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THE FOUNDATION FOR SCIENCE AND TECHNOLOGY

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UK's continuing research excellence

The fifth annual Science and Innovation Investment Framework 2004-2014 report for 2009, published by the Department for Business, Innovations and Skills (BIS) at the end of November, shows that the UK remains second only to USA in worldwide scientific excellence, despite increasing competition from other countries. It is also the most efficient and productive nation for research in the G8. Key highlights include:

- the UK's continued strong performance in delivering world class, sustainable research demonstrates that recent investments in research infrastructure have paid off;
- knowledge transfer and commercialisation activities from the science base have been firmly established across the university sector and within Research Councils;
- there has been an encouraging increase in the proportion of young people reaching expected levels in science and mathematics;
- the UK's strengths in the services and creative industries – where innovation is less likely to be picked up in indicators such as R&D – mean that overall the UK's innovation performance is under-stated.

www.dius.gov.uk/science/science_funding/ten_year_framework

8,500 graduate internships available

HEFCE has called on universities to assist unemployed graduates through the economic downturn, and support employers in the Government's priority areas as part of the Backing Young Britain initiative. Higher education institutions (HEIs) are being invited to take part in the scheme, which will provide £13.6 million to support 8,500 graduate internships.

Prime Minister Gordon Brown recently announced 5,000 graduate internships available for small businesses which sit alongside 3,500 announced as part of Backing Young Britain for other priority areas. HEFCE will work with HEIs, Regional Development Agencies, Higher Education Regional Associations and the Federation of Small Businesses (FSB) to deliver graduate internships in each region.

HEFCE will provide £1,600 for each internship. Employers will also contribute funding to ensure that graduates are paid to at least the level of the minimum wage. Through this additional funding, institutions will be able to place significantly more graduates with suitable organisations in ways which provide a useful and productive experience for both the graduate and the employer. □

www.hefce.ac.uk

Scientific advice to Government

Guidelines to ensure robust scientific and engineering advice to Government are the subject of a consultation launched by the Government Office for Science. The Government says this is a long-planned consultation and runs in parallel with the exercise Science Minister Lord Drayson will be carrying out to deliver a clear set of rules of engagement for the provision of scientific advice to Government.

The consultation provides an opportunity for scientists, academics and members of the public to help revise the guidelines, last updated in 2005. These will set out the way Government departments obtain and use scientific advice and underpin the Government's commitment to evidence-based policy making.

Alongside this formal consultation, Lord Drayson will lead work with scientific advisers, the learned societies, scientists, science journalists and Government colleagues over the coming weeks to outline principles for independent scientific advice which will underpin the relationship between Government and scientists. These will be published before the end of the year and will feed into the guidelines consultation.

Government Chief Scientific Adviser Professor John Beddington said: "The provision of expert scientific advice to government is critical to ensuring that ministerial policy decisions are made in the context of the best possible science and engineering evidence. It is vitally important that the independence of scientific advice is preserved and the work announced today will help reinforce this."

The consultation will remain open until 9 February 2010. □

www.berr.gov.uk/consultations/page53603.html

Higher Education review

Lord Mandelson has appointed Lord Browne of Madingley as chair of the Independent Review of Higher Education Funding and Student Finance. The cross-party appointment signals the start of this review, with Lord Browne leading a group of independent figures drawn from academia and business to analyse the challenges and opportunities facing higher education, and their implications for student financing and support.

In assessing options the review will be expected to take into account the goal of widening participation, affordability and the desirability of a simplification of the student support system.

Lord Browne said: "The Review comes at an important time and our task is a serious one: to make recommendations to secure the vitality of Higher Education in this country while ensuring that finance does not become a barrier to those who have the ability and motivation for further study. We will be open and consultative in how we examine the issues and will set out the process for taking evidence shortly."

Lord Browne will be joined on the review panel by Michael Barber, Diane Coyle, David Eastwood, Julia King, Rajay Naik and Peter Sands.

The review will make recommendations to the Government next year on the future of fees policy and financial support for full and part-time undergraduate and postgraduate students. A report is expected in 2010. □

Engineering a climate resilient Britain

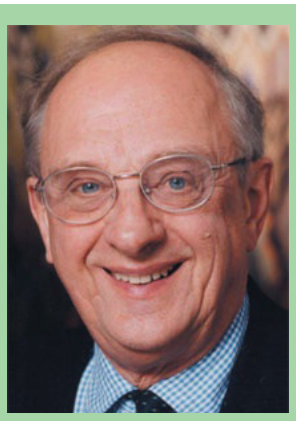
The future of a climate resilient Britain depends on the engineering sector's response to the challenge, according to Environment Secretary Hilary Benn speaking at a joint Defra and Engineering the Future conference in November.

Mr Benn called on the sector to lead the way in building Britain's future infrastructure – from transport networks to nuclear power stations to withstand the changes to our climate.

Hilary Benn said: "The floods of last month, and the collapse of bridges, show us how much a resilient infrastructure matters. Protecting ourselves against negative impacts, and also taking advantage of the benefits of a changing climate, is all part of building Britain's future. The UK's engineering sector is vital to tackling this challenge and is well-placed lead in designing and engineering climate resilient and low carbon infrastructure for global markets, as well as the UK."

Engineering the Future is a banner under which organisations from the professional engineering community are working together to promote the contribution of engineering to the UK's economy. Professor Robert Mair, Senior Vice President of the Royal Academy of Engineering said: "Resilience in the face of climate change is a challenge all engineers must rise to. Engineers can provide the solutions that will protect us from the worst effects of climate change. The challenge has never been greater for engineering." □

A climate where curiosity can flourish



Professor Sir John Enderby CBE FRS is the Editor of FST Journal. He was Professor of Physics at Bristol University from 1976 to 1996. He was elected a Fellow of the Royal Society in 1985 for his pioneering studies into the structure and properties of liquids and amorphous materials. He served as Vice-President of the Royal Society from 1999-2004 and was responsible for publishing. Sir John was President of the Institute of Physics in 2004. He is Chief Scientist at Institute of Physics Publishing.

I count myself lucky to have known John Maddox, most notably through his membership of the Royal Society Dining Club. At our meetings, he always had something interesting to say and his essential humanity, beautifully captured by Charles Wenz's obituary in the last issue, was apparent to all present. I feel deeply honoured to follow John in his editorial work for the Journal.

John had a deep appreciation of history and it is from such a perspective that I wish, in my first Editorial, to address a perennial issue and one that has often formed that subject of discussion meetings here at the Foundation. For every pound spent on scientific research by the State, how many pounds accrue in economic benefit? Economists have never, to my knowledge, reached a consensus, with estimates for the benefits varying from zero to factors of ten! The point is that one is dealing with differences of large numbers, so assumptions made about true costs of research on the one hand, and benefit attribution in cash terms on the other, can lead to widely divergent answers.

The lesson of history

Instead, let us go back in history and look at my favourite year, 1642. It was the year that Isaac Newton was born, arguably the greatest scientist ever to have lived. 1642 was also the year in which Galileo died, having narrowly escaped execution for suggesting that the earth was not the centre of the Universe. It was also the year that no less a figure than the Vice-Chancellor of Cambridge had worked out precisely the year, month, day and time when Adam was created. Charles I, who believed in the divine right of Kings, was still on the throne (just). In short, Newton was born into a world where superstition, excessive deference to established authority and dogma were the norms. By the time he had died in 1721, the scientific method as we now know it – and which has guided all subsequent developments in science, engineering and medicine – was hard-wired into intellectual life.

The extraordinary results of this revolution are plain for all to see. For example, life expectancy has changed from the low thirties in the 18th Century to mid-seventies and beyond today. How did this amazing revolution occur in such a short time span?

When one reads the letters, diaries and other writings of Newton and his contemporaries, one is struck by how driven they were by curiosity. This was not idle curiosity, but curiosity embedded in rigorous experimentation and theory. Nevertheless, it was curiosity and with this in mind, let us fast forward to today. DNA fingerprinting has transformed forensic science and only a few weeks ago exonerated a man who had served many years in prison for a murder he did not commit. Sir Alec Jeffries was driven not by the needs of forensic science, but an intense curiosity about the unique character of highly variable and repeatable patterns in human DNA. I cannot imagine that when Sir Tim Berners-Lee proposed a novel way to link experimenters working on high energy physics, he had any idea how the web would transform the social, economic and business life of the 21st century.

Curiosity, tempered and informed by rigorous and outstanding science, is the hallmark of those innovators whose work eventually impacts on thought and transforms current practice that ultimately leads to social and economic benefits.

The challenge

The challenge facing those responsible for science policy is how to maintain and enhance an intellectual climate in which curiosity can flourish. This is a theme to which we shall doubtless return in future discussion evenings. At the very least, those in authority must internalise the importance of curiosity-driven research. By 'internalise', I mean testing every proposal for 'reform' by asking: will this proposal actually help successors to the likes of Alex Jeffries, Tim Berners-Lee and Peter Mansfield? Such a test will, over the next few months, become of increasing importance as research budgets are squeezed. □

Presentations from the events held by the Foundation for Science and Technology can be found on the Foundation's website at: www.foundation.org.uk

The Government launched its new framework for Higher Education on 3 November 2009.

Higher Ambitions for education

The Government framework, set out in a document entitled *Higher Ambitions*, sets out a strategy which aims to ensure that universities remain world class, that the nation has the high level skills needed to remain competitive, and that the UK continues to attract the brightest students and researchers.

The document notes that "in a knowledge economy, universities are the most important mechanism we have for generating and preserving, disseminating, and transforming knowledge into wider social and economic benefits. They are crucial, too, as the providers of life chances for individuals in an environment where skills and the ability to apply those skills are essential preconditions for employment."

It adds that the demand for higher education continues to grow but our participation rate, though improved over the last decade, is still below that of many other developed economies. Access to higher education remains significantly correlated with parental income and wealth. Too many people with the ability to benefit from higher education are still not entering the system.

Meeting these challenges is made all the more important, says the strategy, by the current economic circumstances and the need to renew our economic base. Universities have a vital role to play in that process. But the constraints on public finances will make it impossible to sustain the growth in public spending on universities seen over the last decade.

Among the key measures proposed in the strategy are:

- more competition between universities, giving greater priority to programmes that meet the need for high level skills;
- business to be more engaged in the funding and design of programmes, sponsorship of students, and work placements;
- the creation of more part-time, work-based and foundation degrees to make it easier for adults to go to universities, with routes from apprenticeships through to Foundation Degrees and other vocational programmes;
- the encouragement of universities to consider contextual data in admissions, as one way of ensuring that higher education is available to all young people who have the ability to benefit;
- a requirement for universities to set out clearly what students can expect in terms of the nature and quality of courses offered;
- a continuing focus on excellence in order to sustain our world class research base, concentrating research funding where needed to secure critical mass and impact;
- encouraging collaboration between universities on world class research, especially in high cost science.

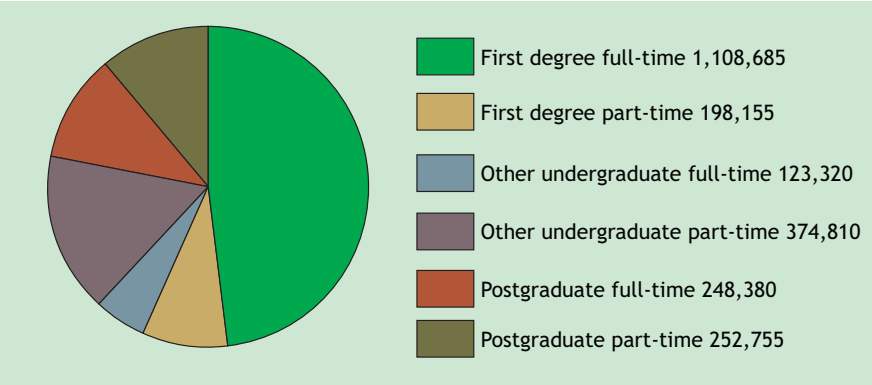


Figure 1. Student numbers by mode and level of study.

Announcing the strategy in the House of Lords, Lord Mandelson said: "Able people and bright ideas are the foundation stones of a thriving knowledge economy and in the next 10 years we will want more, not fewer, people in higher education and more, not less, quality research.

"We have made great progress in the number of young people going to university at 18 or 19 to do a three year degree. But the challenge for the next decade is to offer a wider range of new study opportunities – part-time, work-based, foundation degrees and studying whilst at home – to a greater range of people. All students must continue to enter higher education on their merit. But I believe this means taking account of a student's academic attainment, their aptitude and their potential. Many universities are already developing their use of contextual data in admissions and we hope that all universities will look at their examples and consider incorporating such data in their admissions processes."

The Government wants universities to make an even bigger contribution to Britain's economic recovery and future growth. It is therefore proposing to give greater priority to programmes that meet the need for high level skills, especially in key areas such as science, technology, engineering and maths. The strategy also foresees a greater element of competition between universities for new contestable funding as an incentive to fulfil this priority. The Government says it will – with employers and universities – identify where the supply of graduates is not meeting demand for key skills. And it says it will seek to re-balance this, by asking HEFCE to prioritise the courses and subjects which match these skills needs.

The Government also wants business to be more active partners with universities. The strategy says that employers need to be "to be fully engaged in the funding and design of university programmes, the sponsorship of students, and offering work placements".

"In the decade ahead we will expect more from our universities than ever before," said Lord Mandelson. "They will need to use their resources more effectively, reach out to a wider range of potential students and devise new sources of income, at the same time as they maintain teaching and research excellence."

The Department for Business, Innovation and Skills has also announced that Sir Martin Harris, the Director for Fair Access, will consult with Vice-Chancellors and provide the Government with a report on what further action could be taken to widen access to highly selective universities for those from under-privileged backgrounds. Announcing this, Lord Mandelson commented: "Wider and fairer access to university is a question of basic social justice and it is right that able students with the talent and ability to attend highly selective universities are given a fair chance to do so, regardless of where they live or the school they attend." □

www.bis.gov.uk/policies/higher-ambitions

The Higher Education sector has received substantial funding support from Government over the last decade. But over the coming years, more focus and prioritisation may have to take place. What those priorities should be was the subject of a meeting of the Foundation on 17 June 2009.

The future of Higher Education in England

Alan Langlands

I was reassured by the acknowledgement of the Secretary of State for Business, Innovation and Skills (BIS) that universities and colleges are "as much about the cultural bedrock of our society as the competitiveness of the economy". He has also been quick to acknowledge the centrality of a high degree of autonomy to the success of universities, the importance of the dual support system of research funding and the importance of spreading the opportunity and social mobility that comes through higher education.

I certainly believe it is possible to combine higher education and research with the knowledge and skills which are required to help the professions, businesses and public services innovate and prosper. I would argue that the broad base of research undertaken in our universities has relevance and impact.

The total turnover of our universities now exceeds £20 billion. There are about two million students studying in England and by all international comparators – research impact, trade and overseas recruitment – we continue to do well.

Strong investment in recent years – coupled with the Government's long-term commitment to sciences and publicly-funded research, as well as the introduction of variable fees – has enabled UK universities to maintain their international competitiveness whilst supporting the policy of widening participation. There are significant risks on the horizon, however, which must be taken seriously. These arise from:

- intense competition from the United States, China and India, improvements in European universities and the continued development of city states such as Abu Dhabi and Singapore which are investing heavily in education and research;
- reductions in the growth of public spending – with spending set to increase by only 0.7 per cent per annum in real terms from 2011 to 2014. This effect could be exacerbated by further pressure on the student support budget and any delays in resolving the outcome of the review of student fees;
- threats to university income resulting from cuts in other areas of public spending (e.g. in the NHS, teacher training and the RDAs), cost pressures (e.g. in relation to National Insurance, pensions and banking charges) and fluctuations in the financial and property markets affecting endowment funds and estates rationalisation programmes.

Sir Alan Langlands is the Chief Executive of the Higher Education Funding Council for England (HEFCE). He was formerly the Principal and Vice-Chancellor of the University of Dundee and Chief Executive of the NHS in England. He chairs the boards of UK Biobank and the Health Foundation, a UK-wide charity committed to improving the quality of healthcare. Sir Alan is also a co-opted member of the Office for the Strategic Coordination of Health Research.

At the end of 2007-08, the higher education sector had strong cash balances and healthy reserves, but these are being eroded by cost pressures and the recent budget announcement, which reduced recurrent funding by £263 million for 2010-11. Some universities and colleges will only manage to get through the next three or four years by reducing costs and jobs and developing new ways of working. The budget changes represent 4.64 per cent less funding for teaching, and just under 1 per cent less for research when compared to the projections of the 2007 Comprehensive Spending Review. So how do we respond?

In the shorter term

If the international standing of Higher Education is to be maintained through this period of financial restraint, a clear decision will have to be taken about the relative priority to be given to public investment in universities. The review of variable fees and student support funding also needs to be completed in time for implementation in 2011-12. Even then, some explicit choices may have to be made between protecting the quality of education and research, overall student numbers and levels of participation, and the pursuit of new initiatives. Doing fewer things better may be a perfectly sensible strategy for the future.

If the reputation of higher education is to be maintained, action is also required to ensure that the quality of learning and teaching is maintained in the future and that steps are taken to preserve research

DISCUSSION

Concentration or diversity?

