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European policy-making

Science and governance in the European Union: a contribution to the debate

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Increasing attention is being paid to scientific aspects of policy or administrative decisions taken at a European level. Certain features of the process including the potentially irreversible consequences of decisions, the uncertainties involved, and the pressure on scientists to produce a particular result, indicate the need for a new relationship between science and governance. This should incorporate greater openness and more participation in the process from stakeholders. The European Commission is working to meet these requirements through the establishment of guidelines for applying the precautionary principle, the development of a European research area to integrate research at the European level with that in the Member States, and increased attention to the management and assessment of knowledge.

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THE RELATIONSHIP BETWEEN science and policy can be divided into two related but conceptually different areas (Brooks, 1964, page 76):

- matters concerned with the management and support of a scientific infrastructure and with the selection and evaluation of scientific programmes;
- matters that are basically political or administrative but that are significantly dependent on technical factors, for instance, disarmament policy, pollutant limits, pharmaceuticals licensing, vehicle safety standards.

The European Commissioner responsible for research, Philippe Busquin, recognising the great importance of science and technology for the prosperity and well-being of Europe, has proposed a number of ideas for rejuvenating Europe's research efforts, notably through the creation of a "European research area" (European Commission, 2000a). The main thrust of this initiative concerns the first of the two areas, the improvement of Europe's scientific infrastructure so as to promote European competitiveness. However, the initiative also recognises that science can improve policy decisions and suggests the development of a common system of scientific and technical reference for European Union policy implementation.

In this paper, we are more concerned with this second aspect — providing the technical and scientific support that enables society to make good decisions — although, inevitably, some points concerning a scientific infrastructure will be mentioned in so far as

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they impact on the delivery of scientific advice to policy-makers.

The aim of the present paper is to explore further the needs of policy for scientific input and to contribute towards the debate on developing a scientific and technical reference.

Timeliness of the debate

There are a number of reasons why a debate on the relationship between science and policy in the European Union (EU) is timely.

First, there is the progress in science itself. Developments in life sciences, triggered by an increased understanding of biological processes and rapid developments in technology, are producing new products and services for the market. These products are bringing undoubted benefits to society — *in-vitro* fertilisation is now applied routinely to solving the miseries of infertility, and plants genetically engineered for resistance to pests can reduce the requirements for chemical pesticides.

Similarly the explosion in information and communication technology has revolutionised the factory and the office and enabled people to access a substantial proportion of the world's knowledge from their homes. The promises for the near future are even more exciting, but the impact of these changes needs to be understood and managed. We must learn how to cope with innovations, which could have far ranging ramifications that are long-term, unpredictable and possibly irreversible.

Second, the attention devoted to science by governments is increasing. This is due partly to an increased need for scientific input to regulations and partly to the increasing efficiency and sophistication of lobby groups. A recent analysis by Padilla and Gibson (2000), showed that the proportion of questions, motions and debates in the British Parliament with a scientific content has risen sixfold over the past decade. Questions with a scientific and technical content went from 1% in 1988–89 to 6% in 1998–99. Biological (medicine and food) and environmental sciences (including energy) accounted for most of the growth. Recent reports from the United Kingdom (May, 1997) and Canada (Council of Science and Technology Advisors Secrëtariat, 1999) recognise the need for developing appropriate advice mechanisms and suggest guidelines for producing sound advice.

Third, there has been an evolution in European institutions. The development of an Internal Market with common European standards and regulations, together with the emergence of the European Union as a representative of the member states in trade discussions, such as those at Seattle, or environmental negotiations such as those at Kyoto, means that debate at a European level is appropriate. The particular responsibilities of member states, Council, Commission, Parliament, agencies, scientific committees and courts are unique to Europe and the mechanisms for scientific advice to policy are not, in general, the same as elsewhere.

Fourth, this evolution of institutions is continuing at an increasing pace. The enlargement of the Union to include countries from the former Soviet bloc is imminent and sure to bring new challenges and opportunities to European governance. The European Commission has recently opened a debate on the subject. According to President Prodi (Prodi, 2000) up until now European integration has been a largely economic process establishing the single market and introducing the single currency.

The new frontiers of this integration are Justice and Home Affairs, the Common Foreign and Security Policy, defence co-operation and the crucial question of fundamental political values. These issues go to the heart of national sovereignty and require an even greater level of political consensus than those which dominated the 1980s and 1990s. The Commission is preparing a White Paper to promote and propose a new division of labour between the Commission, the other European institutions, the member states and civil society and a new, more democratic form of partnership between the different levels of governance in Europe.

