The 22nd Annual
Campden Day Lecture

'Science Advice, Policy Making and Public Confidence'

Sir Robert May,
Chief Scientific Adviser to the UK Government

Sir Robert May is currently (1995 - 2000) Chief Scientific Adviser to the UK Government and Head of the UK Office of Science and Technology. He holds these positions on leave from his Royal Society Research Professorship at Oxford University and at Imperial College. After gaining a BSc and a PhD in Theoretical Physics from Sydney University, he spent two years as Gordon MacKay Lecturer (later Reader and, at age 33, the holder of Sydney University's first Personal Chair) in Theoretical Physics. In the early 1970's he became interested in dynamics of animal populations (particularly the "chaotic" dynamical behaviour that can arise) and in the relations between stability and complexity in natural communities. He moved to Princeton University as Class of 1877 Professor of Zoology in 1973. From 1977 until he moved to Britain in 1988, he was chairman of the University Research Board at Princeton University, having broad administrative responsibility for all externally and internally funded research at Princeton University. His current research deals with factors influencing the diversity and abundance of species and in particular with evolutionary and dynamical aspects of the interaction between parasites - broadly defined to include viruses, bacteria, protozoa and helminths - and their hosts with particular emphasis on the role of infectious diseases in the regulation of natural populations of plants and animals.

Sir Robert is author of the book Stability and Complexity in Model Ecosystems (Princeton University Press, 1973), and co-author with R M Anderson of Infectious Diseases of Humans : Transmission and Control (Oxford University Press, 1991). He is editor of the books Theoretical Ecology: Principles and Applications (Blackwell, second edition, 1981), Population Biology of Infectious Diseases (with R M Anderson, Springer, 1982), Exploitation of Marine Ecosystems (Springer, 1984), Perspectives in Ecological Theory (with J Roughgarden and S A Levin, Princeton University Press, 1988), Population and Dynamics (with M P Hassell, the Royal Society and Cambridge University Press, 1990), Large Scale Ecology and Conservation Biology (with P J Edwards and N R Webb, Blackwell, 1994) and Extinction Rates (with J H Lawton, Oxford University Press, 1995). From 1973 until 1988, he was editor of the series Princeton Monographs on Population Biology, and he now edits the Oxford Series on Ecology and Evolution. Recognition of his work includes election to the Royal Society in 1979, the American Academy of Arts and Sciences in 1977, the Australian Academy of Sciences in 1991, Academia Europaea in 1994, and (as a Foreign Member) the US National Academy of Sciences in 1992.

He was awarded a knighthood in 1995 and awarded the Companion of the Order of Australia in 1998, both for "Services to Sciences". Prizes and awards include, inter alia, the Weldon Medal in Biometrics by Oxford University in 1980, the MacArthur Award by the American Ecological Society in 1984, the Royal Society's Croonian Lectureship in 1985, the Linnean Society's Zoological Medal in 1991, the Zoological Society's inaugural Marsh Award for Conservation Science in 1992, the American Mathematical Society's

67th Gibbs Lecture in 1994, and the Zoological Society of London's Frink Medal in 1996. Particularly notable are the Royal Swedish Academy of Science's Crafoord Prize in 1996 (this award, worth US $500,000, is intended to complement the Nobel Prizes by cycling on a 3-year basis among mathematics, earth and space sciences, and "biosciences and ecology"; May is cited "for pioneering ecological research in theoretical analysis of the dynamics of populations, communities and ecosystems") and the 1998 Balzan Prize presented by the President of Italy (this SF500,000 prize was given by the Swiss-Italian Balzan Foundation for May's "seminal contributions to the mathematical analysis of biodiversity, in particular his pioneering work on chaos theory and ecological systems and the development of a variety of methods for estimating the total number of species alive on earth today and rates of extinction").

He holds honorary degrees from The City University, London (1989), Uppsala University (1990), Yale University (1993), Heriot-Watt University (1994), Edinburgh University (1994), The University of Sydney (1995), Princeton University (1996; along with President Clinton, as part of the University's 250th Anniversary celebrations), University of Warwick (1997) and University of Salford (1997), University of Kent (1997), and Imperial College, London (1997).