If research excellence is focussed on too small a number of universities, the scope for desirable research-led education for undergraduates will suffer. Yet perhaps a policy of widening participation in higher education has led to a decline in quality and an undesirable attempt to have degree level studies in fields which are not appropriate? It is wrong to expect universities to produce graduates tailored to the needs of particular jobs - employers had to take responsibility for job-specific training. It should be remembered though that vocational education is cheaper than university education and politicians could decide to move away from the 50 per cent target for universities.

excellence.

The quality and standards achieved in Higher Education have been in the spotlight over the past year. A high level sub-committee of HEFCE has found no evidence of systemic failure in the present arrangements, but some improvements need to be made. For example, action is required to ensure that:

- the Quality Assurance Agency (QAA) has a more public-facing remit, one that reassures the non-expert while encompassing a more flexible approach in its audit methodologies;
- applicants, students, parents and employers have ready access to information about programmes of study and what is expected of students who undertake these programmes;
- the external examiner system (a key part of the system of self-regulation and peer review at institutional level) is formalised, perhaps through more training or a mandatory code of practice.

The plurality of funding for higher education research, from public and other sources, is a major strength of the UK system. HEFCE funding, as one leg of the dual-support system, enables institutions to maintain a dynamic and responsive research base of world-leading quality. This enables ground-breaking basic research, with the potential to drive future innovation and respond quickly to changes in the external environment. Challenges include:

- maintaining the balance between funding for curiosity-driven research and for work targeted on identified national needs and priorities;
- developing a new research quality assessment framework – the Research Excellence Framework (REF) – in a form that recognises and rewards excellence of all kinds, across the full spectrum of disciplines and types of research activity;
- continuing to develop the infrastructure and human capital required to support research excellence, inward investment and industry collaborations.

It important to avoid a narrow interpretation of the current research strategy. The place of curiosity-driven research is secure and, in all the talk of lifesciences, low carbon technologies, Digital Britain and advanced manufacturing methods, we need people who are thinking deeply about bioethics, the regulation of energy markets, the psychology of human/computer interaction and the importance of design.

The longer term

Recent changes in the structure and priorities of Higher Education have largely been achieved through additional investment. For example, the Strategic Development Fund, set up in 2003, has provided £656 million for a wide range of projects including: the realignment of college and university activity in Cornwall; the merger of the University of Manchester and UMIST; and the development of university centres in communities with no previous provision. There has also been a £3.7 billion investment in research infrastructure in the last four spending reviews 2002-2011, leveraging additional resources from industry and the charitable sector.

Faced with the prospect of intense international competition, sustained reductions in public spending and significant cost pressures at institutional level, it seems likely that the strong progress being made by the Government and HEFCE will be at risk over the longer term. We will have to strike a new balance between public expenditure and student contributions, develop a sustainable system of student support and, even allowing for some further improvements in efficiency, recognise that there may have to be trade-offs between volume and quality.

The HE Framework can be a vehicle for these short- and long-term responses. I hope that it will go with the grain of the work currently being undertaken in universities and, whilst recognising the need to make best use of existing resources, that it will support advances in the quality and flexibility of educational provision, that it will be even more responsive to students and to the opportunities of new research collaborations.

In the clamour to deal with the short-term financial pressures facing the universities and colleges and the implementation of detailed elements of the Framework, it will be important not to lose sight of the cliff-edge facing public spending and the difficult policy choices that this is likely to pose. The review of fees and student support will set the scene for a much more important discussion about the future.

The Government has delivered sustained investment and universities and colleges have used this money wisely for the public good. Many of the people who work in our universities are fizzing with ideas and it is important that we build on their enthusiasm – to ensure that we have the high-level skills and the research base we need for long-term economic success, and that universities maintain their essential character. □

Maintaining our position in the world

Michael Arthur

As Chair of the Russell Group I wish to make the case for research-led education and international research excellence. I think the future is bright, if somewhat more complicated than a year ago. My focus, though, is on our future in a global system.

When I travel internationally there are three main things that people in other countries envy about our Higher Education system. First is our international excellence; our performance and our impact on a global scale.

The second is our institutional support of creativity; they are surprised and amazed at how well we do in terms of the ideas and knowledge we generate given the level of funding for our system. The third is the creativity and skills of our graduates.

The rationale for focussing on these three issues is that, in my opinion, they lie absolutely at the heart, the very core, of the future of HE in this country.

International excellence

Our Higher Education system is ranked second in the world to the USA. We are a highly attractive destination for international students. With just one per cent of global population, we produce 7. 9 per cent of world research publications and we account for 12 per cent of all citations and 14.4 per cent of the most highly cited papers (top 1 per cent). In terms of cita-

tion impact – in other words looking a little more at their importance and quality, rather than just the volume – the UK is ahead of the USA in health, biology, environment and physical sciences.

We are one of the highest performing sectors in the UK. This has not always been the case. We have certainly improved dramatically over the last 15 to 20 years, since we concentrated research funding in our top performing universities via the Research Assessment Exercise (RAE). Other nations, including China, Australia, Germany and France, are now attempting to emulate our approach.

However, in the UK things have also changed. After RAE 2001, 75 per cent of all research funding from the Government was concentrated in the top 24 universities. After RAE 2008, that proportion of funding was spread across the top 28. That is going in the opposite direction from our international competitors. With the removal of thresholds of international excellence that informed stepwise increases in funding, some £70 million was directed away from the Russell Group and the 94 Group universities into other HE institutions. I would suggest that this is a long-term mistake. This change in RAE methodology also led to an essential protection of funding for STEM subjects (Science, Technology, Engineering and Mathematics): yet this was at the cost of other subjects, particularly, but not exclusively, the social sciences.

Let me highlight one practical example from the University of Leeds. Our School of Social Sciences and Social Policy is ranked fifth overall in the UK. We increased the volume of research submitted by 59 per cent between 2001 and 2008, but the Quality of Research income has dropped by £250,000 over our next planning period. The amount of money per active researcher in that School has fallen from £37,000 per annum to just £24,000 per annum. In the social sciences and humanities, our international competitiveness is already threatened.

Professor Michael Arthur is Vice-Chancellor of the University of Leeds and Chair of the Russell Group of 20 research-intensive universities. The Government appointed him DCSF Champion for the 14-19 reform programme, and in 2008, he became both a board member of the Qualifications and Curriculum Authority and a US/UK Fulbright Commissioner. He is a member of the Council of the Medical Research Council.

These observations should precipitate a discussion about strategic research policy at a national level: we should be clear about the importance of critical mass and research concentration in driving research excellence and the international competitiveness of our research base.

Institutional support of creativity

In looking at institutional support of creativity and its relationship to dual funding, I will again use the University of Leeds as an example. We are striving to produce outstanding graduates and scholars and to conduct research that has impact on a global scale. We have set up a 'transformation fund' to which staff can apply with ideas that will lift their subject area and our university into a different place. Helped by our dual-funding system, we have created a strategic fund of £4 million per year (and will be increasing that to £7 million per year) to invest in innovative, largely interdisciplinary research ideas with the potential for global impact.

To give you some examples, we have a particular emphasis, in biomedicine and health, on diagnostic devices and medical engineering. Another area is food security and human health, where we are aiming to combat global food shortages. Some of this activity is at the basic research end of the spectrum, but much is focussed on being of direct value to industry and society, ready to fuel innovation and create value for the economy.

I believe that such institutional support of creativity is fundamentally important to the future of HE in our country. It is vital to our relationship with business and industry in helping to drive the UK economy. We must protect science funding for both basic research as well as for applied activity.

Graduates

At Leeds, and I am sure this is true of other Russell Group and research-intensive universities, we aim to inspire our students and lift them to a level that they did not think they were capable of, by concentrating on the relationship between research and education.

For us, importantly, this means involving students in the research process itself. This is not achieved through simply being taught by people who are themselves researchers. We like to get our students actively engaged in research as early as the first day of their course. We want them to understand how knowledge is created, we want them to get used to the fact that knowledge changes all the time. We want them to have the thrill of creating knowledge themselves; we want them to learn how to handle the uncertainty that goes with this process.

We aim to create rounded individuals who are, themselves, capable of becoming the leaders of the future – and certainly individuals who are of value to industry, to the public, the Government and the voluntary sector.

The future

The future of higher education in the UK will be best served if we concentrate research funds appropriately. We must debate and then decide how tight that concentration should be. We must create and maintain an environment that allows institutions to be supportive of creativity and we must link this to research that is of value to civil society and to business, industry and innovation. I would put our dual funding system at the heart of that. And finally, we should recognise and acknowledge the real long-term benefit of a research-led education. The real issue is how we achieve that for as many students in the country as possible in a tight fiscal regime.

Quite simply, we must; our Government must continue to invest in higher education in the UK if we are to retain our international competitiveness and help our country out of recession. ☐

DISCUSSION

Maintaining high standards

How to ensure that the quality of teaching remains high? On the whole, the present mechanisms seem to be working reasonably well but more use could be made of professional bodies whose influence on university education can be very beneficial. Some isolated areas do exist where there are problems, though, and a well-publicised failure can attract disproportionate and highly damaging consequences. Experience in recent years in other fields has shown how quickly loss of autonomy or respect for self-regulation evaporates in the wake of failure. The risk of such political and public reaction is all the higher at a time of financial stringency.

Higher Education — a business viewpoint

John Chisolm

I want to look particularly at the relationship between universities and business. What do companies want from universities? From talking to many fellow industrialists, I would suggest five themes:

- graduates and postgraduates with excellent subject skills;
- graduates who have life skills such as self-motivation, social poise, networking and knowledge-gathering skills;
- flexible continuing education;
- new knowledge that provides a basis for innovation;
- a focus for clusters where innovative activity can take place.

There was a survey carried out by Prospects.ac.uk in 2007 which looked at what people were doing six months after graduating.

Amongst those actually earning, 'traditional jobs' are the ones which we all know about – being scientists or engineers or lawyers or teaching – what many used to think university was about. These people account for about 7 per cent of the total.

Then there are 'modern' jobs – things like computer programming, being a dealer in the city, or indeed joining a management training scheme. But graduates also go into the 'new' jobs across the service sector, becoming salesmen, hoteliers or physiotherapists. There are 'niche' jobs – nurses, sports trainers. There are a whole bunch of graduates who choose 'non-graduate' jobs – being a PA, for example. Finally, there are the 'non-earning' group which comprises those still in education and those doing voluntary work as well those who are unemployed.

That is today's reality. Universities produce people who go out into a very, very mixed community. We have to think how we best educate our people for this world.

We have been living in a 'golden era', certainly uniquely in my experience, of having a Government that has gone out of its way to fund the HE sector – and that is certainly not something we can count on for the future.

Now while companies want educated people from the HE sector, within the sector itself the focus is on academic excellence. At the individual level, career progression, peer esteem and promotion are all centred around academic excellence. At the institutional level, core funding is actually volume directed, but those things that are variable – such as Quality of Research funding – are excellence-directed. So it is not surprising that institutions focus their strategies on demonstrating excellence. The Shanghai Ratings show that we have two universities in the top 10, four in the top 30, 10 in the top 100, which compares to just 23 in the whole of the rest of Europe.

Sir John Chisholm FREng FIEE became Chairman of the MRC in October 2006. Sir John brought together the UK Defence Research Establishments which, in July 2001 became QinetiQ, of which he is now Chairman. Sir John was a founder member of the UK Government's Technology Foresight programme and he is Chairman of the National Endowment for Science, Technology and the Arts (NESTA).

From that point of view we have a university system which works very well. Yet we also need a diverse HE sector for all users. Now there is no conflict between diversity and excellence, in my mind. Raymond Blanc and McDonalds are both in the food business, and are both excellent – but in different aspects of the job. They both serve their markets extraordinarily well. So we need diversity within the HE sector which serves the diversity we have in the economy today.

Now in any market, you expect providers to focus on niches where they can be excellent. You would not expect to find a market in which all providers aim for one part of it – and only serve the other parts by accident. I looked at the funding of various universities. I am a strong believer in the 'follow the money' principle. In life generally, if you look at the money flows, you will discover the core motivation. I looked at universities in North America and in the UK: I compared Cambridge with Harvard, both about the same place in the Shanghai table, and Birmingham with Indiana College at Bloomington, both about 90 in the Shanghai table. What struck me was that Cambridge and Birmingham had a very similar revenue pattern, whereas Harvard and Bloomington had very different ones. That plays to my point that diversity is a good thing.

So, what is the best way to encourage the necessary diversity in the HE sector, without compromising the excellence we are rightly so proud of? Well we could go for the central planning route – we could ask HEFCE to be ever more inventive in its distribution algorithms. Or could we, perhaps, take a different approach?

The market approach

Could we take a more market-orientated approach? In most markets, the product is not designed; independent providers in a competitive arena focus on niches where they can be excellent – that is how markets evolve. This has proved to be the most efficient way of allocating resources in most communities and most markets. So to encourage a similar variety of excellent participants in HE markets, we might consider concentrating research income on truly excellent institutions and teams.

We could make student users more important through a variable fee structure so the market operates more fluidly. We could channel more money to the students and stimulate what used to be an excellent arrangement – industrial scholarship. It has a great benefit in that it provides students with extra money and also a line of sight to what they can productively do with their lives afterwards.

Finally, I believe there would be great benefit in stimulating an endowment culture. This not only promotes a 'giving' culture but more importantly provides 'free' resources. When I say 'free' I mean 'useable' resources for universities to use in the way they think they should in order to pursue an independent strategy of their own. The idea of universities operating, as far as possible, as independent organisations, making up their own strategies, pursuing their own ends in the market in order to create the most diverse and excellent market – that is where I think companies would really like to see universities going. □

How can we use technological innovation to deliver the carbon savings in the transport sector that will be necessary to meet our climate change commitments? The subject was debated at a 0meeting of the Foundation for Science and Technology on 29 April 2009.

Understanding the full picture

Brian Collins

We have to consider a complex set of interactions between social, technical, economic and political processes if we are to accelerate the reduction of carbon emissions from transport. We need to understand the impact of policy decisions about transport and energy on other sectors of the infrastructure, such as water, food (the connection here of course is biofuels) and waste. We are undertaking a project now to try and understand how reducing emissions from transport would impact on this complex set of relationships.

Professor Brian Collins FREng FIET is Chief Scientific Adviser (CSA) for the Department for Transport and also for the Department for Business, Innovation and Skills (BIS). Professor Collins has a special interest in the exploitation of information in modernising national infrastructure, particularly in transport and energy. He is Professor of Information Systems at Cranfield University.

Current emissions

In 2006, emissions from the transport sector constituted 22 per cent of that from all sectors excluding aviation. This is the third biggest after commercial and domestic energy emissions. Within the ground-based transport sector, cars and motorcycles together with road freight account for a substantial fraction of emissions. That means we have to target these modes in the transport sector itself.

If we then want to know how we can reduce the emissions of cars, we need to understand how they are used. A 2002-6 analysis from the Department for Transport shows that, for commuting purposes, most trips are less than 25 miles. A large number of business trips are much longer than that, while the rest are quite evenly scattered in terms of length.

From a policy point of view, we have to understand the interventions needed to give us the reductions that we seek, either as cross-cutting measures or at different scales – national/international, regional/local, and in cities in particular.

We can illustrate this differently by looking at CO_2 emissions as a function of the journey length. While 34 per cent of the total trips in the UK are between two and five miles, they contribute only 15 per cent of the carbon dioxide. Most of the CO_2 comes from the journeys that are up to 50 miles and a further 20 percent or more comes from journeys that are longer than that. It is interesting to see where the balance lies between the frequency of journeys and the emission density of CO_2, because it is somewhat counter-intuitive. That will affect where we put our investment in innovation.

Road map

Having done this analysis, a number of UK Government Departments have developed a road-map to the achievement of sustainable, low-carbon road transport. With industry and academia, we see considerable advantage (and it goes on for quite some time because of the maturity of the market), in further developments in internal combustion engines, in transmission systems and in the use of renewable fuels.

We need greater market penetration by hybrid vehicles, as well as breakthroughs in energy storage – batteries and, later, fuel cells – in order to achieve mass-market electric vehicles. That looks to us to be the only way to deliver the sorts of targets that we expect to agree in Copenhagen at the end of the year, so we have to kick-start this market, recognising that in the short term we will have a 'mixed mode' with hybrids and improved internal combustion engines.

Each country will have a different mix because each is starting from a different baseline. We have different journey types, social habits and geographical scales, so no one size will fit all.

The fuel market, though, is a global market. We must ensure that we maintain our continuity of investment and scrutiny in these areas of technology development because this 'transitional stage' will last about four decades. That sustained investment will be quite difficult to achieve politically and we have to do it globally as well. It is a challenge for the science and engineering community as well as the investment community and our politicians. We have to stay together on it.

One current popular mantra is 'behavioural change' – understanding what will make people change the way they live. The Government is trying to understand the barriers and motivators to overall change and what causes them to occur swiftly, in particular with regard to journey choices. How people choose between different transport options is pretty important.