Hitherto it was assumed that science would conquer nature and ensure a human existence amid safety, comfort and convenience: now it is felt that developments in science create new risks and in our efforts to cope with them we face great uncertainty

Fifth, an increased understanding of the complexity of the natural world has led to a realisation that scientific certainty in a number of important areas will not be achieved in the near future. Examples include the impact of particular greenhouse gases on global climate change, the impact of environmental pollution on human health, and the possible hazards of the release into the environment of new chemical species, such as xeno-oestrogens or genetically modified organisms. Where such risks are involved, some sort of 'precautionary principle' needs to be invoked explicitly, rather than implicitly being assumed to be embodied within the practice of research or regulation. Assessment of risks in a quantitative, technical style needs to be complemented by attention to the contextual aspects of the complex systems in which hazards arise and within which social significance and acceptability must be appraised.

Sixth, recent crises over defects in the regulatory systems in member states have raised the prospect of the serious consequences of a loss of public trust in scientific expertise and advice. The most notorious case is BSE-nvCJD (mad cow disease, Creuzfeldt-Jakob disease), which shows no signs of abating as new evidence continues to emerge about its potential hazards. Since the origins and spread of this disease are so directly related to a certain style of governance, and a corresponding style in the use of scientific advice, governments everywhere must now prove to their public that they are genuinely different. Otherwise there is every possibility that 'the consent of the governed' will not be forthcoming when controversial policies are advanced. The emerging reforms in the scientific advisory system can be seen as part of the general reform of governments, at the level both of member states and the Union, in the direction of greater public accountability and greater public participation.

Risk and uncertainty are common and central to all these developments. They bring a new element into the public understanding of science. Hitherto it had been assumed that science would conquer nature and ensure a human existence amid safety, comfort and convenience. Now it is felt that developments in science create new risks and in our efforts to cope with them we face great uncertainty. Given the rapidity of the change, and the widespread disillusion with governments' management of these problems, it is not surprising that a lack of trust has characterised many recent debates on policy issues.

Trust is essential for the proper functioning of science and governance alike, and is paradoxically more difficult to maintain in a literate, sophisticated society where citizens are able to assess the quality of performance of their institutions. The strength and acceptability of the decision-making system depends to a large extent on its ability to show that it can be fair and transparent and take into account all the legitimate interests and opinions.

The failed trade preparatory meeting of WTO (World Trade Organisation) in Seattle highlighted a growing influence of citizens' groups on global policies. There is a view that the meeting's failure was partly caused by omitting to provide enough opportunities for stakeholders to participate in the process. If science can be located within an interactive, reflexive and recursive process of governance, then public trust in science and confidence in the policy-making process can be restored and maintained.

Risk and uncertainty

Uncertainty

While it is proper for scientists to strive for the deeper understanding that is associated with the reduction of uncertainty, policy makers need to make decisions on the basis of what is known now, not what may be known once the research is complete. In some systems it has even been proven that more research will not help because uncertainty and unpredictability are inherent to the systems themselves — undetectably small perturbations can lead to far-reaching consequences after a certain time. The insights of chaos theory have shown that prediction beyond this time is not possible and explain, for example, why the enormous improvements in computing power and increases in sophistication of computer models have not led to accurate weather forecasts beyond the three or four days that were already possible 20 years ago.

Risk

The development of the mathematics of probability and statistics has tended to obscure the fact that precise quantifiable risk is possible only in a minority of cases. Stirling (1999) has defined two categories:

- completely-understood, self-contained formal rule-based systems (such as games of chance); and
- highly repetitive events affecting a multitude of subjects in long-term stable systems (such as actuarial tables in the absence of war, plague or famine).

Stirling notes that the real world is, instead, imperfectly understood, complex, dynamic and open-ended. The influence of a parameter may be miscalculated or

forgotten. For example, in environmental impact analyses, some substances may be declared harmful when they are innocuous or vice versa. In such cases, it cannot be simply presumed that 'sound science' exists and is 'ready for use' in the policy process.

Thus uncertainty and the management of risk are fundamental components of the relationship between science and governance. However, the difficulties in treating risk management as a traditional disciplinary problem are well illustrated by the outcome of an exercise in definition conducted by the Society for Risk Analysis (*Risk Newsletter*, 1987). More than a dozen legitimate definitions were examined, each corresponding to a different scientific perspective or policy practice and the only consensus was to keep them all, as each reflected a relevant aspect of risk (Funtowicz and Ravetz 1990).