Sir Robert is Chairman of the Board of Trustees of the Natural History Museum, and an Executive Trustee of the Nuffield Foundation. He has held previous positions as a Trustee of the Royal Botanic Gardens, Kew; an Independent Member of the Joint Nature Conservancy Councils (JNCC); Trustee of WWF (UK); President of the British Ecological Society; and an Associate Director of Imperial College's IRC in Population Biology at Silwood Park. He was a member of the UK Cabinet's Advisory Council on Science and Technology (ACOST). Before moving to Britain, he bought the complete set of Ordinance Survey Maps, and with his wife Judith, who is a Senior Editor in Biology at Oxford University Press, he aims to use every one of them in exploring the countryside.

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Introduction

Advances in science and technology have transformed our daily lives, improving health, welfare, life expectancy and economic prosperity. Governments and commercial organisations have come to expect that investment in research and development will continue this positive trend - but how should they spend that money most wisely? Examination of the research output of the leading scientific nations, compared with the support they have given to R&D, can lead to some tentative conclusions about strategies for the management of scientific and technological progress. Increasingly, the effectiveness of those strategies will also depend on the involvement of the public at large in policy decisions leading to advances that will materially affect their lives.

1. Outputs and inputs

(a) *Research output*. National scientific productivity is most easily measured by counting the number of papers published in scientific journals. Alternatively the impact of a country's research can be measured by counting how frequently those papers are cited by others. The United States accounts for around a third of the total published papers, and in recent years Japan has moved into second position with around 9 per cent of the total. The UK is very close behind, followed at a greater distance by larger countries such as France and Germany. The rankings are similar for share of citations.

As with economic performance, it makes more sense to judge scientific output not in absolute terms but relative to a country's population size. On this measure the relative positions in the scientific output league table shift considerably. The leaders are Switzerland, Israel and Sweden, with Scotland also featuring high in the list if considered separately from the rest of the UK. Canada, the Netherlands, Denmark and Finland also perform well. The UK and the US, in that order, only just make it into the top ten, while France, Germany and Japan are several places below.

The bibliometric measures on which these figures are based have some flaws. They fail fully to reflect, for example, the high proportion of research papers that are the product of international collaborations, a trend that will only increase in the future. Already more than a quarter of all UK papers have at least one international co-author. In addition, the figures tend to be biased against non-English speaking countries, although this has not prevented Sweden and Switzerland from topping the list in terms of scientific productivity per capita. However, the figures do provide at least an indication of the degree of scientific activity in different nations.

(b) *Research inputs*. A country's commitment to investment in science might be judged by its spending, as a percentage of GDP, on basic research - what we call the "science base". This is the investment that produces new knowledge, access to the knowledge produced by other countries ("membership of the club") and - most important - a continuing infusion of well trained young people. On measures of overall investment in the science base relative to country size - including money from government, charities, industry and commerce - Japan is unequivocally the world leader, a position it has reached relatively recently. It spends a little over 1% of GDP, well ahead of the US and the UK which both spend around 0.6-0.7%. In between come countries such as Switzerland and the Scandinavian countries that generate a level of scientific productivity disproportionate to their size.

(c) *Value for money*. Measuring outputs - published papers - relative to spending on basic science three or four years earlier shows that some countries generate very much more science than others for every million pounds [dollars] they spend on the science base. The UK has consistently topped this league table throughout the 1990s, a position it owes to relatively high productivity combined with relatively low investment. The UK, indeed, is the only country in which the number of scientific papers published per researcher has increased over the past decade. This increase may be attributed to in part to the introduction of a funding formula for universities in which the level of grants to departments depends directly on their research output. Once again the smaller but highly productive countries such as Switzerland, Sweden and Denmark perform strongly on the value-for-money measure, while larger economies, including France, Germany, Italy and Japan, produce less than half as many scientific papers per million pounds [dollars] invested as the UK.

These comparisons make it clear that increasing investment in basic research will not by itself buy more science. The interesting question is how to deploy that investment so as to stimulate scientific creativity. I believe that much of the discrepancy between countries that do best on the "value for money" measure and those that do least well may be accounted for by differences in the social and institutional structures within which research is conducted, and by differences in the basis on which research funds are distributed.