We need to get people thinking about climate change and the impact of journeys. Do they have any information at the

DISCUSSION

Policy and regulation

Policies need to be consistent, long term, technology-neutral and market-based. Much can be done through tighter regulation and a greater focus on driver performance. But the danger is that such regulatory activity could affect other values (such as the cost of time) and impact on individual systems. Systems engineering and much better data on the impact of policies should underpin any regulatory activity. There is a doubt whether the necessary data will be available quickly enough and our systems engineering capabilities sufficient to feed into new regulations which are needed now if 2020 and 2050 targets are to be met. However, this does not mean we should not attempt to change regulations if new conditions show current practice is out of date.

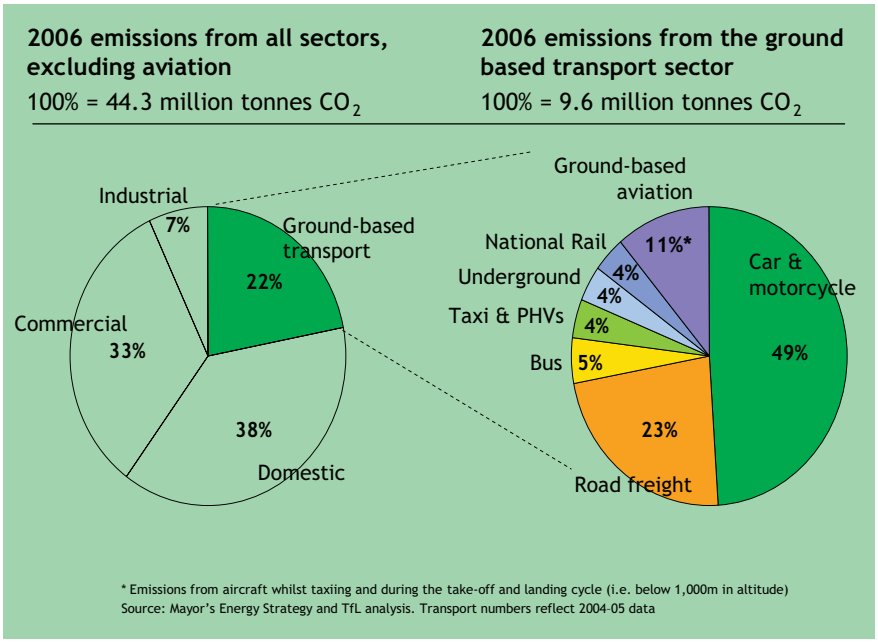


Figure 1. CO_2 emissions from UK transport sectors.

moment that helps them to do that? We are working to give them better information, but it is not yet extensive enough, it is not accurate enough, it is not timely enough. Helping them understand the trends is particularly important. The role of information in increasing public awareness of these issues is crucial.

Innovation is not only about technology and science and engineering. It is also about being innovative in understanding people's behaviour.

Challenges

While much of the developing transport policy is situated in a renewable energy context, if we do not deliver renewable energy in time, electric vehicles may not provide a solution: all we would do is displace carbon dioxide emissions into the energy domain. Now we have got a great deal of technology for renewable energy, but do we have the systems engineering capability or capacity to deliver enough of it in time to provide the amounts of energy we are going to need to power electric transportation?

We have many routes that we could pursue in terms of transport innovation: better internal combustion engines, use of biofuels, hybrids, electric vehicles. Just at the moment we lack the funds to do all of them at once. We must choose what we do and when. We need to ask whether we have the data and the metrics for understanding our innovative processes sufficiently well to know we are making the right choices. Which options should we prioritise and which should we put to one side, at least for now?

Some of these processes under consideration need to be done at industrial scale and that means we need financial models for investment in projects that are intrinsically risky. At the moment the appetite for risk is rock-bottom: this could not have come at a worse time. Yet somehow we have to persevere because the climate change clock is ticking away. So we have to understand how to generate investment for innovation in this sector.

Last, but by no means least, we have the challenge of incentivising people to travel less and to be more energy-efficient, while still somehow maintaining the quality of life that we have all grown up to expect. That is as much in the realm of politics as in the sphere of science and technology: they are all coupled together. ☐

The three-legged stool of transportation reform

Dan Sperling

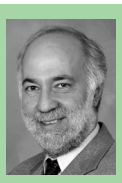
The easy way to think about the challenge of transportation reform is that we have the vehicles, the fuels and the mobility. Think of this as the three legs of a stool. I would suggest that transforming vehicles is turning out to be the easiest, transforming fuels is harder and transforming mobility is by far the hardest. I will focus on the first two, but I will address the third.

Vehicles and fuels

It is forecast that we will have, globally, two billion vehicles by 2020: cars, trucks, buses, cycles and scooters. There is no way we can reduce emissions from existing vehicles and fuel by 50 or 80 per cent by 2050 with existing technology. So we really are talking about new types of vehicles, new types of fuel and new ways of moving around.

The principal long-term energy options for vehicles are biofuels, electricity and hydrogen. For now, though, efficiency is the real winner. This is the technological innovation that will provide large near-term returns, is highly cost-effective, and can (and should) be done over the next few decades.

Some non-petroleum fuels are much better than others as far as their greenhouse gas emissions go, and thus we must become much more sophisticated about policy. A biofuel mandate, for instance, is a bad idea because it does not distinguish between the high-carbon and low-carbon options. Both the



Professor Dan Sperling is Director, Institute of Transportation Studies, University of California, Davis, USA. He is a leading international expert on transportation technology assessment, energy and environmental aspects of transportation, and transportation policy. He chaired the Davos World Economic Forum's Council on 'The Future of Mobility', is a former chair of the US Transportation Research Board's standing committees on Sustainable Transportation and Alternative Fuels, current board member of the California Air Resources Board, and co-author of the book *Two Billion Cars.*

EU and the USA have opted for such a mandate. In both cases, those mandates should be converted to performance-based policies. The EU and USA are both moving in that direction, but very slowly.

Unfortunately, governments and the media often seize upon single solutions: the 'technology du jour' or the 'fuel du jour'. For the USA 30 years ago, this was synthetic fossil fuel (tar sands, heavy oils, coal liquids, oil shale). In the 1980s, we focused on methanol, in the 1990s on battery electric vehicles, in the early years of this decade on hydrogen. Then two years ago it was ethanol, and today it is plug-in hybrids and electric vehicles more generally. What is going to be next? Without strong policy, we will start all over again with the synfuels (now known as unconventional oil).

DISCUSSION

Emissions sources and business inaction

Private vehicle use is not the only king of transport that causes CO_2 emissions. Buses, trains, ships and aircraft also play a part. It is too easy to suggest that public transport can take the place of the car: lightly-loaded buses and trains are just as damaging for emissions. Aircraft only account for a small fraction of emissions, but failure to take action to restrain them is a significant factor in the public mind. Alas, the international politics surrounding air travel make changes in this area very difficult. There is also concern that companies have still not factored into their thinking the environmental changes that global warming will bring about, nor understood the environmental issues facing us. Business schools do not always include environmental issues in their curriculum, and hence graduates do not see how company behaviour can affect behavioural change nor focus on adaptation to environmental challenges.

Picking winners

There is merit in keeping the Government away from the temptation of picking winners. I am a member of the California Air Resources Board, which is the agency responsible for administering the climate policies for the state. We have recently adopted a low-carbon fuel standard which gives oil refineries a performance target of a 10 per cent reduction in carbon intensity by 2020 for transportation fuels. The EU is moving in that direction with the Fuel Quality Directive in its renewable energy programme.

This is good policy. It harnesses market forces by creating tradable credits, is performance-based, does not pick winners and is robust.

I want to highlight the use of information technologies in the transportation sector. We can achieve transformational change using IT. We can use it for smart services, where a vehicle can come and pick you up at your home or your office and take you where you are going. You can call from your mobile phone or the internet. You can develop a smart car-pooling, ride-sharing service. This suits the behaviour of the generation that is now moving into car-owning and transportation adulthood.

The California model

California passed a law in 2006 that requires the state to reduce greenhouse gas emissions to 1990 levels by 2020. In some ways that is not as aggressive as Europe's target, but it is very aggressive for us because we have high population growth. This represents roughly a 30 per cent reduction from business as usual, to be implemented over a 10 year time period. Plus, we have an 80 per cent reduction goal for 2050.

The California model involves the development of policies and rules that could (and hopefully will) be adopted elsewhere. We strive to make sure that everything we do is compatible and consistent with what others do, or might do. One important difference between California and others is that cap-and-trade plays a relatively small role, at least through to 2020.

Only about 20 per cent of the reduction targeted for 2020 will come from cap-and-trade. The rest will come from a whole suite of distinct policies and instruments: requirements on electricity utilities to use renewable energy; energy efficiency standards; low-carbon fuel standards; and so on. The cap-and-trade programme is really an umbrella over the whole process, but not the main policy instrument.

The complementary policies for transportation target vehicles, fuels and vehicle use. We even have a revolutionary law enacted in 2008 to reduce vehicle kilometres travelled. The law imposes a carbon cap on each metropolitan region, leaving it to local governments to determine how to achieve these reductions – through controls on urban sprawl, expansion of public transportation, pricing, and whatever else they might dream up.

Most fundamentally, in California we believe that if we innovate, if we develop new technologies to reduce greenhouse gases and carbon, we will be successful economically as well as environmentally.

In closing I will quote Woody Allen: "We stand at a crossroads. One path leads to despair, the other to destruction. Let's hope we choose wisely." I must say that I am much more optimistic than Woody Allen. Certainly there is reason to be pessimistic. But humans are highly creative. When we focus our resources and capabilities, we find a way forward. Let us hope it does not take us too long to become committed to a sustainable planet. □

DISCUSSION

Regulating public behaviour

Some research suggests that early regulatory action on the demand side – such as behaviour, speed or shopping patterns – would be acceptable to the public. California has a 30 miles per hour speed limit; why not the UK? But should governments play a role in altering behaviour? And anyway, if people cannot see that regulation or innovatory practices are to their advantage quickly, or that they apply internationally, politicians may be reluctant to act. Public perception of regulation is negative; it restricts freedom without delivering compensatory benefits. Low carbon use should be fostered by emphasising benefits – for example, free parking and priority use of motorway lanes – rather than by taxing or penalising high carbon drivers. Such changes must also be preceded by full dissemination of information to the public and full research and debate.

Reducing carbon emissions from transport

Neville Jackson

I want to look at several issues. First, what are our low carbon options? Second, what are the difficulties in technology selection and how do we know what the answer is? Then I want to consider electric vehicles – how can we make electric vehicles work and where are they best suited? I will then move onto long-term vision and road map, where we see technology moving over the next 30 to 40 years. From a UK perspective, what are our opportunities? We are a small country working in a big global market. What can we expect to do? I will end with three key messages.

Professor Neville Jackson is Group Technical Director, Ricardo plc, a global independent technology provider and strategic consultant to the world's automotive and associated industries. He is also a visiting Professor at the University of Brighton, Vice Chairman of the European Automotive Research Partners Association based in Brussels, and a member of the European Council for Automotive Research programme review board.

The options

There are many technical options for reducing vehicle CO_2 emissions. First of all, we can improve the vehicles' energy efficiency with combustion-engine/battery hybrids, alternative ways of storing energy, downsized combustion engines, next generation combustion engines with heat recovery, and we can make vehicles lighter.

The alternative strategy (in fact we should follow both) is to reduce the carbon in fuel. Possibilities here include second and third generation biofuels, hydrogen fuel cells (as long as we get the low carbon hydrogen), natural gas and biogas, and the plug-in hybrid option where we can use part of our energy from the grid. All of these technologies have challenges and there are no clear winners. We are likely to need all of these; there is no single, simple solution. We should beware of jumping from one favourite solution to the next.

So, being realistic, what can we do?

As far as plug-in hybrids goes, the challenge we have is the cost of the battery. At the moment we have not even attained £800 per kWh, although in the long term we hope to achieve £400 per kWh. If we have just a 10-mile range that will use 80 per cent of the total capacity of the battery, the battery will probably cost between £1,000-£2,000. If we want a 40 mile range, though, we are talking about anything between £8,000 and £16,000 just for the battery pack. This is a big challenge.

These electric vehicles will be expensive. One alternative is to sell people the car and then lease them the battery. The total cost of ownership then becomes closer to a conventional vehicle, although this is highly dependent on the price of petrol and diesel. If these remain inexpensive, it makes the economic challenge greater.

A fuel tank with a 300-mile range costs around €250 for petrol or diesel that is in use today. For compressed hydrogen at 700bar, the tank would cost €12,000 in volume production. A nickel, methylhydride or lithium-ion battery is around €25,000 and it would also weigh about 1000kg to travel that distance.

For long distance driving, quite frankly the best solution is the internal combustion engine with a very efficient transmission. In between, we have some choices. In the city, maybe a parallel hybrid is possible (plug-in as well, very similar to a Prius). Alternatively, rather than making a bigger battery to drive our electric vehicle further, it is a much better idea to fit a smaller battery and a small, range-extender petrol engine so you never run out of range. 'Range anxiety' is a huge issue with battery-electric vehicles, which are anyway likely to be more efficient just for city use.

Long-term vision

Ricardo estimates that by 2050 over two-thirds of energy for transportation will come from electricity, maybe less than 25 per cent from conventional oil and the rest from liquid bio, natural gas, biogas and so on. That will achieve a 70 to 80 per cent reduction in carbon. But in order to get there we need breakthroughs for electric vehicles and fuel cells.

At the moment vehicle fuel efficiency is regulated by tailpipe CO_2. Increasingly we will see these regulations based on well-to-wheels CO_2 emissions: where did the fuel come from, and did we produce carbon getting it into the tank?

We must make sensible use of lifecycle analysis: how much has it cost us in energy terms and in carbon terms to produce this vehicle, to use it and then dispose of it at the end? When we know that we can make the right decisions.

What are the challenges for the UK? There is very little advanced automotive research and development carried out here. Yet we have many opportunities. The formation of a new automotive innovation growth team has stimulated UK auto-industry cooperation, so is a major step forward.

I am very encouraged by what is going on in the UK Research Councils: a much bigger focus on the economic impact and extra coordination with industrial research and funding of industrial research.

The UK's leading position in motorsport can also be used to stimulate automotive skills, especially in engineering. We have a world-leading industry in that sector. What can we do to exploit it and move us towards low carbon?

Key messages

My three key messages are, first, that the auto industry should be more innovative.

Second, economics rules, OK. Lower carbon vehicles cost more money to make than they can deliver in savings on fuels bills, and that will be the case for the foreseeable future. We need to work on long term, not short term, fiscal and/or policy support for them to be viable – and we need stability.

Third, the UK strategy should be to lead in key areas and not try to do everything, because if we attempt that we will fail. Personally, I would concentrate on efficient diesel engines, intelligent transport systems, next generation battery chemistry and the developments towards lighter weight structures coming out of the UK motor sports sector. □

Is it possible to put a value on biodiversity — and if so, how should it be done? These were the questions considered at a meeting of the Foundation on 6 May 2009.

Can a value be put on biodiversity?

Bob Watson

Much of the conceptual thinking on ecosystem services and economic valuation originated with the Millennium Ecosystem Assessment (MA). There are four types of ecosystem services that underpin human wellbeing. First, there are provisioning services – provision of food, fibre, fuel. They are traded in the marketplace and so have 'economic value'. Then there are a series of regulating services such as climate, pollination, air quality, and floods, which are not normally traded in the marketplace (although the new carbon trading system provides a market for climate regulation through carbon). There are cultural services – aesthetic, spiritual, educational, recreational – but few of those are traded, except recreational and some educational services. Finally, there are supporting services such as nutrient cycling and soil formation. All of these services provide the basis of human wellbeing – security, the basic materials for a good life, human health and good social relations: ecosystems add value to human wellbeing.

We have recently initiated a UK national assessment, covering England, Scotland, Wales and Northern Ireland, which should be complete in two years time. It will mirror the international assessment and, like the MA, will comprise three elements:

- current status and trends and how these link to human wellbeing;
- scenarios for the future to 2050;
- options for action to capture the positive outcomes and avoid the negative.

Ecosystem services contribute directly to economic welfare through the generation of income and wellbeing. While the provision of food and fibre has market value, the provision and protection of coastal infrastructure by coral reefs and mangrove swamps has non-market value: we need to recognise both. We therefore, have to consider the 'value' of all services.

When we assess the impact of a potential policy, or when we evaluate the impact of climate change on ecosystems, we need to take a 'whole ecosystem' approach. The approach works equally well for converting a mangrove swamp to cropland, as it does for building a third runway at Heathrow, or a road. The methods have to include a combination of both economic and non-economic valuation techniques.

Professor Bob Watson CMG is Chief Scientific Adviser for the Department for Environment, Food and Rural Affairs (Defra). His early career was at JPL, NASA and in US Office of Science and Technology Policy at the White House. He became a scientific advisor, manager and chief scientist at the World Bank before moving to the UK to take up a Chair of Environmental Sciences at the University of East Anglia and become the Director for Strategic Direction for the Tyndall Centre.

Biodiversity and climate change

One question is how to apply the ecosystem approach to biodiversity and climate change – two issues that need to be brought together. For too long they have been viewed as independent, but we all know that climate change affects biodiversity and changes in biodiversity affect climate change. Climate change is a major threat to biodiversity at the species and ecosystem levels, biodiversity needs to adapt, and a resilient/healthy ecosystem is likely to be less vulnerable to climate change in the future.

