, from nuclear power to genetically modified organisms, and the distinct change in the perception of science from the technological optimism of the 1950s.

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Post-normal science

The type of uncertainty that complex problems such as the enhanced Greenhouse Effect confront us with is strong, not weak. Does this make the enhanced Greenhouse Effect a very different problem from that repeatable experiment in controlled conditions around which scientific objectivity was classically formulated? Some may fear that accepting the role of partial ignorance in epistemology and the need for belief in science means all is conjecture. On the contrary, a clearer picture is required of the process by which information is accepted as valid and on what grounds.

Funtowicz and Ravetz (1990; 1992a; 1992b; 1993; 1994a) have been conducting a constructive analysis of how society might proceed beyond the postmodern temptation to be nihilistic, while avoiding the modernist temptation (prevalent in the models discussed here) to claim a single optimal answer. Their recommendations are for opening up the process of knowledge validation because:

> The nature of policy debates involving science has been transformed by the success of non-expert stakeholders in contributing to the assessment of quality. Previously only subject-speciality peers could assess quality in connection with refereeing or peer-review. But when science became used in policy, it was discovered that laypersons (e.g. judges, journalists, scientists from another field, or just citizens) could master enough of the methodology to become effective participants in the dialogue.
>
> (Funtowicz and Ravetz, 1994b: 203–4)

One response to the call for more participation is to incorporate this within existing models and frameworks. Jaeger (1996) has suggested conflict resolution techniques be used to obtain consensus subjective probabilities. Interviews are to document individual attitudes and opinion, while focus groups document social processes of attitude formation. The aim is to assess the acceptability of new policy options. More than this, Jaeger wants tools of co-operative risk management to foster standards of justice when attempting to blend individual probabilities and utilities into socially acceptable decisions. This moves beyond standard expected probability theory because the role of debates in modifying preferences is seen as central to co-operative risk management in order to overcome social dilemmas (Jaeger, 1996: 15). The aim then becomes agreeing standards for what is a fair way of sharing risks, and regarding scientific input as sharing knowledge about plausible consequences of various actions. However, the reversion to producing ‘subjective probabilities’ seems reminiscent of the attempts by economists to reduce catastrophic unique events to known risks. The response to the need for opening up debate cannot be to then curtail the outcomes in the most effective way possible by returning to the very models which denied the need for debate in the first place.

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Consensus is also unlikely to be a part of an open process of debate about understanding of science and would be counterproductive. As Wilenius and Tirkkonen (1997) point out, attempting to create unanimity, on issues such as climate change, is likely to appear unnatural, and to lead to a loss of vital information and the suppression of viewpoints. Their use of modified Delphi techniques to address climate change policy options in Finland aimed to get researchers communicating with policymakers. Developing such techniques beyond expert groups is even more challenging but necessary.

A new methodology for science is appropriate to deal with strong uncertainty and, as Funtowicz and Ravetz (1993) recognise, it must be based upon assumptions of unpredictability, incomplete control and a plurality of legitimate perspectives. They regard an extended peer review approach as particularly relevant where systems uncertainties or 'decision stakes' are high and the research goals are issue-driven (as opposed to a core science approach motivated by curiosity). While critical of determinism when facing complex environmental problems, this approach does recognise the role core science has played in human society. Scientific success through the extension of laboratory experience has given many advantages in terms of health, safety and general comfort of living for many. As discussed, this experimental work isolates a part of natural systems and keeps it unnaturally pure, stable and reproducible, e.g. work on the CO_2 fertilisation effect on crops.

Unfortunately, as Funtowicz and Ravetz (1993) point out, while the successes of the normal scientific approach may be unstable, the method has become dominant over all other ways of knowing, e.g. commonsense experience, inherited skills of living. As has been shown above, a result is that public decision-making must at least appear to be scientific. The method of science is therefore adopted by those wishing to lead the policy debate, such as economists. The inability of science to provide experimentally derived theories to explain and predict the enhanced Greenhouse Effect has lead to the development of mathematical models and computer simulations which are essentially untestable. So the case made by Funtowicz and Ravetz seems particularly relevant to the enhanced Greenhouse Effect and can be summarised by two quotes:

> Now scientific expertise has lead us into policy dilemmas which it is incapable of resolving by itself. We have not merely lost control and even predictability; now we face radical uncertainty and even ignorance, as well as ethical uncertainties lying at the heart of scientific policy issues.
>
> (Funtowicz and Ravetz, 1993: 741–2)

> We would be misled if we retained the image of a process where true scientific facts simply determine the correct policy conclusions. However, the new challenges do not render traditional science irrelevant; the task is to choose the appropriate kinds of problem-solving strategies for each particular case.
>
> (Funtowicz and Ravetz, 1993: 744)

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This latter argument implies that a new methodology for classifying problems and applying methods will need to be developed. However, further insight can be offered on the place of wider debate in this package.

Indeterminacy and the need for social discourse

Wynne (1992: 116–17) has provided a complementary analysis to that of post-normal science with a different classification of uncertainty. Funtowicz and Ravetz have described normal science as operating effectively when both the size of the decision stakes and scale of system uncertainties are small, while post-normal science is relevant when both are large. In contrast, Wynne rejects a scale going from risk to ignorance in such a two-dimensional space in preference for the relevance of different concepts of uncertainty being determined by the conditions placed upon knowledge. He has observed that the implied objectivity and independence of the two factors (i.e. systems uncertainties and decision stakes) is misleading. Focusing on the social context, he argues that apparently technical applied science questions are actually subject to assumed indeterminacy; such questions seem 'normal' only because the surrounding context is artificially assumed to be constant and effectively unimportant. He interprets 'decision stakes' as social commitments, and argues a two-way connection. First, the social commitments influence the way that lack of knowledge is expressed by any party (i.e. either as weak or strong uncertainty). Second, social commitments are themselves indeterminate and conditional because they depend to some extent upon unknown aspects of systems and their interactions. For example, while the stakes (or social commitments) are certainly high under continued emissions of GHGs, they are also indeterminate due to unpredictable interactions between natural and social systems.