Acceptable risk

A common response to criticisms of official decisions on risks has been that there is no such thing as a zero risk. Hence the occurrence of accidents or disasters did not invalidate the judgement of acceptability, or tolerability, or even the stated scientific probabilities of occurrence of such events. Just as 'danger' was scientifically tamed to become 'risk', so 'safety' was scientifically redefined as 'acceptable risk'. This comfortable view depends, however, on a deep, hidden assumption: that accidents or disasters are a 'chance' occurrence, perhaps obeying a Gaussian distribution, the concatenation of sets of circumstances that come together randomly, and that exposure to this random distribution is the *sine qua non* of life.

The unravelling of this scientific reduction of risks began when the public saw that, for every disaster that occurred, there was always an explanation in terms of specific errors of commission and omission. Every disaster seemed to have been waiting to occur, and in retrospect seemed capable of prevention by elementary prudence and competence. Turner (1978) and Perrow (1984) showed that accidents, even disasters, are not merely 'man-made', but also in a sense 'normal'. What was 'safe' depended partly on the technical aspects of the hazard but mostly on the institutions and people, and the broader culture through which the hazard was controlled.

Further, we increasingly encounter situations in which the available scientific evidence is insufficient to determine the answer to the question of safety. Even if 'sound science' (results that are laboratory-based and conventionally quality-assessed through journal publication) is available, it may be of doubtful relevance to a hazard in the real world of natural variability and imperfect regulation. In an increasing proportion of risk issues, particularly those relating to ramified and future effects on natural environments and human health, it is almost impossible for 'sound science' to provide enough evidence.

Under these circumstances, other criteria will dominate in the debate; and the science itself will need to be managed with an understanding of its deficiencies in quality and certainty. During the BSE crisis, the cull of the British cattle herd was criticised by farmers on the seemingly reasonable grounds firstly that scientific analysis (Anderson *et al*, 1996) showed that the disease would become extinct anyway, and secondly that none of the culled animals would have entered the food chain. They felt that they were being sacrificed for political expediency to mollify the European consumers.

The question "how safe is safe enough?" thus confronts us with scientific ignorance in ways that are novel in the management of our science-based technology. It is significant, in this regard, that the practices of traditional medicine and engineering reflect an awareness of ignorance; thus 'clinical judgement' is invoked in medicine, and 'safety factors' are employed in engineering design, precisely to cope with experts' ignorance of all the things that might give us unpleasant surprises. Similarly, in debates on novel technologies with possible remote and irreversible effects on the environment and human health, awareness of our ignorance becomes the crucial element.

The precautionary principle

The precautionary principle encompasses one approach to dealing with risk and uncertainty. It has been enshrined as part of environmental policy within the Treaty establishing the European Community as modified at Amsterdam. Indeed nearly all discussions of the precautionary principle focus on environmental or health risks (rather than security or the economy, for instance) and the problem of allowing or not allowing a certain activity or product.

While the precautionary principle is growing in acceptance, it lacks a specific, widely recognised definition. With few exceptions, it remains only a concept, provides few guidelines for policy makers, and fails to constitute a rigorous analytical framework. The most well-known definition is that formulated in the 1992 Rio Declaration on Environment and Development:

> "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."

Most scientists would argue that full scientific certainty is the exception rather than the norm in environmental matters, so there can be few who could object to this principle. Another component of the precautionary principle is given in the Ministerial statement after the Second International Conference on the Protection of the North Sea, London, in November 1987 that,

The European Commission has stated that it will under no circumstances invoke the precautionary principle to justify arbitrary decisions but will only act after a scientific evaluation of the possible negative impact of inaction and an uncertainty analysis

> "in order to protect the North Sea from possibly damaging effects of the most dangerous substances, a precautionary approach is necessary which may require action to control inputs of such substances even before a causal link has been established by absolutely clear scientific evidence."

In the 1992 Ospar convention for the protection of the marine environment of the North-East Atlantic we read of:

> "... the precautionary principle, by virtue of which preventive measures are to be taken when there are reasonable grounds for concern ... even when there is no conclusive evidence of a causal relationship between the inputs and the effects."