It is quite clear that biodiversity and ecosystems can contribute to adaptation to climate change and we have to recognise that some climate change adaptation strategies – hard structures such as sea walls, levies, etc – can have a negative impact on biodiversity.

It is equally clear that ecosystem management can contribute to the mitigation of climate change, e.g. the slowing of deforestation and the processes of reforestation, afforestation and low/no till agriculture. Obviously there are some activities that contribute both to mitigation and adaptation. We need to bring these activities to the attention of both the Biodiversity Convention and the Climate Change Convention.

To make ecosystems more resilient we need to consider both global ecosystems and more focussed protected areas. What is the right spatial scale, to what degree do corridors work, etc. We need to assess how to manage protected areas – the pluses and minuses of fire management, for example – and we need to think about functional connectivity. With respect to species, *in situ* adaptation measures need to be considered alongside human-aided translocation and *ex-situ* conservation.

One example is that of coastal ecosystems – mangrove swamps, coral reefs, sand dunes and salt marshes. These can play a very significant role in adapting to sea level rise, storm surges and extreme weather events, e.g. cyclones, while continuing to deliver other goods and services. They act as buffers against such events and can be integrated with 'hard defence' measures, for example sea walls.

When we consider intervention in specific areas, we need to consider the impact on all services. For example, if a mangrove

DISCUSSION

Underestimated and misunderstood

People are now more aware of the hazards of climate change, but they have not yet had to deal with the concept of biodiversity whose importance is often underestimated or misunderstood. There is of course an international convention on biodiversity, but action to cope with species loss often has to be taken at local rather than global level. This means improving public understanding and involving policy makers at all levels, especially local. People today may be preoccupied with the credit and financial crisis, but the threats to the natural environment are of much greater significance.

swamp is converted to housing or shrimp farms or crops, we have to ask what services we have today (nursery/adult habitat, seafood, fuel, wood, timber, etc) and what is the current value (either to an individual or to society at large)? If this mangrove swamp is to be converted to housing, a shrimp farm or crops, what services do we lose and what do we gain in both the short and the long term?

Another example is water adaptation. Freshwater systems can provide water regulation in the face of climate change. Therefore we need to reduce the degradation of watersheds as they can contribute to water purification and potentially flood control. An example of this was the Catskills Watershed outside New York City. A new water purification plant was estimated to cost between $8 to $10 billion, yet protecting the Catskills environment was estimated to cost just $1 billion. The choice was between a hard structure, a water purification plant, and protecting an ecosystem – they chose to protect the ecosystem. This is obviously one of the classic examples.

It is quite clear that forests, especially primary forests, are extremely rich in biodiversity and ecosystem services. We need to reduce deforestation and forest degradation and we need sustainable management of our forests coupled with afforestation and reforestation. We need to think about non-forest land management practices as a mechanism for bringing biodiversity and climate change mitigation together.

The economic framework

So, how do we change the economic framework? As noted earlier, we have to take all ecosystem services – and not just those bought and sold in the marketplace – into account when making a decision. We must remove the subsidies in agriculture, fisheries and energy that rarely help the poor. Instead, we should make payments to landowners, in return for them managing their lands in ways that protect and enhance ecosystem services. Agriculture today should no longer be thought of as production alone. We need to pay farmers not only for producing food, but also for maintaining and enhancing ecosystem services.

We need to integrate biodiversity into every sector. We need appropriate pricing policies for natural resources such as water – without putting a price on scarce resources they tend to be wasted. We can also apply fees, taxes, levies and tariffs to discourage activities that degrade biodiversity and ecosystem services and we need market mechanisms to control nutrient releases, carbon emissions, etc.

At international level, we have a series of environmental Conventions, e.g. on climate, biodiversity, wetlands and land degradation and, of course, the World Trade Organisation. These entities need to work together: they cannot remain isolated.

The bottom line is we are spending the Earth's natural capital. We are putting a strain on the ability of the planet's ecosystems to sustain future generations – and these services are absolutely critical for their survival. ☐

Safeguarding the treasury of the poor

Pavan Sukhdev

Is it sensible to put a value on biodiversity? Why should we need to? Can we just not do what is sensible and obvious, which is not to destroy biodiversity and not degrade ecosystems within which we survive as a society, and within which, in turn, the economy survives? The answer, at least on present evidence, is that we cannot do what should be sensible and obvious. So we have to give biodiversity a 'value' if we are to include it in our economic calculations and decisions. To put it in context, the problem is that nature is a wild and wondrous thing and we are trying to equate it to something which is very simplistic, which is the value of money.

In a sense, we already do this in the implicit trade-offs we make when we give production and the flow of goods and services a higher priority in our economic system – in terms of the jobs they generate, the economic wealth that is generated and the reduction in poverty.

We can apply a degree of measurement of the interaction between nature and humanity by measuring the ecosystem services. We can measure the envelope, if you like, of humanity's interaction with nature and vice versa. If we can give that a 'value', then we have at least some glimmering of a comparison, using today's money yardstick, of those interactions.

Pavan Sukhdev is Project Leader for the United Nations Environment Programme (UNEP) Green Economy initiative, a major UNEP programme to demonstrate that the greening of economies is not a burden but rather a new engine for growth, employment, and the reduction of persistent poverty. He is also Study Leader for the G8+5 commissioned report on The Economics of Ecosystems and Biodiversity (TEEB).

Without such a yardstick we rely on implicit trade-off choices. I say 'implicit' because our system is so geared toward the production of goods and services and towards the measurement of jobs and money flows that we do not recognise the 'externalities'. This inevitably leads to the emaciation of ecosystems and the destruction of biodiversity.

So what is biodiversity? We are evolving a consensus which recognises biodiversity in the wider meaning of the word. We have identified five important aspects of this which we have been attempting to quantify:

- Species richness – its diversity, its recreational and medicinal value, and the contribution to ecosystem resilience and robustness;
- Species rarity – identifying species close to extinction, quantifying their ethical and recreational value;
- Biomass density – important for delivering carbon storage, water provisioning and regulation, etc;
- Primary productivity – production of biomass and food production potential;
- Genetic diversity – quantification of bio-prospecting value and insurance value against future floods, etc.

We picked these because each of them is an answer to the question: 'what in nature is valuable to human beings?'

Assigning value

So that is the 'what?' The next challenge is to assign dollar values to something so complex and difficult. There is an acceptance that, yes, ecosystem functions do provide food, fuel, fibre, flood prevention, drought control, etc. And the availability of these services

is changing. The incremental changes in availability can be ascribed a dollar value (see Figure 1).

In Phase 1 of our report, released in Bonn in 2008, we looked at land-use change in terms of 'mean species abundance'. We found that we have lost more biodiversity in the last 50 years than has ever happened in the same period at any time in the history of mankind. It means that an area the size of Australia (7.5 million square kilometres) has been converted into other uses during that period.

People sometimes jump to the conclusion that the main driver of this land-use change is agriculture, but in our model the human imprint on natural areas was the largest driver. We call it 'infrastructure' but it is actually encroachment, largely: as societies get richer they expand faster into natural areas to convert them into residential use. The second driver, interestingly, is climate change. The third largest is agriculture, which is the conversion of natural areas into, first, extensive agriculture and then intensive agriculture.

Three key messages came from the report. The first was the sheer economic size of the losses in terms of human welfare. The second was the very strong link between poverty and the losses of ecosystems and biodiversity. The third message was about the ethical issues surrounding discount rates.

So the first point we made was that on this model of 'business as usual' over the 50 year time-span between 2000 and 2050, we would end up, if we did nothing different, with a 7 per cent loss of GDP.

But you see it is not just the numbers. The second point is about poverty and I use fisheries to illustrate this point. There are numerous forecasts about the loss of fisheries and what it means for wellbeing, but it is not just about the $80 billion of income, it is really about the fisher-folk and their jobs which are at risk. When we control trawling in our areas, then of course it moves elsewhere. A man from Africa once told me, in very memorable words, "When you stop trawler fishing in your areas, they come to my land and my canoes come home empty." So it is those jobs, the livelihoods of the poor, that they are talking about.

Actually it is the risk to health of losing fisheries, of losing fish as the main source of animal protein for a billion people in the developing world, that is the real 'elephant in the drawing room' that we have to worry about. So it is not just about the numbers, it is about jobs. And it is not just about jobs, it is about livelihoods.

So biodiversity is not the preserve or luxury for the rich, it is a necessity for the poor. Nature is truly the treasury of the poor and that is the point which often gets missed. We have tried to make this point in economic terms.

DISCUSSION

Global and local

There is a great need for better evaluation of what is going on, and better measurement of species loss. They should perhaps be brought into national accounts, together with new ways of measuring wealth and wellbeing (such as is now being undertaken in a variety of places, ranging from the Joseph Stiglitz/Amartya Sen commission to the work of the Club of Rome and even the *Financial Times*). There is an obvious difficulty in dealing with local issues within a framework of universal values. We have to decide how to bring an understanding of the issues into our educational systems as well as to the attention of society in general. The world is becoming more aware of environmental issues, but understanding biodiversity is among the most difficult to grasp.

The next stage

The second phase of TEEB is now underway[1]. All of the numbers I have mentioned are based on valuing eight out of the listed 18 ecosystem services of forests. In Phase 2 we aim to cover the others.

We are looking at the thresholds beyond which ecosystems cease to function – the whole question of valuation then becomes irrelevant because you just do not have the system anyway. We had not explored the true connection between biodiversity and ecosystem – in other words, resilience aspects – and we need to do that. We also had not looked at urban and agricultural biodiversity because our focus really was forests. We had covered discount rates and ethical choices but we had not provided an appropriate framework within which to address the future.

If I were to describe our efforts in Phase 2 in one word, that word would be 'mainstreaming' because if there is a benefit from this recession it is to finally make us understand that financial and physical capital are not the only form of capital. We understand human and social capital, we understand the importance of community. We need to recognise better the value of nature.

One important priority is to understand how to enable the citizen and the consumer to take responsibility for their impacts on ecosystems and biodiversity. That could result in an Economics of Ecosystems and Biodiversity for Consumers, if you like, which sets out the economics of what it takes to produce a kilogram of beef – for example, the consumption of 15,000 litres of water – and what that means for the Earth. □

1. The TEEB for Policymakers report was released on 13 November. It is available at: www.teebweb.org

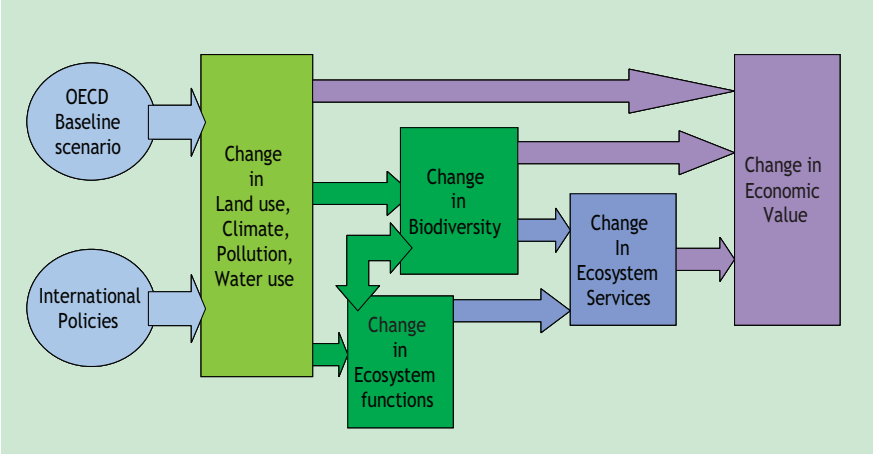


Figure 1. Translating changes into economic value.

The ethical dimension in valuing biodiversity

Robert May

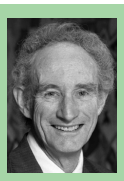
Over the past 150 years, in a manner which has no precedent, the human population has expanded seven fold and in that time energy consumption per capita has also increased seven fold. So in that sense alone we are stamping a 50-fold larger footprint upon the earth.

That shows up in a variety of ways. Some time ago, researchers at Stanford estimated that, of all the organic material that grew each year from the equator to the poles, something between a quarter and a half – they estimated 40 per cent in fact – was taken directly or indirectly for human use. Interestingly, just a couple of years ago that same number, 40 per cent, emerged from land-sat studies. More recently Jeffrey Sachs' book has an independent estimate of 45 per cent.

Sachs estimated that perhaps 60 per cent of all run-off water is used by humans. The Natural Environmental Research Council's Centre for Ecology and Hydrology at Wallingford believes that rising global demand (more people, higher demand per person) will exceed the declining (as a result of deforestation of watersheds) sustainable supply of fresh water around 2040.

Consequences

This inevitably has consequences for the continuance of other species. Of all known species, about 20 per cent are in one of the defined categories of threat drawn up by the International Union for Conservation of Nature and Natural Resources (IUCN). Not many fish, not too many plants, and by the time you get to invertebrates, only six in 10,000 species of insect are known to be threatened. However, this is only a measure of the species we know about. We know far less, for example, about insects than mammals. Estimates range widely about the total number of species on our planet and we therefore know even less about how many are becoming extinct.



The Lord May of Oxford OM AC Kt FRS holds a professorship jointly at Oxford University and Imperial College, London. He is a former President of The Royal Society, and Chief Scientific Adviser to the UK Government. His research interests include how populations are structured and respond to change, particularly with respect to infectious diseases and biodiversity. In 2007 he received the Royal Society's Copley Medal, its oldest and most prestigious award.

Suppose, though, you look among the better known species and ask what fraction became extinct in the last 100 years. Assuming that is representative, how does that correspond with the average extinction rate, the average species life-time from origination to extinction, seen over the half-billion year sweep of the fossil record? Well, in the last 100 years, the rate has increased by two or three orders of magnitude – it is now in the same order of magnitude as the five great mass-extinction events in the fossil record.

What would it cost to do something about preserving some of the diversity? Andrew Balmford and others at Cambridge have carried out some significant work here. The costs of preservation are necessarily imprecise but their argument is that to do a better job – enlarging protected areas, compensating local people, greening agriculture – would only cost a few percent of annual GDP. If we were managed by a supreme dictator who was a really rational accountant, that is what we would be doing.

Yet these decisions are compounded by questions of equity. A study carried out a little over 10 years ago found that two thirds of the threatened species are in countries which had an annual GDP per capita of about $500-600.

More generally, if you ask about the size of the human footprint in different regions you see there are huge disparities of equity. It is why, in setting the UK's climate change targets we first estimated the globally sustainable emissions of carbon for the middle of the century which would limit the probability of a 4°C rise in temperature to less than 1 per cent. We worked on the basis that we had to do to come down to that, while recognising the need for China and India to come up to that, albeit more slowly than their current trajectory.

Social science

Those problems of equity are why the really important science here is not biological science, it is social science. It is a difficult kind of social science – we have to ask 'why do we care about valuing biodiversity?' I group the reasons under three headings.

First, there is the narrowly utilitarian reason that it provides specific sources for items of value to human beings – like drugs. I do not think that is a good reason myself: before long we will design drugs direct from the molecular level.

You could, second, try and establish a value for ecosystem services – the things we really depend on – but even here, maybe we could be clever enough to live in an impoverished world. Such a world, though, would probably resemble that of the cult movie Blade Runner, and that raises the question 'do you want to live in that world?' So the final reason is ultimately ethical and cultural, it is about the kind of world we want to live in. It is less tangible and it is certainly a reason that is easier to embrace if you live in the privileged, developed world than if you live elsewhere.

That is why I think we need a social science that understands us well enough to ask 'how do we motivate human beings to care about our own futures and act accordingly? □

DISCUSSION

Measuring and understanding

Although the information now available about damage to ecosystem services may be incomplete, it is reliable as far as it goes. We have to put much more effort into measurement, understand the impact of our actions, and draw the right conclusions for future policy and behaviour. In some respects it is easier to measure the damage to plants and vertebrates than to invertebrates, and in particular the worms and micro-organisms whose functions are vital to life itself. Nor do we properly understand the effects of such human activities as the use of nitrogen fertiliser.

Medical research has received significant extra funding over recent years and a new funding structure. The issue of which areas to prioritise and the challenges still facing the sector were discussed at a meeting of the Foundation on 20 May 2009.

From bench to bedside: strategic aims of the MRC

Leszek Borysiewicz

The aims of the Medical Research Council (MRC) are deceptively simple: 'to encourage and support high quality research with the aim of improving human health; produce skilled researchers; advance and disseminate knowledge and technology to improve the quality of life and economic competitiveness in the UK; and promote dialogue with the public about medical research'.

In 2007-8 our operating expenditure was about £625 million. We made 300 grants to researchers and distributed £236 million in grants and training awards to universities and medical schools. We also provided £343 million to fund over 500 programmes in our research units and institutes, which produced more than 2,000 publications in peer-reviewed journals.

MRC Technology (MRCT) has been very successful in commercialising the discoveries made by our scientists. Revenue from licensing receipts for 2005-6 was £141 million including an £85 million buy-out, bringing our total income from MRCT to £384 million.