The UK operates a system of "dual support" for basic science, which features a highly competitive approach to the allocation of funds for both infrastructure and direct costs. The direct costs are funded by bodies such as the Research Councils in response to proposals for future research submitted by individual scientists and subjected to peer review. Funding for research departments in universities, which provide most of the infrastructure, is weighted by an evaluation of the recent research performance of each department.

This competitive focus on excellence appears to generate a higher rate of productivity than systems in which basic science expenditure is allocated via formulae designed to give fair shares to all, or where funding depends on seniority rather than good ideas. Research laboratories in countries that do well on the value-for-money measure are also characterised by relaxed social structures in which younger people are genuinely free to express their individual creativity, and are relatively unconstrained by deference to those higher up in the hierarchy.

(d) *An increase in British investment*. The British government under Prime Minister Tony Blair recognises that the UK cannot hope to secure its place in an increasingly competitive and technologically advanced world without a real increase in investment in the science base. Throughout the 1980s and early 1990s UK spending on basic science as a percentage of GDP remained low in comparison with other scientifically-active nations. Buildings and equipment were increasingly inadequate to meet the needs of top-class research. A year after his election in May 1997, Mr Blair declared that "the science base is the absolute bedrock of our economic performance" and announced an increase in the science budget of 15% in real terms over the three years from 1999 to 2002. Much of this increase will go towards building and refurbishing laboratories and providing new equipment. The Wellcome Trust, the UK's largest medical research charity, has contributed an additional £400 million to the total, including £100 million to build a new high-intensity synchrotron X-ray source. With over £300 million of extra government funding also going to the universities each year, the total increase in spending on the science base over three years amounts to £1.4 billion.

2. From idea to product

(a) *Creating networks*. Britain has a proud heritage of technological innovation: the steam engine, the jet engine, the hovercraft, as well as vaccination and penicillin, are all associated with British inventors and scientists. However, there is a common perception, especially overseas (although not among scientists), that our technological achievements are part of a once-great past, with contemporary figures contributing little to the cutting edge of design and technology. Additionally we have a reputation, partly deserved, for failing to capitalise on our inventions; it is certainly true that American rather than British companies made the most from the commercial production of penicillin, and a similar story can be told about the jet engine.

This view, although widely held even in Britain itself, is increasingly out of date. In some small specialised areas, such as computer games and Formula 1 racing cars, British designers and inventors are at the forefront.

The UK has contributed more than its fair share to the worldwide trade in high-tech products such as aircraft, computer and communications equipment and pharmaceuticals over the past decade. It earned around £500 per head of the population from high-tech exports in 1995, more than the comparable figure for any of the other G7 nations.
This encouraging performance is not reflected across industry as a whole, however, and on other measures the UK clearly needs to do better. Data on ownership of patents provides an indication of a country's capacity for commercial exploitation of advances in basic research. Relative to GDP, Britain's share of US patents falls well below those of the US, Japan, and smaller European countries including Sweden, Switzerland and the Netherlands. On ownership of European patents, again relative to GDP, it is outclassed by Germany, Denmark, Sweden, Switzerland and the Netherlands.

The British government recognises that investment in the science base will not improve these figures without additional incentives to encourage collaboration between academic science and commercial enterprise. Only recently has the UK systematically undertaken a Foresight Programme, now into its second five-year cycle.

The programme brings together people from academic, professional and commercial backgrounds in a series of panels to identify areas of opportunity in future markets. This provides, amongst other things, a basis for decisions on research with a strong prospect of commercial development in the medium to longer term. The reports of the panels feed into funding decisions made by Research Councils and other bodies, but perhaps more importantly begin the process of interaction between academics and people from business and industry. The Foresight process is, indeed, more important than the product.

(b) *Encouraging entrepreneurship*. A number of specific incentives take this process further, while encouraging creative people to take the potentially risky step into business. The University Challenge scheme has provided £60 million to help innovators in universities to explore the possibilities for commercial development of their discoveries. The Science Enterprise Challenge, worth £25 million, will endow up to eight new centres to promote the commercial development of cutting-edge science through providing infrastructure support for spin-out companies. The 'reach-out' fund will enhance interactions between universities and the businesses in their neighbourhoods. And there are proposals for tax-free stock options to motivate the directors of start-up companies. However, we still have some way to go before the British business culture applauds risk-takers and recognises that such entrepreneurship necessarily entails honourable failures as well as successes.