Again most scientists are happy with 'plausible' evidence of a causal relationship and would not need the relationship to be conclusive. The difference between the precautionary principle and the 'sound science' approach is wider than the management of uncertainty. Rather it concerns decision-stakes or the methodological issue of whether the absence of evidence of harm should, reasonably, be deemed to be the evidence of the absence of harm.

The precautionary principle has also been accepted as a basis for regulating trade in genetically modified organisms. After protracted negotiations, the 133 nations at the January 2000 United Nations Montreal conference agreed that the new bio-safety protocol would have equal status with World Trade Organisation regulations. The Protocol allows countries to restrict imports of genetically modified products if they fear that these products may harm human health or get into the environment and damage it. It covers foodstuffs, as well as seeds for farmers and feed for animals.

The Commission's Communication on its interpretation of the precautionary principle (European Commission, 2000b) argues that the principle is only specifically mentioned as a treaty obligation for environmental matters but that it is implied in other sectors – particularly consumer health. The Communication, coming at the outset of the new Prodi Commission, provides an indication of how the principle will be applied in the coming years.

Triggering precautionary principle's application

The precautionary principle is only one of the principles of governance. It must be balanced against others, such as limited government and individual liberty. Aware of this, the Commission has stated that it will under no circumstances invoke the principle to justify arbitrary decisions but will only act after:

- a scientific evaluation of the possible negative impact of inaction; and
- an uncertainty analysis.

Both the evaluation and analysis will be carried out in a transparent manner that involves all interested parties "to the fullest extent possible".

Application of precautionary principle

The Commission's application of the precautionary principle will be based on:

- Proportionality — measures should not be disproportionate to the desired level of protection and should not aim for zero risk.
- Non-discrimination — they should be applied in a coherent manner for comparable situations and should not be geographically dependent.
- Consistency — measures taken should be consistent with those taken in equivalent areas where the risk is well understood.
- Demonstrated benefit — cost–benefit studies of proposed measures should be made. The measure proposed must produce some benefit and economic studies must be performed where possible.
- Monitoring — measures should be monitored and research to improve basic understanding should continue.

Burden of proof

The Community practice of prior approval for new products such as drugs, pesticides or food additives is an example of the application of the precautionary principle. These are assumed hazardous unless the manufacturer can provide reasonably strong evidence otherwise.

The principle can also be invoked in court proceedings. Thus American courts have turned down scientifically reasonable appeals against Environmental Protection Agency decisions, such as that to suspend the herbicide 2,4,5-T, on the grounds that the precautionary principle gives the benefit of doubt to the authority deciding to implement a precautionary measure.

Other interpretations

Tickner (2000) has proposed a guide for precautionary decision-making that is mostly consistent with that proposed by the Commission but is slightly wider in scope. For instance, he suggests that it:

- obliges the setting of goals for reductions in hazardous substances, processes, products and practices (an example is the EU's Framework Directive 96/62/EC on air quality that establishes objectives for ambient air quality in the Union);
- implies the polluter-pays principle (this is also enshrined in the consolidated European Communities treaty but is considered as a separate point);
- compels the evaluation of alternative products or activities, for instance, the decision to phase out one chemical is inextricably linked to the decision to replace it with another (this could be considered as part of the cost–benefit exercise proposed by the Commission).

Not the last word

The Commission's Communication is not intended to be the last word on the matter but rather a point of departure for a broader study of the conditions in which risks should be assessed, appraised, managed and communicated.

Policy-related science

There are many features of scientific endeavour — good laboratory techniques, careful and precise reporting — that are common in all branches of science. Furthermore, the science used in resolving policy issues draws heavily on the rich background of fundamental research performed for curiosity only, and uses the technology produced by applied research. Nevertheless, there are real differences between, on the one hand, 'policy-related' or 'precautionary' research whose aim is to explore an issue or support a policy and, on the other hand, fundamental, curiosity-driven research or applied, product-driven research.

Those involved in policy-related research are moving towards a new way of working. Rather than assuming that the lack of public trust can be solved by better public relations or explaining their work to the public better, enlightened scientific agencies are now committed to 'transparency and participation'. A number of experiences have led to this change, most notably the insights gained from knowledge assessment.

By 'knowledge assessment' we understand the complex processes of quality assurance, operating on the equally complex processes of the production of that knowledge. The two processes, while distinct conceptually, are inseparable in practice. There has been a change from previous practice in which quality assurance was principally a matter of evaluating research reports through journal refereeing, and of research proposals through peer review. Now we must appreciate how all the aspects of science in the policy context, technical, social and ethical, are involved in its assessment as well as in its practice.