Our foundation lies in basic science. Among our alumni are 28 Nobel Prize winners in physiology, medicine or chemistry. This attests to our success, but also to something else which is inherent in the MRC strategy – taking basic science from the bench and moving it forward.

The MRC will continue to support basic science through all of its phases. However, we are also expected to translate discoveries into clinical benefits. To do this we must follow an artificial and often tortuous pathway, beginning with basic medical research and moving on through the stages of prototype development, preclinical development, early clinical trials and, finally, late clinical trials.

Translating research

This translational journey requires a number of milestones to be reached. We need to ensure that research and development is supported through all stages and that the journey from bench to bedside is as smooth as possible.

Sir Leszek Borysiewicz FRS FRCP FMedSci is Chief Executive at the Medical Research Council. Previously he was Deputy Rector at Imperial College London, responsible for the overall academic and scientific direction of the College. He was a founding Fellow of the Academy of Medical Sciences. As a physician, Sir Leszek specialises in viral immunology, infectious diseases, cell-mediated immunity, virus-associated malignancy and vaccine development.

One of many changes within the MRC has been the development of a Strategy Board to allow us to look at large-scale funding and new opportunities without recourse to interminable debate. The Strategy Board will facilitate rapid decision-making and provide a forum where strategic funding can be considered. It is made up of the chairs of four boards – Molecular and Cellular Medicine, Population and Systems Medicine, Infections and Immunity, and Neurosciences and Mental Health – together with the chairs of four groups – Population Health Sciences, Translational Research, Global Health, and Training and Careers. The Strategy Board advises on the allocation of resources to Boards and to specific areas of research,

We have identified 10 priorities for health research in the UK:

- stratification of phenotype;
- regeneration and replacement;
- tracking response to intervention;
- measure, understand and modify environmental and inherited influences on health;
- early detection of the opportunity for effective intervention;
- primary prevention;
- behaviour modification;
- understanding the burden of illness;
- development of new interventions.

These 10 priorities have been used to inform the development of a new strategic plan.

After consulting over 500 stakeholders we set as one of our goals the creation of a non-prescriptive agenda. We are trying to ensure that we can lead and influence major sectors of activity while ensuring that the formation of national and international partnerships is enshrined in the process.

Strategic aims

We have four strategic aims. The first is to pick research that delivers. We want to set research priorities that are most likely to deliver step changes in the potential for improved health outcomes. The two

DISCUSSION

A new lifesciences model for the UK

Because the NHS is slow to adopt new drugs or procedures, the willingness of investors to fund new developments in the UK is constrained. Expenditure on research and development in the USA is much greater, and also represents by far the larger market for UK-researched drugs. The USA also constructively engages engineers in the lifesciences. However, this is not a model for the UK with its smaller economy and very strong research base. As a result of OSCHR and the MRC, there is the opportunity to focus on crucial sectors and develop strategically. Lifesciences now form one of the largest sectors of the UK economy and more needs to be done to ensure that disciplines other than medicine are involved.

themes we have chosen are 'resilience, repair and replacement' and 'living a long and healthy life'. What builds in resilience to infection or to tissue degeneration? How do we determine what these mechanisms are and what might we learn about preventing and mitigating disease? These themes will also address the biology of aging and tissue degeneration, as well as the translation of stem cell research into new treatment strategies. Last, but by no means least – and I say that because it so often has been 'least' – they will include mental health and wellbeing. This is an area where we have failed to make the sort of ground-breaking discoveries that have occurred in other fields. In some ways it is one of the most challenging agendas, but it is one that we must not shirk.

The second strategic aim is to bring the benefits of excellent research to all sections of society, making it relevant to the entire population. To achieve this we will need to become involved in regulation, ethics and governance, and work with decision makers as well.

Our third aim is to secure progress in international medical research. The UK is in an enviable position in relation to the problems of global illness. We want to secure international partnerships that will enhance the competitiveness of the UK knowledge base, and support global research to address health inequalities.

Finally, none of this will happen if we do not support our scientists, so our fourth aim is to sustain a robust and flourishing environment for world-class medical research. We intend to do this by strengthening our capacity for training and development. Making population-based data accessible to a wider community of scientists is absolutely key. We need a framework to allow linkage of datasets and we must engage in the current debates about data privacy in the context of medical research.

How will we measure our success in achieving these four strategic aims? Our criteria for success include: a demonstrable advancement in the national and international knowledge base resulting in a positive economic output; a measurable impact on the development of policy and practice; participation in global health research policy and implementation; and a measurable increase in the number of skilled people working in health and medical research and development.

The MRC will remain driven by the quality of the science being produced. The development of capacity is absolutely key and will be crucial in enabling scientists to look into the future and maintain the UK's pre-eminent position in biomedical research. □

Supporting and coordinating medical research

John Bell

The Office for Strategic Coordination of Health Research (OSCHR) coordinates the work of the two major health research agencies in the UK – the Medical Research Council (MRC) and the National Institute for Health Research (NIHR). We are charged with eliminating duplication and ensuring support for the translational pipeline. To help achieve this we have developed the 'lead organisation model' in which one organisation takes the lead on a piece of research, with resources being shared.

We focus on UK-wide working, with particular emphasis on translational medicine, e-health and public health. The increase in the research budget has accommodated a great deal of this but, importantly, it has also served to protect the basic science base. So, we also monitor and protect the 'ring-fence' around the health research budget – a notional concept that I think is increasingly fragile.

In our business progress report last year we described a number of items of unfinished business. We still have work to do to improve our communication with the academic community and other stakeholder communities, in particular to explain our role. Our engagement with industry is much better, but can still be improved.

Capacity building is another area we need to work on. In addition, the public health agenda needs boosting and we face challenges in that area. E-health is progressing but we need to ensure that the NHS is aligned with the overall e-health mission.

The MRC's strategic plan highlights some central issues. One is the ability of other funding agencies to work with the MRC. I think they are doing this remarkably well, given the fact that for many years the MRC was the only public sector research funding agency in the UK and must now share that role with several others (including the NIHR, the Wellcome Institute, charities and others).

Basic science

Maintaining excellence in basic science is central, particularly for translation. I think we all support excellence, but aligning it with improved translational capacity will produce a double win. The MRC has always had, and will continue to have, global reach.

The MRC maintains a commitment to a basic science agenda. This has been the fundamental ground on which enormous success has been achieved. However, there are challenges and the reality can be more complicated than we may imagine. An example is research into aging, which has been the leading cross-council research priority for many years. Despite this, our biomedical research in this field has not had the same impact as similar work undertaken in America and Germany for example.

One of the challenges is the emphasis on multi-disciplinary work in the field

Sir John Bell FRS PMedSci is President of the Academy of Medical Sciences and Chairman and Regius Professor of Medicine at Oxford University. He is Chair of the Office for Strategic Coordination of Health Research (OSCHR). Sir John has been extensively involved in the development of research programmes in genetics and genomics and a UK-wide clinical research programme.

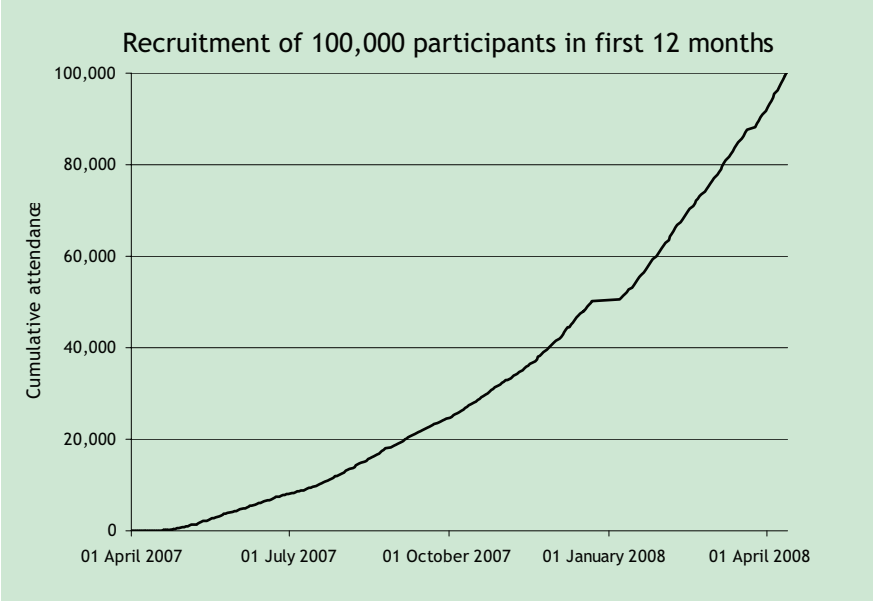


Figure 1. Recruitment to UK biobank.

of aging. Although this is well accepted, there is still a role for a single-discipline approach to advance the basic science. For example, research suggests that dietary restriction may improve longevity. This has been shown in every species in which it has been tested. Wisconsin monkeys were the subjects of the most recent experiment, which found that nutritionally-deprived monkeys lived longer. (Having said that, the monkeys that were deprived of food became very cranky!) Clearly, there are advantages and disadvantages to dietary restriction, but the data from this study have revealed some fundamental biology that should not be ignored. The lesson to take from this is that although there is an important role for interdisciplinary work, it should not prevent very focused research into a single subject.

Another challenge is taking 'research to people', which involves translation, regulation, ethics, governance and communication. The activities of the MRC and the NIHR have improved translation, but there are outstanding issues with regulation. We welcome the continued involvement of the MRC in dealing with the complexities of ethics and governance within a highly regulated environment.

A further major challenge is posed by the economy. I am glad that improving economic competitiveness is in the MRC charter. They have developed a number of new programmes for translation. One such is their developmental pathway funding scheme, which the Americans now appear to be pursuing as well. There is a bill before Congress proposing that up to $2 billion be put into a scheme that looks very much like that of the MRC.

Other exciting developments at the MRC are the new Centre for Drug Discovery and interactions with the Technology Strategy Board, which I think are going to be central elements in the important area of stratified medicine.

Communication is crucial to the success of these developments. When I talk to people in industry they tell me that the improved interface with the NIHR and the MRC has transformed their approach to working with researchers in the UK. There is now good alignment with both large and small companies. We are slightly constrained by academic capabilities, which are not always as broad as they are believed to be. There is also the lack of a unanimous view from industry regarding its priorities.

Working globally

Working globally is very important and is at the heart of UK biomedical research. We monitor healthcare requirements around the globe and spend resources accordingly. The Wellcome Trust and the MRC have longstanding global programmes. The NIHR and the NHS are increasingly interested in global research. This work requires partnerships and the ability of UK agencies to participate in shaping the agenda.

Infections and chronic diseases are two examples of areas of global health research that are very well covered by UK agencies. The funds directed to the study of infectious disease in the developing world are impressive by any standard. However, there are limitations as to what we can do and important decisions have to be made about the funding of global programmes.

We need to ensure we support scientists through capacity-building programmes, provision of population-based data and improvements in the research environment. Biobank, which was supported by the MRC, the Wellcome Trust and the Department of Health, is a very impressive example of collecting population-based data. Between April 2007 and April 2008 around 100,000 participants were recruited; the total number now stands at around 250,000. This makes it the world's largest data bank for genetic epidemiology.

Public health issues require further debate. Funding for public health research is limited and difficult to secure since it requires input from different sectors and various Government departments. It is a diverse field with a wide range of areas of interest (infectious disease, chronic disease, mental health and so on). The MRC has a spectacular record of discovery in public health, but the question remains: can we go further?

A number of other issues are also open to question. Should we focus mainly on large science, or on small science? Is the 'ring-fence' secure? I do not think it is, and if it were to be breached there would be a major impact on health research. What partnerships should the MRC forge? How can we balance multi-disciplinary with single-discipline science? There are many challenges ahead. □

DISCUSSION

Why is the NHS such a poor customer?

Why is the NHS failing to be an effective customer for new products and treatments? Is it because the NHS is risk-averse and fails to get rid of out-of-date practices? The driving force in the NHS is service delivery, which does not always align with academic or industrial aims. Some research developments will not be capable of being delivered because NHS priorities have not been understood. Universities must take the lead in developing new partnerships and devising new ways of working with the Health Service.

Economic challenges in drug discovery

David Cooksey

Lifesciences have become the biggest industrial sector in the UK, overtaking financial services. We were therefore very surprised when the Review and Refresh of Bioscience 2015 (BIGTR2) revealed that British participation in global clinical trials had dropped from 6 per cent in 2002 to 2 per cent in 2007. The reason for this was partly cost: competitive economies around the world (such as Singapore and many others) made strenuous efforts to capture development work for the pharmaceutical industry in a way that the UK could not. This will be a major challenge for the new Office of Life Sciences.

In BIGTR2 we concentrated on five areas. The first two were: finance and taxation; and regulation. Over the past 15 years, the pharmaceutical industry has evolved from in-house working to a mix of in-house and collaborative working with the biotechnology sector. As a former venture capitalist, I know this raises problems. For example, an investor in a digital media company will see a product produce a positive cash flow after two or three years and profits after three or four. By contrast, in the biotechnology industry the development of a product can take 13 or 14 years. NICE (the National Institute for Health and Clinical Excellence) can then add a delay of 31 months on average, although I am told this is improving. This timescale makes it extremely difficult to finance early-stage biotechnology companies.

The third area we examined was how to ensure the availability of a trained workforce to carry out research and clinical development. Researchers and developers also need to know how to take their products out into the marketplace; this is very important.

Fourth, we reviewed the bio-processing capability of the UK. It is vital that we have the capacity in terms of both physical assets and trained staff to manufacture the drugs that are developed.

Finally, we asked the question: is the NHS an asset or a liability in terms of research and development? The NHS should be a wonderful base on which to develop new drugs, and in some ways it is. It should also be the prime customer for these new products. However, Britain has the lowest uptake of new cancer drugs of any country in Europe, despite all of the efforts of the NHS to do better.

There are two gaps in translation – the move from basic to applied research and the delay in the uptake of new drugs when they are developed.

Sir David Cooksey GBE is Chair, Review and Refresh of Bioscience 2015 and also of the UK Centre for Medical Research and Innovation. In 2006 he published the Cooksey Review of UK Healthcare Research Funding, which was adopted as Government policy. Sir David was one of the founders of the private equity and venture capital industry in Europe and has also participated widely in public life.

Changing the development process

In economic terms there is a case for changing the drug development process. The old, small-molecule blockbusters have largely been discovered and it is unlikely that we will find many more low-cost drugs that are highly effective and make important differences to the health of individual patients. It is very encouraging to learn that the Technology Strategy Board is going to work on 'stratified medicine' and regenerative medicine, as we move towards a 'personalised medicine' agenda. This calls for us to identify patients who will benefit from a particular drug, which may be an expensive one. This means that the drugs that we develop are going to serve increasingly smaller patient populations.

If a drug takes 13 or 14 years to come to the market, there may be only five or six years left on the patent in which to recover the cost of its development. The cost of developing a drug has risen from $500 million some 10 or 15 years ago to somewhere between $1 billion and $1.5 billion now. Therefore the cost of drugs will be driven up, not down, over time. There will soon come a time when it will be so expensive to develop new drugs that it may not be worth bringing them to the market, since NICE will argue that the quality threshold cannot be met at the price the manufacturer is prepared to sell the drug for. We need to look at the way in which we authorise new drugs.

Part of the problem is that we tend to have a single gateway; we have to get every aspect of a drug approved and its safety profile completely established before the regulators will allow the drug to go through. The US Food and Drug Administration (FDA) is the worst offender, and for a very good reason – to avoid litigation through large class actions in the USA. We need to approach liability in a different way and look at bringing drugs to a larger proportion of the population earlier. We can use stratified medicine techniques to do this. This would change the economics out of all recognition and do ten times as much to control the cost of drugs in this country as NICE ever will.

That is the major challenge and I think this country is very well situated to take the lead in making these changes. We can do this by creating a new drug development pathway that gets the balance of risk and reward right – and drives prices down. We need to make NICE a much more effective tool for improving innovation in the delivery of healthcare.

We must have the right incentives to ensure that we have people of the right calibre working to translate our fantastic capability in drug discovery into drugs and therapies that people want to use and for which the NHS will be a better customer. □

DISCUSSION

The role of NICE

The existing remit of NICE (the National Institute for Health and Clinical Excellence) requires it to focus on whether new treatments provide value for money in the NHS. Such judgements are made in far too narrow a context. They ignore other considerations such as export potential and societal benefit. Innovation is inhibited. Failure to get NICE approval means that many drugs that could have global potential or societal benefit never come to market. However, it is important to recognise that there are overall public expenditure constraints that cannot be ignored, and the money that NICE has saved the NHS over the years is considerable. The problem of delays in approval is being tackled but the major difficulty is that many new products are brought before NICE too late in the day.

How does science advice reach the decision makers and the politicians in large cities – and how should it be used? This was the subject of meeting of the Foundation held at the Royal Society on 3 June 2009.

Can city managers make better use of science?

Boris Johnson

Boris Johnson is Mayor of London. His career in journalism has included 12 years at the *The Daily Telegraph* and editorship of the *The Spectator*. His books include *Lend Me Your Ears, Friends, Voters and Countrymen* and *The Dream of Rome*, the latter on Roman history which also became a series for television. In 2001 he was elected MP for Henley on Thames and in 2008 Mayor of London.