This leads to three broad prescriptions in order to address partial ignorance and indeterminacy. First is the need to recognise the existence of ignorance and indeterminacy, and then to understand their complex social character, even within the domain of scientific knowledge. Second is the need to shift away from 'end-of-pipe' solutions towards considering upstream industrial processes, e.g. product design, research and development. This will broaden the range of explicitly recognised uncertainties which society is adopting as new products and technologies are introduced and old ones reassessed. Third, there is a need for social discourse on scientific information. The exaggeration of the scope and power of scientific knowledge is institutionalised and creates '… a vacuum in which should exist a vital social discourse about the conditions and boundaries of scientific knowledge in relation to moral and social knowledge' (Wynne, 1992: 115).

Thus, despite differences in approach and explanation of risk, uncertainty and ignorance, Funtowicz and Ravetz and Wynne come to a similar key conclusion about addressing the issue. 'The most important need is surely to develop "regulatory" cultures which successfully encourage greater public debate on the social benefits,

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costs and indeterminacies of different products and processes, as well as on conventional environmental strategy questions' (Wynne, 1992: 124).

Conclusions

An idealised scientific inquiry into the enhanced Greenhouse Effect might require very strong standards of proof, and pursue a research project in orderly stages. However, the very nature of scientific progress implies that Earth will be experiencing its consequences long before rigorous science has been able to convince sceptics of its existence. This is in part because of the modern state of scientific knowledge which persists in hiding beliefs and reasons for commitment to a body of knowledge. Scientific progress requires a willingness to accept some ideas which cannot be established conclusively because they lie beyond evidence or logic, while accepting that both evidence and logic are necessary for the scientific endeavour. Popper is quoted in Loasby (1976: 27) as stating:

> I am inclined to think that scientific discovery is impossible without faith in ideas which are of a purely speculative kind, and sometimes quite hazy; a faith which is completely unwarranted from the point of view of science, and which, to that extent, is 'metaphysical'.

Economics has adopted much from the natural sciences in methodological terms and follows the process of attaining knowledge by restricting its visions while denying the blinkers are on. Treatment of uncertainty in economics is perhaps best summarised by Loasby (1976: 9):

> When someone says he is uncertain, what he usually means is not just that he doesn't know the chances of various outcomes, but that he doesn't know what outcomes are possible. He may well be far from sure even of the structure of the problem he faces. This normal state of partial ignorance is simply not defined in the theory of decision-making under uncertainty, in which 'uncertainty' acquires an esoteric meaning. This meaning serves to hide from the layman the fact that the economist, faced with a very awkward problem, has succeeded, as so often, not in solving it, but in denying the legitimacy of its existence.

Neither economics nor science is currently addressing the key aspects of uncertainty – namely, partial ignorance and indeterminacy.

Once some areas of ignorance which cannot be easily placed into the framework of weak uncertainty are accepted, the process of assessing the validity of new knowledge must become open, rather than restricted to objective scientific and economic analysis. Where altering the potentialities of systems causes changes which are, in principle, unpredictable the appropriate response is to maintain options (Faber,

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Manstetten and Proops, 1992). This implies accepting the importance of different views on the same problem, questioning current knowledge, and emphasising criteria of flexibility and reversibility.

Scientific and economic knowledge must be placed explicitly within its social, moral and cultural perspective. This requires recognising that research communities are secluded and create closure and internal validity around particular constructs. Broadening the social circle of discussion is essential when deploying such knowledge in society. This allows questioning of the methodology, epistemology (commitments and expectations), definitions of boundaries between Nature and culture, and the boundaries between objective determinism and human responsibility. If the process of creating scientific knowledge denies this openness then the extent to which it 'naturalises' and limits our moral, cultural and policy horizons will remain hidden (Wynne, 1992: 127).

The level of social commitment determines the scale of the problem at hand and so the type of uncertainty which is relevant. In previous human history climate change has made whole regions uninhabitable, forced mass migrations and encouraged exploration beyond known boundaries (Niedercorn, 1983). The belief that such potential futures can be neglected as irrelevant to current decisions (as in the case of surprise when our fair coin lands on its edge) seems to depend heavily upon faith, in this case in the power of technology. That is, much of society is heavily committed to one perspective on the issue due to the scientific and technological nature of modern economies.

The fundamental question is whether society can and will act today to address changes or problems which loom in the future, rather than whether scientists are able to provide conclusive proof of future risks (Lee and Kromer, 1987). An important aspect of that decision in international negotiations focuses upon different values. In economics this is the debate over the costs of controlling GHGs versus the benefits of that control.

Notes

1 Keynes developed these ideas between 1906 and 1911. Although book publication was delayed until 1921 his ideas received wide attention from 1911 onwards. Some authors cite Knight (1921) as the source of the division of risk and uncertainty, but Keynes' work clearly predates this by a decade.

2 The emphasis is placed upon the intertemporal impacts of enhancing the Greenhouse Effect because they are the most neglected but most threatening. However, from the discussion in chapter 3 the uneven regional distribution of impacts is also of obvious concern and should be remembered. Many of the ethical issues and matters of compensation, which will be raised later in the book, apply equally to both. In addition, the issues are often interconnected and inseparable, e.g. resource-rich regions amongst current generations benefiting while resource-poor regions amongst future generations suffer.

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