We may consider the components which characterise policy-related research, and see how they differ from other, more familiar, types of research. These components are:

- purposes: what is it for?
- people: who does it?
- problems: how do we frame problems to reflect the purposes, and also provide useful results with available resources?
- procedures: how do we cope with uncertainty?
- product: what does the research produce?

In this very brief survey we identify crucial features relevant to the new situation.

Purposes

Policy-related research has a different objective from either pure or applied research:

- In basic research, the defining purpose of a project is the advancement of knowledge. There are special institutions for this work, usually but not always associated with advanced teaching, and also institutional structures whereby researchers are insulated from external pressures and demands. Their communities, normally restricted to peer groups, can set their own criteria of quality (adequacy and value), subject only to a general and long-term contract with the wider society.
- For the more applied work, the defining purpose is the development of devices or techniques. The researcher enjoys less autonomy and endures more external direction. The products of research are less likely to remain the intellectual property of the researchers, but normally belong to their employers. The research 'community' includes not only the peer group but also other parts of the organisation in which the research is done.

Policy-related research is different. The output of the research is but one input among many in a policy process run by people, and the scientific contribution is rarely conclusive. The 'purposes' are as complex as the context of its use: they include the maintenance of the scientific quality of the output, of the legitimacy of the process and of the acquiescence of the public in the policy process of which it is a part, and also the extension of democracy to this new area of governance.

People

Experts are often invited to offer advice to government. They are recruited from among the community of successful scientists who are presumed to be 'disinterested' in the sense of acting with integrity as well as technical competence. However, if these experts are tied through dependency of any sort to an institution with a corporate interest in the policy under consideration, their 'disinterestedness' in the process cannot be taken for granted.

The public's lack of technical background or negotiating skill is being redressed through NGOs and consumer groups, which can deploy their own scientific and technical expertise, and through the Internet, which brings new empowerment to citizens

To the extent that a policy debate hinges on its scientific input and not merely on a reconciliation of interests, its style should be more on a 'forensic' model than a 'legislative' one. This allows for all experts to be advocates for some stakeholder interest or other, but then the equivalent of judges and juries must be found. This formulation parallels a debate on court cases in which some feel that a lay jury cannot be expected to understand the complex issues involved and will become confused in an adversarial approach when scientists from each side come up with different conclusions. Jasanoff (1998), based on studies of the O J Simpson trial, decided that citizens are quite capable of managing uncertainty and distinguishing crucial issues of good practice from those involving esoteric technicalities.

The task is to create in the policy-relevant domain the sense of collegiality that has enabled informal quality control to be so effective in the traditional research sector. For this, techniques of negotiation, mediation and even reconciliation may be appropriate.

The public's lack of technical background or negotiating skill is being redressed through NGOs (non-governmental organisations) and consumer groups, which can deploy their own scientific and technical expertise, and through the Internet, which can bring a new empowerment to citizens. They are no longer tokens in the process, and are becoming recognised as essential partners.

Problems

In the framing of a problem, the issue, characterised by its purposes, becomes translated into a relatively precise specification of what questions can be put in a scientific way, and what reliable answers can be hoped for. The framing of the problem also frames our future ignorance, for what is excluded from enquiry at this stage will not be discovered (or maybe, at best, by chance, by mistake, by anomaly or by deviancy). Hence the framing of the problem is not purely technical, but has its own policy dimension. This is why purposes and people are involved in this phase as well.

The values that are first expressed through the purposes should also be recognised in the framing of the problem. This can be seen clearly in the design of statistical tests. The 'confidence limit' in a test of significance expresses the relative importance (for the relevant community) of the different error-costs that are inevitable in any such test.

If the numerical confidence limit has a large value (say 0.1), then the test will be more sensitive, or inclusive, and the possibility of accepting false correlations (Type 1 error) will be higher. However, if it is small (say 0.01), then the test will be more selective, or restricted, and the possibility of rejecting true correlations (Type 11 error) will be greater. Thus if we are testing for the physiological effect of a suspected pollutant, a lower numerical confidence limit will reduce the risk of society wasting money on unnecessary controls (Type 1 error), but will also increase the risk of unrecognised harm being done (Type 11 error).

There is no possibility of avoiding both errors, and the apparently objective quantitative parameters of 'confidence limits' express the values that shape the enquiry.