These are extraordinary political times. The expenses row has left Westminster enveloped in a miasma of guilt with a level of pollution rising off the House of Commons of a kind we have not seen since the Great Stink of 1858, when the whole place had to be evacuated. And who sorted that out? Not a politician but one of the greatest engineers of the Victorian age, Joseph Bazalgette, whose magnificent sewers still carry the effluent of London along the embankment. It is not just because I am Mayor of London that I am proud to say that at the root of every great scientific breakthrough of the modern era you will find a London scientist.

Electricity? London. Michael Faraday was born in Southwark and died at Hampton Court. Computers are all descended from the invention of Alan Turing, born in Maida Vale. The theory of evolution — the single most influential scientific teaching in the world in the past 200 years — was first propounded in Bromley, now a London borough. When you consider the historic dominance of this city in scientific and technological endeavour, when you think how penicillin was discovered on Praed Street and how Brunel built Paddington Station, it breaks your heart to see how little value schools seem to attach to the study of science.

Last year in the London borough of Islington, not one school entered any pupils for a separate science GCSE. In Southwark, the birthplace of Faraday, only 13 pupils did physics A level, and only 3.5 per cent of those who did GCSEs in 2006 were entered for physics A level two years later. With figures like that it is no wonder that, if this country goes ahead — as I believe it should — with a programme to build nuclear power stations, we will almost certainly have to recruit nuclear scientists from France or Korea.

With so little interest in schools it is no wonder that we have seen a 26 per cent decline in engineering and technical graduates in the past few years, together with the closure of 80 science and engineering departments at universities and colleges – and this at a time of massive expansion in higher education. To cure this malaise we must do several things. We must stop the absurd pretence that all subjects are academically equal; indeed, we should consider a funding premium for the 'crunchy' subjects, especially sciences. We must get the message across that a science graduate will earn, on average, 30 per cent more than a humanities graduate; and we should demonstrate the huge opportunities for those who are skilled in science and technology to help transform our city and improve the lives of Londoners.

We are making investments now in London on a scale not seen for 50 years, and it is vital that those investments go ahead. Next year the Underground will be 150 years old, and for the first time in its history we will be putting air conditioning on the sub-surface lines (Metropolitan, District and Circle), but you still risk an armpit-sniffing hell on the deep lines. When people notice the difference there will be overwhelming passenger pressure for a miniaturised air-conditioning system that can fit the deep tunnels too.

We will be going ahead with Crossrail, the biggest infrastructure project in Europe, adding 10 per cent to London's rail capacity, generating 13,000 jobs and necessitating the creation of a tunnelling academy. Take that together with the Thames Tideway tunnel — a gigantic 'Cloaca Maxima' that will prevent sewage overflowing into the River Thames — and the Olympics. These engineering projects will deliver jobs and growth now, enabling us to boast that we are the new Victorians and to say to our sons and daughters for the first time in a generation that they have a future as engineers.

But I want to go further. I want London to lead the world in the development of the low-carbon economy. We are kick-starting a £100 million programme aimed at averting climate change — not just because we want to save the planet, but also because we want to save people

DISCUSSION

The systems approach

While the systems engineering approach is a powerful tool, the inability of local authorities to spend resources in accordance with their own perception of needs and priorities may make it less effective. Central Government makes it very clear how Government money (over 80% of local government revenue) should be spent. A local authority may, for example, find it difficult to shift resources to the prevention of health problems, partly because of institutional problems with the National Health Service, but also because there would be vested interests opposed to limiting hospital services in order to allow expansion of preventative medicine. In addition, there are, perhaps, too many authorities and agencies involved in taking decisions.

money on their fuel bills and create jobs. The low-carbon economy is one of the few sectors showing growth in spite of the downturn. We estimate that there are 10-15,000 jobs and three to four billion pounds of turnover that could be added to London's economy, with hard-headed practical programmes such as retrofitting – that is, lagging. Britain may be lagging in science but we will never be lagging in lagging! We have started on 42 Greater London Authority (GLA) buildings, with an estimated saving of £1million a year in fuel and other costs, meaning a payback after only eight years. That is the kind of model that we want to spread across Whitehall. I want London to be the electric capital of Europe with 100,000 electric vehicles on the streets by 2020, some 25,000 charging posts by 2015 and 1,000 GLA vehicles to go electric by 2015.

I have a simple vision for London — a cleaner, greener, safer city, with happy pelotons of cyclists scudding through streets dappled with sunlight passing through the canopy of leaves of some of the thousands of trees we plant. We also have our wonderful urban realm projects that do away with the railings, a bike lane scheme and electric cars and, by 2011, there will be a new prototype bus for London. It will be lighter, greener, cleaner and will help to solve our emissions problems and the insanity of using diesel.

We need British scientists to solve these problems and as a technological optimist I believe the opportunities are huge. I will always be open to your suggestions and I will encourage you by any means that is open to the Mayor of London ☐

Social sciences in the city: think big

Alan Wilson

First, I would like to add my backing to the Mayor's drive for more scientists in London. I chair an organisation, the Science Community Supporting Education (SCORE) partnership, that represents various learned societies and has exactly the objectives that the Mayor mentioned at the beginning of his speech.

My theme here is the role that social scientists can play in tackling some of the big issues facing London — and other major cities — today.

Cities obviously need well-informed plans and evidence-based policies, and this is achievable if central government policies are related to an urban scale. My work involves building computer models of cities that we can use as a kind of 'flight simulator' for testing different kinds of urban policies. That way we can understand the basis of the hard problems and what they are about, and then I believe we can make a lot of progress.

Before setting out to try to improve things, it is as well to establish a baseline. City leaders should ask themselves some basic questions. What is the city's role in the national or regional economy? Is it competitive with other cities? Is it prosperous and sustainable? What is its skills base? Is the population stable or shifting? Is there an adequate housing supply? How are we coping with health, education, policing, telecoms and transport issues?

Different cities will have different strengths and they need to make the most of them. There was a time a few years ago when it was fashionable to develop IT or biotech clusters.

Sir Alan Wilson FRS FBA is Professor of Urban and Regional Systems at the Centre for Advanced Spatial Analysis, UCL, and is Chairman of Arts and Humanities Research Council. Formerly a theoretical physicist, he switched to the social sciences in the 1960s through research on the mathematical modelling of cities. He became Professor of Urban & Regional Geography at the University of Leeds in 1970 and was Vice-Chancellor of the University of Leeds from 1991 to 2004. From 2004-2006, he was Director-General for Higher Education at the (then) Department for Education and Skills.

The country can only support a certain number of such hubs which raises the question: how do we manage that kind of competition? We would need to identify those cities best suited to the role: those less likely to succeed would need to identify alternative models more suited to their strengths.

'Wicked problems'

These are all issues on which we can make a great deal of progress. But we also face what social planners call 'wicked problems'. These are more difficult to solve because we have only incomplete, contradictory or inconsistent information about them. These intractable problems, which have faced cities for decades, include the challenge of how to regenerate inner cities and chronically poor towns (these days often seaside towns). Also, how to respond to climate change, poor quality housing stock, homelessness, ill-health, crime and prisons, long-term unemployment, 'failing' schools and combinations of these problems in what we normally call 'multiple deprivation'.

For an example that illustrates these kinds of problems, I turn to an Economic and Social Research Council (ESRC) sponsored study being carried out at UCL, looking at the students going to universities from different areas. If we feed in the postcodes of students' homes and their universities, our maps show that the destination universities for students from Outer London boroughs are well scattered around the UK. Take the data from inner London and there is a much less broad geographical spread.

The same information can be sorted differently using two geo-demographic categories — one of a prospering population in London and one characterised as blue-collar workers in London. Looking at the blue-collar population across the whole of London, we see a dramatically different picture, with a notably lower proportion of homes sending students to university and a concentration within that reduced number on institutions closer to home, in the London area.

Of course many of these problems are linked. Housing problems are often treated simply as a shortage of houses but there is more to it than that: low-income problems can become housing problems. And low income can be the result of education and skills problems. Clearly we need to break the cycle of

multiple deprivation. Having more students in inner city areas taking physics A-levels could — in a roundabout way — be a practical response to the inner city problem.

I mentioned earlier as a 'wicked problem' the prisons: this is a mixture of a cycle of deprivation and the fact that, in prisons, we do not have the scale of mental health and education facilities needed to tackle the problem from the inside, by helping offenders change their lives.

There are paradoxes in all this. Speaking as Chair of the Arts and Humanities Research Council, I would certainly support the development of a cultural environment that might, at first sight, seem to support the better-off population in the cities. But as well as making us more 'cultured' and improving our quality of life, cultural development can, for example, attract inward investment into cities like London relative to competing cities around the world. And that can contribute towards solving problems throughout society.

DISCUSSION

Scientific skills

The public sector badly needs a more systematic approach to policy and to the design of major projects. Understanding complexity and interrelationships – the wider picture – is essential, but there is always the danger of losing the focus and concentration necessary to implement a project successfully. The answer lies in seeking, first, to define the problem and only then designing solutions. A modelling analysis should illustrate the wider picture; the policy choice based on it requires the politician to be able to communicate effectively to the public; implementation requires focus. It is also important to recognise the importance of media specialists. But in all three stages – definition, policy choice and implementation – scientific (whether pure or applied or social) skills are needed. There should be more academic input into the public sector, but a significant problem is the failure of academics to realise the time scale in which politicians need to take action. With this in mind, it is up to academics and city managers to identify emerging problems and work on them before they become acute.

Science

So let me then say something about the science. Whatever decision-support systems, analysis systems and planning systems we use, they have to be underpinned by good intelligence systems. I am a geographer so, obviously, I am interested in the development of GIS, geographical information systems.

There is much more to GIS than mapping. We need to add an analytical capability to make GIS intelligent. We need an intelligent GIS — call it a city intelligence system or a Government intelligence system — that integrates the kind of information available and enhances it by the use of computer modelling and other such techniques. That is my dream, a system that could deliver the analytical capability for tackling urban development problems in general, but particularly those 'wicked problems' that have proved so hard to tackle.

As an example of the kind of thing that can be achieved, take retail. Here the private sector has been using sophisticated computer modelling for decades. A GIS-based model covering London's 620-plus wards and 220 retail centres, intelligently programmed and with the right data input, can tell you just about all you could want to know about the flow of money and people from any one of those wards to any one of those retail centres.

You can look at the detailed flows into any one centre, factoring in major new centres like Westfield. You can add Stratford to Westfield and then do 'what if" simulations. You can do that for different types of consumers, different types of store, different kinds of goods – and you can break that down into a very, very fine level of detail.

With that sort of detailed information available, the major supermarkets and stores can make decisions on multi-million-pound investments with reasonable certainty. The same approach can be used in the public sector to tackle the kinds of problems that modern cities face.

Education is one area that throws up a broad range of issues which can be analysed with analogues of the retail model. A rich database is now potentially available with detailed information on the performance of each school. Using this data it is possible to address policy questions such as how to combine secondary schools into 'federations', sharing resources and talents to embrace 'failing' schools. Simulations would point to the optimum ways of doing that.

Other questions amenable to this sort of number crunching are working out what widening the remit of the higher education sector would mean for schools, and should all small towns have universities.

Health is also a fertile ground for the scientific approach. It is a sector that is data-rich, but the data are rather disorganised. GIS approaches, combined with patient data, are clearly well suited to revealing more about the geography of general practice delivery, as well as related topics such as the value of polyclinics, the hierarchy of tertiary (university hospitals), secondary (general hospitals) and primary (GP-run) clinics in terms of accessibility and ability to deal with emergencies and elective surgery.

Performance indicators

We live in a performance-indicator culture. We publish league tables relating to schools, universities, hospitals and so on. What we normally do with these indicators is to focus on an institution and ask 'is it really working?' But you can actually, with the analytical capability that I have been talking about, turn that round: 'Is the service being delivered to the residents of a particular ward?' It is perfectly possible to have a system with a very efficient institutional set up, but one does still does not deliver to pockets of the population. I suspect that dental services is one example where a ward-by-ward analysis might reveal gaps in coverage, though performance for each individual practice might appear satisfactory. That area-based rather than institution-based analysis is typically not done, but it could tell us a great deal.

Of the other problem areas facing cities, housing is perhaps a difficult one to tackle with these types of analysis. We can measure the balance between home ownership, private rental market and social housing market, but do we understand the balance between these sectors and the relationship to other issues like employment? And where does homelessness fit in?

I have argued the case for a scientific approach to the analysis of a city's problems. Yet at the moment I do not see any city intelligence system or Government intelligence system that

DISCUSSION

A Victorian legacy

Not only are the built structures in London predominantly Victorian, but so are the institutional structures of local and central Government. Does the structure of Government departments recognise the cross-cutting problems of modern society? Is it necessary to have 150-plus local authorities and innumerable quangos and agencies all working to different remits and failing to share data? In many cases, it is not the scientific resources that are lacking, but the failure to use them efficiently while repeating the same exercise in different contexts.

can actually handle the kind of information in the way that I have been talking about: nothing that combines data on each problem area with GIS information and other relevant databases.

There are some very good computer model applications available; I mentioned the way that the private sector has applied these in the retail sector. This technology has been extensively applied in the public sector in transport planning.

There are examples of successful application of scientific principles in local government of course. But as Boris Johnson pointed out, it can be expensive. And it can take time which is a serious problem when, typically, Government wants answers quickly. I believe we need to investment in city intelligence systems throughout the country, and only then can responses come quickly: with these resources in place we would not be starting from scratch when tackling individual problems as they arise.

Yet we simply do not have the capacity in quantitative social science that would actually drive such a programme across the country.

How can we develop a good city intelligence system? Ultimately, it is not simply a resources issue. A tremendous amount of Government resources go into this already, but we should not try to solve one problem 160 times in 160-plus local authorities: one overarching 'national government net', rather than many local ones, would be the answer.

Finally, back to the costs. We are used to the idea of 'big science' — mainly elementary particle physics accelerators like CERN – as something that we should support. Yet I have argued for decades that the sort of social science I have been discussing ought to be treated as 'big science'. The investment could be done almost at once and then there would be a national capability for delivering into different city areas. What I think is needed is a 'CERN for cities'. □

Science and technology in local government

Tim Allen

The challenges facing local planners and local government today are complex, and we need to make the most of scientific methods if we are to overcome them. My definition of 'science' for this purpose is a broad one that embraces pure scientific endeavour, but focuses mainly on 'usable' science and technology — and social science too. Overall, more Joseph Chamberlain than Albert Einstein: the former, as mayor of Birmingham during the late nineteenth century, applied the science and technology of the day to improve living conditions and health for the city's population.

It is worth reflecting on the context within which city managers, and local government more widely, operates. We are incrementally dismantling the State as designed during the 1930s and 1940s. And it certainly was a 'designed' State. The agriculture programme introduced after the Second World War is a good example. It set out to industrialise our agriculture with food production as the priority. It took a comprehensive approach that embraced technology and science (both pure and applied) at its core and took them directly to the people working on farms to foster radically new practices. It worked and food production boomed even if the policy failed to respond to the environmental considerations that emerged subsequently.

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We do not seem able to adopt this approach in the 21st century and perhaps lack the confidence to do so. Perhaps it would not be workable. We cannot turn the clock back: society is now too complex and changes too rapidly, it is generationally and geographically too diverse – with increasingly different values and expectations – for such 'top-down' policies to be viable.

For example, a rapidly aging population profile will place huge demands on our resources. Despite the fact that people are living for longer more healthily, the number of people aged 85 and over is projected to double in less than 20 years. We therefore need technological solutions that might enable our elderly people to live longer in their own homes rather than in care. This could include more pervasive use of diagnostics that link homes to the GP's surgery in order to give an early warning of problems such as high blood pressure: in this way we can pre-empt problems rather than just respond to them.

Not only do we have an aging population profile but also a fertility rate higher than at any time since 1972, but with the additional school-age population unevenly distributed across the country and even within cities. How do public services respond after years of reducing school places in response to an expectation of fewer school-aged children?

So, societal change challenges those responsible for local public services: they

need a sophisticated understanding of the current and expected nature of change, and the best that science and technology can offer, to help them respond. In short, this extends the debate beyond areas such as climate change where the scientific dimension is more obviously important.

Resource issues

The economic context for this is really important, and is certainly exercising the Local Government Association, which is a cross-party organisation. Nationally, we face major problems over resources – repaying debt, balancing capital investment against revenue demands and ensuring that investment and lifestyles remain sustainable. Increasingly, local authorities need to frame policies in the light of local conditions and aspirations, enabling and helping citizens to make their own choices about risk, cost and access to social and other services.

This means that the public sector is becoming more of a facilitator than provider of many services – outside a core of remaining universal entitlements and those that are offered to specific groups in particular need. This increasingly means that authorities need a sophisticated understanding of conditions locally, and need to be able to provide much more accurate and real-time information so that individuals can make informed decisions for themselves and anticipate, avoid or mitigate the consequences.

Clearly to achieve this shift involves good communications between the State, in whatever guise, and the public. In this context, today's politicians (certainly those that I work with in local government) are increasingly concerned to reach out to their electorates and communities, and to exploit 21st century communications — Facebook, Twitter and the rest. There is plenty of potential for science and technology to enable better communication.