3. Science, politics and public trust

(a) *Opening up debate*. No plan for the management of scientific creativity and technological innovation can succeed unless it takes account of the social and cultural context in which these activities take place. Since the time of the earliest democracies, the problem has been how to conduct a dialogue between government and people so as to develop public trust in government decisions.

In an increasingly complicated and technologically-driven society much of this dialogue concerns issues that demand scientific understanding, or where there is considerable scientific uncertainty. At the same time in many societies, including Britain, an automatic respect for authority is rightly being replaced by a greater demand for public consultation.

This trend has been accelerated in Britain by episodes such as the BSE crisis, in which the risks to human health of an epidemic of brain disease in cattle were initially underestimated by government ministers and their advisers. Current widespread concern about the health risks of genetically modified foods undoubtedly owes much to an increased mistrust of official statements on food safety in general.

In response to this public mood, the Office of Science and Technology has produced a set of guidelines, *The Use of Scientific Advice in Policy Making* (http://www.dti.gov.uk/DTI/Pub), that have wide consultation and openness as central principles. Opening up discussions (in which the scientific evidence is itself not always clear cut) to participants who are not scientifically qualified further complicates the decision-making process. We are convinced, however, that it is the only way to handle difficult questions that arise in areas such as genetic modification, cloning, and xenotransplantation where large numbers of people could potentially be directly affected by the technology, and where there are difficult ethical considerations to take into account. With these principles in mind, we have set up three new advisory committees, on food safety, human genetics, and agriculture and the environment, each of which includes non-scientists with expertise in areas such as ethics, law, consumer protection and the environment as well as those qualified to assess the scientific issues.

(b) *A global warning*. The repercussions of advances in science and technology, especially those emerging from a new understanding of the molecular basis of life, are so far reaching that they transcend national boundaries. Yet the lack of any international leadership on these issues has forced national governments to make their own policies, each inevitably swayed by the culturally dominant belief systems - be they ethical, political, commercial or scientific - in their own countries. The issue of international trade in genetically modified foods, for example, has already led to hostile confrontations between supporters and opponents of the technology.

Applications of biotechnology in the area of human health could lead to similar conflicts. Germline therapy, human cloning and xenotransplantation are all within the capabilities of modern biotechnology, yet each raises questions that need to be tackled through international debate. Could the use of genetically modified pigs as organ donors pose the risk of a new pandemic as previously unsuspected viruses spread through the human population? Would such use accord with the respect for all life - not solely human life - which is such a strong feature of many Eastern cultures? Should reproductive cloning be allowed, and can scientific and ethical perspectives from very different Eastern and Western cultural traditions be combined to reach a consensus on what it means to be human?

I think there is a real need to create international fora in which these matters can be discussed and guidelines agreed. We already have a model in the Intergovernmental Panel on Climate Change, which collates the expertise of over 3000 scientists from around 170 countries. This body has been highly influential in delineating world opinion on climate change, with all its variety of opinion and uncertainty, providing much of the evidence that persuaded governments to agree to control emissions of greenhouse gases at Kyoto in December 1997.

A global commercial free-for-all in biotechnology could all too easily lead to the kind of backlash already experienced by those in the GM food industry. Ultimately the benefits to human health and economic prosperity, for which scientists in universities have striven so hard, could be delayed by decades. The UK has already begun to take a lead in asking how international consultation followed by regulation can ensure that new developments are introduced in a manner that is broadly acceptable. The OECD conference on the health and safety aspects of GM foods, which takes place in Edinburgh at the end of February, is a step in the right direction.

I believe we need to do more to extend such discussions across the range of 21st century science and technology, so that we can outline international agreements on the broader questions that are already upon us, and be ready to face questions that will emerge as the century unfolds. Without preparing the ground in this way, the top-level science and technological innovation so carefully cultivated by governments may ultimately fail to bear fruit.