Procedures

A traditional research problem depends on a background of trusted, reliable information, and is expected to yield a definite conclusion. By contrast, in the policy-relevant fields, researchers must make do with what is available. Frequently this material has not gone through a peer-review process, and so its quality cannot be assumed.

For example, benchmark studies of computer models in quite standard industrial hazard exercises (Amendola *et al*, 1992) show that, when a range of expert teams exercised their judgement, vast differences in the results appeared. More recently, a study of standard parameters in environmental health revealed striking differences in values among those listed in standard sources, some discrepancies being enormous (Marino, 1999). To incorporate the management of severe uncertainty into the research methodology of policy-related science is a skill whose development is urgently needed.

In basic research and in applied work, to embark on a problem that cannot be solved (in terms of some accepted criteria of adequacy) is to court failure, to waste resources. However, in the provision of information for policy purposes, science must nonetheless simply do its best, even if its products are inadequate, by the criteria both of its field and of its clients' needs.

Policy-making cannot wait for conclusive facts, in science-related fields any more than in others; part of the art of policy is to make do with inadequate, confused and contradictory information. What policy-relevant science offers is not so much objective, conclusive facts in a scientific demonstration, as 'evidence' in a policy process, rather like in a court procedure or a public inquiry. As evidence, its quality will be assessed in relation to its function in particular arguments at particular points of a process.

A consequence of this insecure state for policy-related science is that knowledge assessment must be developed hand-in-hand with the research itself. According to Gibbons (1999), if society participates

in the production of policy-relevant scientific knowledge, such 'socially robust' knowledge is less likely to be contested than that which is merely 'reliable'. Methods must be developed for coping with the various degrees and sorts of uncertainty, both in the input data and in the methods of research themselves. Results should be expressed not as single discrete values but as an 'envelope' showing consequences of assumptions. Appraisal methods should be selected for their suitability for extended peer review, including minority opinions.

Even within the research process, the uncritical attitudes characteristic of the 'normal science' described by Kuhn (1970) are no longer appropriate. It is necessary to develop reflective researchers, analogous to the "reflexive expert practitioners" advocated by Schön (1983).

Products

As scientific findings advance through the policy process, they shed quantitative precision and gain an accretion of qualitative meanings. A policy decision involving science has a simple core. It may be binary choice: to ban or not; or it may be the setting of a sharp level of a variable, defining a limit between the permitted and the prohibited.

Yet surrounding that simple core is a penumbra of considerations about direct costs, error costs, and acceptability to various stakeholders, enforceability (technical and legal), and (especially in the USA) security against litigation from either side. It is that penumbra of conflicting commitments and values, the 'decision stakes', that shape the negotiations in which the scientific 'facts' are interpreted, disputed, and then deployed in the policy process.

Quality-assurance of policy science necessarily involves all the stakeholders in the policy process. Such an 'extension' of the peer community that assures quality may seem strange or threatening to those who believe that only scientists can understand scientific results sufficiently to assess their quality. Nevertheless, citizens, increasingly well informed through better education and access to information, are quite competent in making the judgements that affect them, particularly when they concern that essentially complex attribute, 'safety'.

Extended peer assessment

Funtowicz and Ravetz (1993) have suggested that, in the policy context, the classical five components of scientific problem solving can be enriched by a sixth. This 'post-normal' assessment differs from the previous 'normal' scientific work of "puzzle-solving within paradigms" (Kuhn, 1970). Instead of providing 'scientific facts', the objective of the extended peer-review process is to deliver uncertainties, error-costs, and also the social and ethical dimensions.

When the focus of activity was in 'pure' or basic research, the informal quality-assurance methods of the research communities worked well, would not be significantly improved by outside interference, and in any event were appropriate for the tasks in hand. Now that science is being called on for systematic and planned effort to supply information to the policy process, an extension of the quality-assurance community is required.

There are a variety of possible goals for every process that involves stakeholders. These may include: quality of the outcome (such as wealth, health or public safety); legitimacy of the process; acquiescence of the public; and extension of democracy. Each set of stakeholders will have its own ranking of those goals, and their assessments of the process will not be homogeneous. Post-normal assessment provides no guarantee that the process will be successful by all criteria, but it does provide the only means to avoid major policy failures of the sort that we have recently witnessed.

The rebuilding of trust should be a prime objective for policy-related science. Once lost it can only slowly be regained. It must be accepted that all stakeholders, including scientists, have interests. Respect and trust should be developed on this honest basis. Scientists who dogmatically reject alternative views in their work do not inspire trust. Neither do governments who treat all sensitive information as confidential.