There are certain dimensions of technology – geographic information systems for instance – that can be key to people accessing services more easily and at lower cost, without going through traditional channels into a council or a public service. There are huge opportunities here. The best councils are doing this already, and doing it in an exemplary fashion, but again uptake is not consistent and there are opportunities to make much better use of the available technologies.

One area where technologies can help is with flooding. Following Tewkesbury, Hull and other recent flooding incidents, there is an expectation that new legislation will place a duty on councils to deal with surface water flooding risk. Realistically, it seems unlikely that sufficient funding will be available to tackle the problem everywhere, so how do people make responsible decisions about where to invest, and where not?

Part of the answer is to understand how technology can point us to the cheapest and best solutions. And we need the best and most sophisticated predictive science to help us understand and assess the risk, and to facilitate decisions about where to deploy available funds to best effect.

In tackling such complex problems we may be able to learn from, and translate, approaches used by scientists when tackling complexity. If we cannot create national 'master' designs that parallel the 20th century approach, then maybe a 'systems' approach to tackling complexity offers a way of approaching problems like flooding.

The systems approach

A systems approach to handling waste, for instance, would involve more than dumping waste into holes in the ground, getting taxed for it and doing a little recycling. It would encompass reuse with new approaches to reusing materials and sustaining products in use for longer before they become waste.

Waste and recycling feature in the Government's environmental targets for local government. Other targets cover disparate topics such as: carbon dioxide reduction from local authority operations; per capita carbon dioxide emissions in the local authority area; tackling fuel poverty; adapting to climate change; reducing nitrogen oxides and primary PM10 particulate emissions through local authority's estate and operations; improving street and environmental cleanliness; and improving local biodiversity through active management of local sites.

For some of these targets to be achieved, a major scientific input is required – in matters of carbon dioxide reduction and biodiversity, for instance. And in others, the more general benefits of a systems approach would be considerable.

And we need direct scientific input into one of the major challenges we face: how to grow green economies without compromising their 'greenness'. We need to devise a sophisticated model of sustainable development by developing 'green' business models, energy efficiency, carbon dioxide and waste, reducing pollution, and sustainable housing.

Yet, a 'scientific' approach can still involve the simplest of technologies. Some years ago, one of our member councils became a unitary authority. They inherited, amongst other things, responsibilities for running transport services. One problem they identified was that disabled people could be empowered if bus services were made readily accessible. They realised that Greenwich had already made progress in that area: what Greenwich had done was to consult a German academic who was, believe it or not, an expert in kerbstones. A simple piece of technology transfer, using the right kind of kerbstones, freed people in wheelchairs to get from their homes to the services they needed. That was brilliant: not fancy technology but simple and appropriate.

A coordinated approach

The point is that a solution had already been found to a problem, and rather than having to solve the problem again – perhaps using much more elaborate and expensive methods – a coordinated approach enabled access to the already available technology.

In conclusion, the public services sector, which is already under pressure, will now be even more challenged in resource terms. As we seek new solutions, there is a huge opportunity for science and technology to come up with some of the answers – helping us do things more cheaply, more effectively, or in different ways. We must build new partnerships between the public services and science and technology: the Local Authorities Research Council Initiative is one forum where we are taking tentative steps to rebuilding that relationship.

It is time to take the Joseph Chamberlain approach, and to rebuild the confidence in science and technology that our Victorian forebears exemplified. We need to apply the latest advances in technology to everyday problems. So it is interesting that Chamberlain's city is now interested in establishing a centre of excellence in fuel cell technology, drawing upon their tradition in manufacturing and the motor industry. Fuel cell technology may or may not be the future, but it is one possible future with the potential to generate a 21st century version of past glories. ☐

What was the role of mathematical modelling in creating the circumstances leading to the credit crunch – and are there lessons to be learned? This was the subject of a dinner/discussion at the Royal Society on 10 June 2009.

The role of models in directing economic activity

John Kay

The principal risk management tools used by the world's major banks and, crucially, imposed on them by the regulatory machine, are based on a structure called 'Value at Risk Modelling'. It was developed in the early 1990s in JP Morgan, the American bank. The basis of this modelling was that a number of discrete asset classes (which might be loans, securities or mortgages) were defined and then a matrix constructed, based on historical estimates of the variance of returns on each kind of asset and the covariance between them. This variance/covariance matrix was used to calculate the 'value at risk': it gave a value for the amount you might lose, let us say, on one day in a thousand.

The models depended on two groups of assumptions. One was that the data were essentially normally distributed. The second was that the data, and particularly the covariances between them, were stable over time. These twin assumptions are still described as the 'centre piece' of this technique.

Problems with the model

On an everyday basis, these models worked pretty well. They described the normal experience of banks over a period of years. There were, however, a couple of problems which were really evident from an early stage. One concerned the normality of the distribution. Although speculative market price changes do very often follow a normal distribution, these distributions have what people describe as 'fat tails' – there are many more extreme events (and particularly extreme downward events) than the normal distribution would predict.

The other issue was the stability of the underlying variance/covariance matrix. Almost necessarily, the matrix was derived from a period of relative stability – because that was characteristic of the period from which the data were collected. The Asian crisis of 1997 which spread across the world's financial markets raised the question whether covariance assumptions which held in ordinary times would hold when markets were subject to extreme strain and turbulence.

Professor John Kay FBA is one of Britain's leading economists, has held chairs at Oxford, London Business School and the London School of Economics, and writes a weekly column in the *Financial Times*. He is the author of *The Truth about Markets*, which anticipated the present crisis, and *The Long and the Short of It*, which describes it.

Rating agencies also used financial models. These agencies grade securities, particularly bonds; they examine the creditworthiness of governments and companies and assign their bonds a rating. The first four categories for the security of bonds are known as 'investment grade', the lower ones are commonly called 'junk'.

Rating agencies expanded their role from the late 1980s. First, the assets held by banks and other institutions attracted different risk ratings depending on the grading they received from the rating agencies. Second, through a process called 'securitisation', banks would take packages of loans and sell these off, or sell them in tranches. Rating agencies found a new job in terms of rating the synthetic securities that were created by the activities of banks.

The models which rating agencies used to assess the security of these packages and to attach ratings to them were fundamentally the same type as those used by the banks in terms of 'value at risk'. As banks sold ever-more complicated versions of these packages, they hired people who were familiar with the models the rating agencies used. One result was that banks were able to 'reverse-engineer' the packages, designing them to meet the rating agencies' criteria. This was all part of the extraordinary process by which bundles of rather ropey mortgages could receive the same security grading as bonds issued by the US Treasury!

So there are two important areas in which financial modelling contributed to what we recognise in the current crisis. Models gave banks and regulators false reassurance about the effectiveness of their internal risk management processes: and through rating agencies they underpinned the processes of securitisation and regulatory arbitrage, which allowed the appearance of profits generated by complex balance sheets.

This all came unstuck in the 'credit crunch' starting in July/August 2007. There was suddenly increased uncertainty about the value of assets that banks held on their books. Uncertainty spread to the value of the banks holding these assets and thence to a whole variety of other assets around the world.

So that is how financial modelling is associated with our current crisis and our current problems. Now this is not the

DISCUSSION

Problems with the models

The academic financial mathematics community has consistently and over a long period warned of problems, in particular the assumption of normality. Indeed, the FSA had been well aware of the academic debates over the appropriateness of the models being used, and had at times raised these issues in regulatory discussion with the sector. But what were these institutions to do with this knowledge that the modelling might be problematical? The hard fact is that, in spite of such theoretical arguments, there has been a powerful business judgment overlay: the approach was generating very substantial profits and there was no incentive to change it.

first time that people have talked about deficiencies in these models. Should we then elaborate these models to make them, in a obvious sense, more realistic? I am sceptical about that. Take a simple, but very different problem: you wait for a bus at the bus stop, you know that they are due to arrive every 10 minutes, you know the frequency, but you do not know the exact schedule. A simple model for this kind of situation, is to assume that buses arrive at a fixed 10 minute interval, and the longer you wait for a bus, the higher the probability that the bus would arrive in the next minute.

Unfortunately, we do not fully believe that kind of model. There comes a time when we abandon the wait for the bus and decide to make the journey in some other way – abandoning the model as well because it does not seem to work on this occasion.

We could build in all manner of other factors, possible events, etc, to make the model reflect the real world better. I do not have to spell out that such a model is not imaginable and indeed that there will still be factors which you cannot conceivably know about.

There are two different sources of uncertainty about the probabilities in models. One is the stochastic element built into the model you are computing, the other is the underlying uncertainty about the relation of the elements of the model to the particular world in question. In almost all of the situations we confront – in business, economics, finance and politics – our judgements about how we should use models are a combination of the 'in-model' risk determined by the mathematical structures we have created and the 'off-model' risk that is created by our uncertainties to how well the model actually applies to the world it seeks to describe.

Metaphors

That leads us, I think, to a fundamental observation about the way in which one can use models: we are looking for models that are useful and are illuminating rather than models which are true. The model of the arrival of buses is neither a true model nor a false one; it is useful in certain situations but sometimes we adopt other models to complete our journey.

An economist called George Akerlof illustrated a particular process by reference to what a 'market for lemons'. A 'lemon' was a car that had been made on a Friday afternoon, when people had come back from the pub, so it was regularly developed unexplained faults. Akerlof suggested that the characteristics of a lemon were that it was relatively easy for the owner to recognise that he had bought one, but it was quite difficult for a purchaser to recognise that he was getting one.

Now if a proportion of the car stock were lemons, the second-hand price of cars should reflect that. However, it would not then be attractive for people with good cars to put them on the market, although it would be very attractive for people who owned lemons. Thus, the proportion of lemons on the used-car forecourt would be higher than in the population as a whole – so the price of used cars would fall still further and that would accelerate the process. Once people start to recognise this, the prices fall until one gets to the point where the market simply dries up. That is, indeed, what happened to the market for complex securities after 2007.

The Akerlof model has nothing to do with the used car market; it is a metaphor and one you can apply quite effectively to situations like the market in toxic assets. This is, I believe, the role of models in economics. They are metaphors; some of them are mathematical metaphors, some of them are literary metaphors. Some are more powerful than others. It is not, however, meaningful to ask whether they are true or not. We should have a mental toolkit of these and it is a matter of judgement and skill to decide which particular tools to take from the toolkit at any particular time. □

The problems of mathematical modelling

Paul Sharma

Why is the use of mathematical models within the financial services sector particularly problematical compared to, for example, the use of mathematical models in the study of physical phenomena (floods, or earthquakes, etc)? The first remark I want to make, though, is that there is probably no alternative. There is probably no realistic alternative to the widespread use of mathematical models, of mathematical analysis, or if you prefer 'quantitative' analysis for financial services. At some point, the more subtle forms of knowledge need to be rendered into what are quite often yes/no decisions or decisions whose outcome must be a specific number. A bank must decide how much capital it needs to hold and that requires a decision that is a single number. A trader must decide 'do I buy or sell this security?'

There is no way of avoiding decision-making, despite the presence of uncertainty. The question is, how does one arrive at those decisions? In today's world of finance, the answer cannot be purely intuitive: it cannot be purely a matter of judgement. In fact, there is a significant body of evidence to suggest that the widespread use of 'naked' judgement is itself deeply problematical. If you were to resolve questions such as how much capital does a bank need purely by unaided judgement there would be questions of competitive fairness and of due process of law.

There is no realistic alternative to a significant reliance being placed on mathematical models in regulatory and management decision-making within the financial services sector. But these models themselves are very problematical, for a number of reasons.

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The first reason is what I call a 'self-referential' problem. With mathematical modelling of, say, the frequency of hurricanes or the frequency or severity of earthquakes, no matter how good my model gets it is not going to change the thing I am seeking to measure. A mathematical model assessing credit risk, on

the other hand, may affect my behaviour in the granting of credit. My change of behaviour affects the behaviour of the people who are seeking credit. In other words, the very presence of my model affects the thing that I am seeking to measure.

Traders adopt and apply new modelling approaches, but so does everybody else as word spreads around the market. In other words, I have the problem of modelling the behaviour of people who are using models. So as soon as you begin to model the financial services world, you change the thing you are modelling.

Another reason why applying mathematical models to financial services is difficult, is the extreme event problem. Now modelling extreme events in financial services does not make us unique. People who study floods model extreme events, people who study hurricanes model extreme events. However, in the financial services world the extreme event is not simply a larger version of the normal event.

The physical world

There are instances in the physical world where the same problem arises. Suppose I were doing mathematical modelling of wave heights and the frequency of large waves, and I collected a large amount of information. No amount of data, or data analysis, would give me any real help in modelling tsunamis because the causal process for ordinary tidal waves is quite different from that of a tsunami. Likewise one suspects (one does not fully know) that while we have a lot of data about normal behaviour, including 'large' normal behaviour, the 'killer' events represent a different kind of occurrence and have a different causal process behind them. That makes accessing that kind of event, by a mathematical model, particularly problematical.

One can see this illustrated in the models that a number of people use in the financial services world for operational risk. Banks and insurance companies tend to take one of two approaches. There is the approach which says that an extreme operational risk loss is the consequence of the simultaneous failure of a number of different controls. The failure of any one is an 'ordinary' problem event and therefore the 'extreme' problem event is the simultaneity of a number of 'ordinary' rare failures. People who take that point of view of course consider themselves to be 'data-rich' because they have data about these 'ordinary' semi-rare control failures: they can infer from these semi-rare ordinary control failures what the probabilities and severities are of their coincidence leading to a much more severe control failure.

Then there are people who say 'no, the causal mechanism for my medium and small size failures (in terms of operational risk) is quite different from the causal mechanism for the extreme failures'. No amount of looking at market to market mis-pricing data would tell me my 'Nick Leeson risk'.

Now while one can discuss who is correct in calculating operational risk, I think the more one looks at extreme market dislocations, the more one sees that this is not simply an extreme event of the ordinary way in which the markets behave.

The third reason spans beyond the financial services sector and that is the problem of data – and also the problem of the preferences of the individuals who are creating the models. Research shows that it is really the comparative lack of data that is the main limiting factor preventing models from being better than they are. So, therefore, this is where resources should be directed.

The attraction of mathematics

However, the people creating the models did not get their PhD in mathematics and join this particular financial services company in order to engage in laborious data mining; they enjoy the mathematics and making more and more sophisticated models. Therefore the resources came to be disproportionately channelled into increasing the sophistication of the model, often where the benefit (given the data limitations) is marginal. The data limitations are partly simple data cleanliness problems and they are partly inherent because the data needed is the kind that informs you about these rare, extreme events.

There are ways of proxying the rare, extreme events, though, and there are creative ways of looking for proxy data, but that is a relatively neglected subject compared with ways of making models more mathematically sophisticated. There remains a certain lack of interest in addressing the data problem. □

DISCUSSION

Models of real life?

Any ambition to add further refinement and complexity to mathematical models of financial systems is misguided since they can never fully reflect reality. There is a difference between modelling the natural world and modelling human behaviour in the social and economic sciences. The question remains, though: if not modelling, then what? The most appropriate answer seems to be, a combination of: better understanding of complex systems behaviour and behaviourally-based models; simplification and abstraction to the essentials; with the addition of the essential element of practical experience and judgement.

Did over-reliance on mathematics create the financial crisis?

David Hand

The Turner Review[1] enumerates the events leading up to the crisis. These produced an environment stimulating financial innovation and a huge growth in securitised credit instruments and derivatives. And this is where the mathematics comes in: there has been much greater mathematical complexity in the tools for modelling and pricing financial risk.

Was the mathematics wrong? The short answer is 'no'. Mathematics is concerned with deducing the consequences of a given set of initial premises. It is possible to make mistakes in the deductive process but here, since so many people were using and had checked the deductions, it is essentially inconceivable that the mathematics was wrong. Yet, while the deductive mathematics underlying a measure may be fine, the assumptions on which the mathematics is

built may not be so robust.

The notion that sophisticated securitised credit instruments improve financial stability appears to have been a fundamental premise, a core belief, but with little or no supporting empirical evidence. Similarly, there appears to have been an assumption that natural selection in the financial markets would mean that innovations, and in particular mathematical innovations, would be beneficial, since those that did not work would be selected out.

In fact, anyone familiar with evolutionary processes knows that evolution can lead in unpredictable directions, especially in complex environments. In any case, when we use the term 'beneficial' we mean beneficial to the economy, and the people in it. Yet evolution does not tend towards a pre-set goal.

A familiar premise of the mathematical models was that assets could be sold rapidly and easily if necessary. But, as we saw some years ago, with the collapse of Long Term Capital Management, this is not true if everyone tries to do it simultaneously. At a lower level, there are also criticisms of things such as assumed distributional forms, and the independence of events and players. As statisticians know very well, normal distributions do not occur in nature.

Useful tools

The eminent statistician George Box said that 'all models are wrong, but some are useful'. This means that one should always have a healthy scepticism about models. Furthermore this scepticism should be greater for some usages: consideration of tail areas of distributions should engender more scepticism than results based on the central limit theorem. To put it bluntly, one should avoid the hubris of assuming that one's models are correct.