Improving policy-related research in the EU

The European Union is the world's most rapidly evolving supra-national organisation. Its citizens are already enjoying an increased freedom offered by its Internal Market and benefit from the increased bargaining power that can ensue in international negotiations when 370 million people speak with one voice. Its neighbours are, almost without exception, clamouring to join it and Europe's governments are currently preparing an inter-governmental conference on institutional reform to examine how collective decision-making can be improved in a Union of 30 nations.

The challenge facing the Union is to develop a system that allows Europe to maintain the rich cultural diversity that is its strength, yet permits decisions to be made for the common good that might, in the short term, damage the interests of some. The EU's policy-related science is faced with a similar challenge. EU policies — on the economy, health, environment and security — require both the development of European scientific capabilities and knowledge and the management and assessment of this knowledge.

Developing European capabilities and knowledge

The development of a scientific infrastructure for the improvement of European capabilities and knowledge is the main subject of the Commission Communication "Towards a European research area" (Commission, 2000a). This suggests a number of steps that need to be taken to improve matters, including the improvement of researchers' mobility,

In the digital age, we must realise that 'information' and its usefulness are context dependent, and resources have to be spent as much on facilitating learning and interpretation by users, as on production of the information itself

improved networking, and the development of Europe-wide centres of excellence.

The Communication notes that the principal instrument used so far in Europe is the Framework Programme and that this accounts for only 5.4% of the total public effort. Much of the funding at a national level is spent on basic research in which diversity and differences of approach are positive factors.

However, there is also a need for a more coherent and co-ordinated approach for developing the capabilities that Europe needs if it is to support the policies of the 21st century. For instance, the objective of integrating environmental policy into sectoral policies will not be feasible unless commonly agreed frameworks for assessing concepts such as biodiversity or land degradation are developed.

All this will require a re-focusing of European research. First, this will involve an overhaul of the Framework Programme itself. Rather than scattering the funding over a large number of projects, some large integrated projects may be needed. This might require reconsidering the way projects are selected and monitored. Secondly, and more importantly, the resources of the Framework Programme are not nearly enough to cover all the policy needs, so it must be better integrated with research in the member states. New mechanisms for pooling resources for the common good will need to be developed.

Managing and assessing policy-relevant knowledge

The part of the Communication concerning policy-related research insists on aligning methods, harmonising procedures and comparing results. It further suggests that "the Commission's Joint Research Centre (JRC) could play a role in the development of a scientific and technical reference area". The JRC cannot, on its own, do this work but will need to be networked with the European scientific community to provide a more complete knowledge base.

The Commission has already started considering how to develop this reference area. At a workshop in March 2000 (Kyriakou, 2000), the situation in other areas — Canada, Japan, the United States as well as individual member states of the Union — was examined. Differences in approach resulting from constitutional differences were identified, examples being the significant role of the courts in the United States, or the role of regulatory agencies in other countries. For instance, the main aims of the European Environment Agency are to describe the present and foreseeable state of the environment and provide relevant information for the implementation of Community's environment policy. Unlike its American counterpart it has no powers to establish or enforce standards.

There is a general acceptance, that improved governance at all levels in all geographical areas needs better management and assessment of scientific knowledge.

In the digital age, there is a vast amount of information potentially available at the policy-maker's desktop that needs qualifying, authenticating and assessing. More than ever, it becomes important to realise that 'information' and its usefulness are context dependent, and resources have to be spent as much on facilitating learning and interpretation by users, as on production of the information itself.

The JRC is currently studying how to harness modern Internet-based information technology to provide reliable, timely and comprehensive access to a scientific knowledge base, some of which will be available within its own organisation but much of which must be obtained by filtering, processing and aggregating knowledge that is made available from the wider scientific community through networks. An action plan has been produced (Wilkinson, 2000).

Clearly information technology can only solve part of the problem. Although the JRC already has a large number of collaborators and networks, many of these are only on a short-term basis and are dissolved when projects end. More permanent networks need to be established for providing a continuous updating of knowledge and an ability to supply fresh knowledge on request.