The late Leo Breiman said "when a model is fit to data to draw quantitative conclusions ... the conclusions are about the model's mechanism, and not about nature's mechanism ... It follows that if the model is a poor emulation of nature, the conclusions may be wrong." My own view here is that we are really trying to model human behaviour. And humans can be unpredictable. They can even be perverse.

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When dealing with human beings we are not merely dealing with intrinsic randomness – as we might in quantum physics. When we study human beings, we certainly have intrinsic randomness but we have other factors too – human motivations, intransigence, greed, and so on. Electrons may have their uncertainties, but they are not greedy.

That brings me to another question. Was it in fact inappropriate mathematics?

Models such as pricing models are fine, in isolation, and at a low level. Yet difficulties can arise when they are put together and embedded in a larger system. In such a situation a model of the entire complex system, and not of merely a tiny part of it, is needed – an econometric model, in fact.

A concrete example of this sort of limitation is in automated trading systems, which all react the same way to given market conditions, as we discovered in 1987. The correlation between their behaviour induces a massive swing in one direction or another – a run on a stock or a drying up of liquidity.

Over-reliance?

If there was an over-reliance on mathematical models it was placed on them by the higher echelons of management. Perhaps the phrase 'naive belief' might be better than over-reliance. The only defence I can think of, and poor one at that, is that the mathematical models were developed after the senior bankers had begun their careers and were already in senior posts. This at least explains, though it does not justify, why they did not understand what they were doing.

One might ask, were managers in fact given warnings on which they failed to act? Well, if a given strategy appears to be earning large sums of money, and in particular large sums of money for you, then you might not be inclined to look too rigorously at criticisms of it. This is, perhaps, a natural human trait: along with greed, an unwillingness to believe bad news, and a tendency to follow the herd.

There have been many financial crises in the past. One has to ask whether the causes of this one are different in kind. It is certainly true that mathematical financial innovations played a role. It is also true that, had people been more aggressively warned about their limitations, had they listened and taken those warnings on board, then things might well have turned out differently. But for that to happen, many other things needed to be done differently too.

At bottom, can I really argue that one cannot blame the mathematicians? They built and applied the tools, so surely they should share the responsibility? This is, of course, well-worn ethical ground, having been covered in other contexts, such as the relation between nuclear physicists and the atomic bomb. I believe that it is nonsensical to say that everyone should share the blame. In a mugging, who bears the responsibility: the man who wields the knife, the owner of the cutlery factory which made it, the factory's receptionist?

I think it would be a terribly retrograde step if we stepped back from the use of quantitative tools. These kinds of tools have revolutionised so many aspects of life in general and have had an immense impact for good. However, the mathematical tools have to be used in a proper context. Putting the 'quants' in a back room, instructing them to work their mathematical magic, and then blindly applying the results to the outside world without considering the wider implications is a recipe for disaster. And we now have the product of that recipe. □

1. The Turner Review: www.fsa.gov.uk/Pages/Library/Corporate/turner/index.shtml

The full version of this talk can be found on the Foundation website at: www.foundation.org.uk

DISCUSSION

Mathematics and statistics

There may be additional problems with the use of continuous variables to represent discrete price movements. It is essential to gather data of extreme events, otherwise the modelling of risk premiums will be based on periods of time that do not reflect what is happening today, an example being the modelling of risk premiums based on mortgage history that only went back to the 1990s, a period of growth not decline in prices. Many such issues are more in the domain of the statistician than the mathematician, though.

The Lord Lloyd of Kilgerran Lecture was given by Professor David Delpy, the Chief Executive of the Engineering and Physical Sciences Research Council (EPSRC), at a meeting on 10 December 2008.

Lighting up the brain

Delivering the Lord Lloyd of Kilgerran Lecture – through which the Foundation recognises individuals who have applied science and technology for the benefit of society – Professor David Delpy outlined the 25 year path that had led from an initial understanding of the transparency of human tissue and the way it responded to light, to the development of medical instrumentation which enabled doctors to measure the patterns of oxygenation in the brains of new-born babies.

He showed the differential effects of the absorption of light by oxygenated and deoxygenated haemoglobin. With infrared light it was possible to see the pattern of blood vessels beneath the surface skin so that there could for example be accurate insertion of a needle into veins.

This technique was extended by the development of infrared spectroscopy machines which enabled oxygen levels in the blood of baby brains to be observed in real time. After initial funding through Research Councils and Vickers Medical, long-term funding had been secured through a Japanese company, Hamamatsu Photonics.

Infrared spectroscopy could now show changes in oxygenation and indeed diminishing oxygenation in relation to breathing and heart beats. It could also be used for muscle exercise studies, which could be valuable, for example, in Olympic training. Professor Delpy noted that Duke University in the USA, where some of the original research had taken place, had patented work done there but these patents had not been exploited. This meant that development had been hindered in the USA, where the patents applied, to the benefit of EU and other countries where the patents did not apply.

Reacting to stimuli

Further developments had led to the ability to show activity in the brain which enabled researchers and practitioners to better understand the brain's reaction to stimulus or pain in a patient who would not keep still or be restrained. Professor Delpy described how the light followed random paths as it passed through brain tissue. Sophisticated analysis of the detected signal enabled brain features to be observed. The techniques had value not only in the brain, but in other parts of the body such as the breast, where the results of treatment of tumours could be observed over time without invasive surgery or high doses of X-rays.

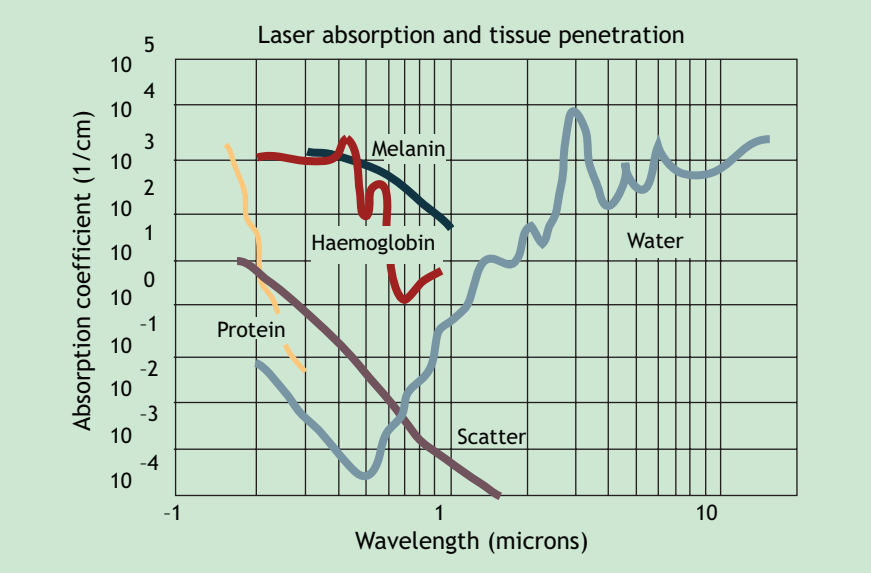
He drew two important lessons from the development process – first, the importance of team working, and second, reading broadly around and outside one's own narrow discipline. The teams he had worked with were interdisciplinary and, although focussed and led, had been given the opportunity and discretion to develop their own ideas. Reading outside a subject was the best way of discovering insights which others had and which could have benefit for one's own project. It was, he said, always the journal 'next door to the one that you ought to be reading' that contained the ideas which might be of real value.

Long term commitment

In the discussion that followed, a number of speakers expressed their appreciation of the willingness of Hamamatsu to undertake long term funding for the project, compared with the short term perspective of some UK companies. Was this the result of differing cultural perspectives, they wondered? It was noted that in the USA, the UK and other EU countries there was an emphasis on returns within a shorter time period than in Japan, where there was a social and corporate tradition of building up new industries over the long term. Yet Japanese practice seems now to be coming closer to the Western norm.

Concern was also expressed about the impact of over-zealous protection of intellectual property (IP). Professor Delpy felt that there was a real danger in universities being too keen on protecting their research through IP; if they did, product development could be impeded. There was no need to worry about whether a good idea would be picked up if not protected, nor that the prizes would go to others than the originator of the research. Commercial success came through product development and the application of know-how. That is what academics must understand and if they wish to share in the results they must themselves understand how commercial products were developed.

The Lord Lloyd of Kilgerran Lecture is given annually and nominations are welcomed by the Foundation. For more information, please contact the Foundation for Science and Technology via email at office@foundation.org.uk, or by telephone on 020 7321 2220. □



The absorption of light by major tissue chromophores.

Reasoned advice for policy makers

Archimedes

A principal aim of the Foundation dinner/discussions is to debate, and perhaps influence, issues where major policy decisions are in the offing. The choice of subject for the 27 June meeting 'The Future of Higher Education' (see pages 5-8) was, therefore well chosen. We all know that Government spending is going to be savagely curtailed; it is inconceivable that the education budget will not suffer; and popular pressure will want to see politicians preserve spending on primary and secondary education rather than on the tertiary sector. So what messages would policy makers take away for the 27 June discussion that would help them frame policies?

Disappointingly few. If I had been a policy adviser wondering how to cope with a severe restriction on educational spending, I would have hoped to have gained some insights into both priorities and sacrifices. For example, the standard of students leaving schools is appalling; is it therefore a priority to preserve or enhance school spending, at the possible expense of tertiary education? Are the needs of the 50 per cent who do not have tertiary education more, or less, important than the 50 per cent who do? Within tertiary education, should higher education (universities) be the priority and further education (colleges) be cut? If so how are we going to enhance the technical and vocational skills we so badly need? If universities are to suffer, should research be preserved at all costs, and the savings fall on teaching? Should certain forms of teaching or research suffer in order to preserve spending on others?

It is not the fault of the presenters if such issues are not discussed. Inevitably they will be constrained by official caution, or the need to press on one particular issue. If one of them does put forward a contentious proposal, it needs to be challenged. It is for the audience in the hall, who are invited for their knowledge and wide range of interests, to make the running. To some extent it did; there were different views on how many institutions should do research if excellence was to be achieved; or on whether the balance between access and excellence was right.

Yes, institutions should be more diverse; but Sir John Chisholm's view that the diversity should come about through the market for graduates, rather than through some decisions about social need, was not challenged. Yes, tuition fees should be raised, but on what principle, and how and where, was left in limbo. Yet, overall, too many speakers thought that reference to the excellence of the UK science achievement, the poor standard of schools, and the importance of universities' independence was enough. But it does not help policy makers to choose.

Perhaps this audience has an excuse. If the Prime Minister will not acknowledge that severe cuts will be needed in public services, including education, why should they consider seriously policies for such cuts? However, I believe the audience at Foundation events is too sophisticated to accept such fantasies. They should look harder at the policies which fiscal and tax pressures will force to be considered, and help policy makers to understand how such policies can be implemented with least damage. □

Archimedes is an experienced observer of the evolution of public policy who contributes occasional comments on topical issues.

Recent dinner/discussions organised by the Foundation for Science and Technology are listed below. Summaries of these and other events – as well as the presentations of the speakers – can be found on the Foundation website at: www.foundation.org.uk

Christmas Reception
9 December 2009

Speaker — **David Willetts** MP for Havant and Shadow Minister for Universities and Skills
Respondents — **Professor Alan Thorpe**, Chair Research Councils UK and Chief Executive, Natural Environment Research Council
Sir Anthony Cleaver, Chairman, EngineeringUK

Synthetic Biology — a threat or an opportunity?
18 November 2009

Professor Richard Kitney OBE FREng, Professor of Biomedical Systems Engineering, Department of Bioengineering, Senior Dean and Director of the Graduate School of Engineering and Physical Science, Imperial College London
Professor Pamela A Silver, Director, Harvard University Graduate Program in Systems Biology, Department of Systems Biology, Harvard University
Professor Nikolas Rose, Director, BIOS Research Centre for the study of Bioscience, Biomedicine, Biotechnology and Society, London School of Economics and Politics

A national infrastructure for the 21st Century
11 November 2009

Sir Mark Walport FMedSci, Director, The Wellcome Trust and member of the Prime Ministe's Council for Science and Technology
Professor Brian Collins FREng FIET, Chief Scientific Adviser, Department for Business, Innovation and Skills and Department for Transport
Professor Tim Broyd FREng, Group Technology Director, Halcrow Group and Chair, Policy Panel, Institution of Civil Engineers

The impact of climate change on Scotland
29 October 2009

Professor Geoffrey Boulton OBE FRS FRSE, General Secretary, The Royal Society of Edinburgh, and Member PM's Council for Science and Technology

Professor John Mitchell OBE FRS, Director Climate Science, The Met Office
Dr Andrew Dlugolecki, Visiting Fellow, Tyndall Centre, University of East Anglia and Chartered Insurance Institute

The Digital Britain Report - keeping up with the competition from other nations
14 October 2009

Dominic Morris CBE, Strategic Director, Digital Britain, Departments for Business, Innovation and Skills, and Culture, Media and Sport
Professor Dame Wendy Hall DBE FRS FREng, President, Association of Computer Machinery (ACM), School of Electronics and Computer Science, Southampton University
Dr Alfred Spector, Vice President, Research and Special Initiatives, Google
Erik Huggers, Director, Future Media and Technology, BBC

Beyond the recession - what can science and innovation partnerships do for you?
7 October 2009

Professor Peter Gregson FREng, President and Vice-Chancellor, Queen's University Belfast
Eoin O'Driscoll, Chairman, Forfás, Ireland's National Policy Advisory Board, and Managing Director, Aderra
Dr Iain Gray FREng, Chief Executive, Technology Strategy Board

Engineering: turning ideas into reality — the House of Commons Select Committee Inquiry
7 July 2009

Phil Willis MP, Chair, House of Commons Select Committee on Innovation, Universities, Science and Skills
The Lord Browne of Madingley FRS FREng, President, The Royal Academy of Engineering
Richard Olver FREng, Chairman, BAE Systems
The Rt Hon the Lord Drayson, Minister for Science and Innovation, Department for Business, Innovation and Skills (*note responding to the debate*)

The Future of Higher Education in England
17 June 2009

Sir Alan Langlands FRSE, Chief Executive, Higher Education Funding Council for England
Professor Michael Arthur FMedSci, Vice Chancellor, University of Leeds
Sir John Chisholm FREng, Chairman, QinetiQ and Chair, Medical Research Council

Financial models — key tools for risk analysis or the vector of global financial collapse?
10 June 2009

Professor John Kay FBA, Writer and Columnist for the *Financial Times*
Paul Sharma, Director, Wholesale Prudential Policy, Financial Services Authority
Professor David J. Hand FBA, President, The Royal Statistical Society and Head of Statistics, Imperial College London

Can city managers make better use of science?
3 June 2009

Boris Johnson, Mayor of London
Sir Alan Wilson FRS FBA, Centre for Spatial Analysis, UCL and Chairman, Arts and Humanities Research Coun
Professor Tim Allen, Director for Analysis and Research, Local Government Association

What should be the priorities for medical research in the UK?
20 May 2009

Sir Leszek Borysiewicz FRS FRCP FMedSci, Chief Executive, Medical Research Council
Sir John Bell FRS PMedSci, President, The Academy of Medical Sciences and Chairman, Office for Strategic Coordination of Health Research
Sir David Cooksey GBE, Chair, Bioscience Innovation and Growth Team

Can a value be put on biodiversity?
6 May 2009

Professor Bob Watson CMG, Chief Scientific Adviser, Department for Environment, Food and Rural Affairs
Pavan Sukhdev, Study Leader for TEEB and Project Leader Green Economy, UN Environment Programme
The Lord May of Oxford OM AC Kt FRS, Department of Zoology, Oxford University

How fast can the rate of change of technology be accelerated to reduce carbon emissions from transport?
29 April 2009

Professor Brian Collins FIET, Chief Scientific Adviser, Department for Transport and Department for Business, Enterprise and Regulatory Reform
Professor Dan Sperling, Director, Institute for Transportation Studies, University of California, Davis
Professor Neville Jackson, Group Technical Director, Ricardo
Professor Julia King CBE FREng, Chair, King Report on Low Carbon Cars, Vice-Chancellor, Aston University

Raising skills in the UK workforce — mental capital, skills and wellbeing
1 April 2009

Professor Tom Kirkwood CBE, Institute for Ageing and Health, Newcastle University
Lord Layard FBA, Centre for Economic Performance, London School of Economics and Political Science
The Rt Hon John Denham MP, Secretary of State, Department for Innovation, Universities and Skills

To what extent should UK funding for science and innovation be focussed?
4 February 2009

A lecture by **Lord Drayson of Kensington**, Minister of State for Science and Innovation at the Department for Innovation, Universities and Skills.
Responses by:
Lord Rees of Ludlow OM Kt PRS, President of The Royal Society
Sir Peter Gershon CBE FREng, speaking on behalf of The Royal Academy of Engineering
Dr Peter Ringrose, Chairman of the Biotechnology and Biological Sciences Research Council and Member of the Technology Strategy Board
Trudy Norris-Grey, Chair, Innovation and Science Committee of the Confederation of British Industry (CBI)

Lighting up the brain — a 25 year journey from basic science to commercial instrument
10 December 2008

Professor David Delpy FRS FREng FMedSci, Chief Executive, Engineering and Physical Sciences Research Council

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