The Communication also proposes "the development of new and sustained forms of dialogue between researchers and other social operators". This reflects changes in the 'social contract' of science. Formerly it was seen as performing a service to government, providing the technical information on which policy decisions in the relevant areas could be based. Now it is coming to be seen as assisting in the processes of governance, a much more diffused activity whereby a whole society manages its affairs. Expertise is no longer exclusively possessed or controlled by official organisations. Citizens are becoming engaged in the deliberative processes of science-related governance issues. By incorporating them at the outset of any negotiation they will be more likely to accept its outcome.

Partly this better dialogue can be achieved through the same knowledge management techniques that will, by making better information available on policy and on the scientific basis for it, lead to a more informed debate. However, this needs to be accompanied by a widening of the knowledge base through involving more stakeholders and by a better assessment of the knowledge in a structured manner —

explaining the uncertainties and clarifying the affiliations of the scientists who produced the work.

Next steps

The Commission has opened the debate on a European research area. This paper has explored a number of the issues involved, particularly with regard to the question of a scientific reference for EU policy. Europe is already beginning to move — through scientific committees, through the proposed creation of a Food Authority and through a refocusing of the Joint Research Centre.

The system is complex, unique and changing quickly. Therefore further analysis is needed (of how the system is working at present, what its shortcomings are, what the needs of policy are and what constitutes good scientific practice) both within the member states and at the European Union level.

In parallel with this analysis, a consultation process will continue through a series of workshops and conferences where ideas can be explored. The objective of the consultation will be to clarify further the current level of understanding on science and governance in the EU and to develop an approach for moving forward.

The outcomes will then be developed into a more concrete proposal for action in time to help the discussions that lead to the Sixth Framework Programme.

References

A Amendola, S Contini and I Ziomas (1992), "Uncertainties in chemical risk assessment", *Journal of Hazardous Materials*, 29.

R M Anderson *et al* (1996), "Transmission dynamics and epidemiology of BSE in British cattle", *Nature*, 382, 29 August.

H Brooks (1964), "The scientific adviser", in R Gilpin and C Wright (editors), *Scientists and National Policy-Making* (Columbia University Press, New York).

Council of Science and Technology Advisors Secretariat (1999), *Science Advice for Government Effectiveness*, Canada, May.

European Commission (2000a), *Towards a European Research Area*, COM(2000)6, January.

European Commission (2000b), *On the Precautionary Principle*, COM(2000)1.

S Funtowicz and J Ravetz (1990), *Uncertainty and Quality in Science for Policy* (Kluwer Academic Publishers, Dordrecht).

S Funtowicz and J Ravetz (1993), "Science for the post-normal age", *Futures*, 25(7), pages 735–755.

M Gibbons (1999), "Impacts: science's new social contract with society", *Nature*, 402(C81), December.

S Jasanoff (1998), "The eye of everyman: witnessing DNA in the Simpson trial", *Social Studies of Science*, 28(5–6), October–December, pages 713–740.

T S Kuhn (1970), *The Structure of Scientific Revolutions* (University of Chicago Press, Chicago).

D Kyriakou (editor) (2000), "Science and governance", special issue of *IPTS Report*, 45, June.

D J Marino (1999), "Variability in physical constants from standard data sources and its implication for risk assessment", *Final Program. Society for Risk Analysis Meeting, Atlanta, GA* (Abstract P1.20).

R May (1997), *The Use of Scientific Advice in Policy Making* (UK Office of Science and Technology, Department of Trade and Industry).

A Padilla and I Gibson (2000), "Science moves to centre stage", *Nature*, 403, pages 357–359.

C Perrow (1984), *Normal Accidents: Living with High-Risk Technologies* (Basic Books, New York).

R Prodi (2000), "Shaping the new Europe", European Parliament, Strasbourg, 15 February.

Risk Newsletter (1987), 7(3), September.

D A Schön (1983), *The Reflective Practitioner* (Basic Books, New York).

A Stirling (1999), *Interim Report on Precautionary and Science-based Approaches to Risk Assessment and Environmental Appraisal*, prepared under the ESTO (European Science and Technology Organisation) network for the EC Forward Studies Unit.

J Tickner (2000), "A map towards precautionary decision making", in C Raffensperger and J Tickner (editors) *Protecting Public Health and the Environment: Implementing the Precautionary Principle* (Island Press, Washington DC, forthcoming).

B Turner (1978), *Man-Made Disasters* (Wykeham Press, London).

D Wilkinson (2000), "Knowledge management at JRC: supporting the creation, maintenance and utilisation of scientific knowledge in support of EU policies. An action plan", JRC internal document (version 23).