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THE FOUNDATION FOR SCIENCE AND TECHNOLOGY

COUNCIL AND TRUSTEES

THE FOUNDATION FOR SCIENCE AND TECHNOLOGY

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#ThisisEngineering aims to enthuse a new generation

#ThisIsEngineering is a new campaign by the Royal Academy of Engineering in collaboration with EngineeringUK and industry partners. It aims to give more young people from all backgrounds the opportunity to explore a rewarding engineering career across a wide range of industries from film, to sport, gaming and music.

It comes as the Government has designated 2018 as the Year of Engineering in a bid to tackle the engineering skills gap and widen the pool of young people who join the profession.

ROYAL ACADEMY OF ENGINEERING

#ThisisEngineering is backed by a consortium of major engineering companies, and has been created in response to significant demand for engineering talent in the UK. Findings from a forthcoming EngineeringUK report show that there is an annual demand for at least 124,000 engineers and technicians with core engineering skills, and an additional 79,000 roles that require engineering knowledge and skills alongside other skill sets.

On 1 February, Business Secretary Greg Clark also announced, as part of the Industrial Strategy, a Government investment of £184 million for 41 UK universities to help train the next generation of world-class engineers and exceptional scientists at British universities.

www.yearofengineering.gov.uk
www.raeng.org.uk

Sam Gyimah is new science minister

Policy Exchange (CC-BY-2.0)

Sam Gyimah MP has been appointed Minister of State for Universities, Science, Research and Innovation. As Minister for Higher Education, his responsibilities cover both the Department for Business, Energy and Industrial Strategy (BEIS) and the Department for Education. He took up the post on 9 January. He was elected the Conservative MP for East Surrey in 2010.

Previously, he had held the posts of: Parliamentary Under Secretary of State at the Ministry of Justice from July 2016 to January 2018; Parliamentary Under Secretary of State at the Department for Education from May 2015 until July 2016; and Parliamentary Secretary at the Cabinet Office from July 2014 until March 2015.

He spent five years working for Goldman Sachs and then went on to help build and develop a number of small businesses in the training, recruitment and internet sectors.

His predecessor as Science Minister, Jo Johnson MP, has been appointed Minister of State at the Department for Transport and Minister for London.

Decarbonising the transport sector

Within a week of taking up his new role as a Minister in the Department for Transport, Jo Johnson set out the Government's ambition to phase out all diesel-only trains by 2040. Referring to the already-adopted target to end the sale of all new conventional petrol and diesel cars and vans in the UK by 2040, he argued that the rail industry would have to 'clean up its act' as well.

In a speech to the Knowledge Quarter conference held at the British Museum on 12 January, he noted that in absolute terms, carbon emissions from rail had increased by 33% since 1990. And he told his audience that this state of affairs could not continue. In order to tackle the problem "with the urgency it deserves", he committed the Government to setting tough new environmental performance goals for each rail franchise.

Last summer, the UK Plan for Tackling Roadside Nitrogen Dioxide Concentrations was published by Defra and the Department for Transport. It outlines how councils with the worst levels of air pollution at busy road junctions and hotspots will be expected to take robust action. While this is focussed on delivering nitrogen dioxide (NO_2) compliance at the roadside, the Government plans to issue a comprehensive Clean Air Strategy which will address other sources of air pollution in 2018.

Local authorities will be able to bid for money from a new Clean Air Fund to support improvements which will reduce the need for restrictions on polluting vehicles. This could include changing road layouts, removing traffic lights and speed humps, or upgrading bus fleets.

PM announces new Institute of Coding

The next generation of digital specialists could be created through a new Institute of Coding, a consortium of more than 60 universities, businesses and industry experts set to receive £20 million to tackle the UK's digital skills gap.

Speaking at the World Economic Forum 2018 in Davos, Prime Minister Theresa May spoke about how the Institute of Coding, a part of the Government's efforts to drive up digital skills through the Industrial Strategy, will equip people of all ages with the skills they need.

The consortium is formed of businesses including IBM, Cisco, BT and Microsoft, small and medium-sized enterprises (SMEs), 25 universities, and professional bodies such as the British Computer Society and CREST.

The 25 universities involved, led by the University of Bath, range from sector leaders in business and computer science (UCL and Newcastle University), experts in arts and design (University of the Arts) to specialists in widening participation and outreach (Open University and Birkbeck, University of London).

Successful launch promises low-cost, high-payload spaceflight

Space X, the American developer of rockets and spacecraft, successfully launched its Falcon Heavy rocket from Cape Canaveral, Florida, on 6 February. It is designed to carry payloads of up to 64 tonnes into low earth orbit. That is three times as much as the European Space Agency's Ariane 5 and nearly twice as much as the new rocket's nearest rival, the Delta IV Heavy, according to Space X. Indeed, only the massive Saturn V rocket used on the Apollo moon programme could deliver more payload into orbit.

SPACEX – FALCON HEAVY DEMO MISSION (CCO)

The Falcon Heavy is also partly reusable, with the two side boosters landing safely afterwards. The third, central booster was lost, something the company later ascribed to its running out of ignition fuel.

The founder of Space X, Elon Musk, believes that the new rocket with its increased payload and partial recyclability could represent a 'game changer', by reducing the cost of launches dramatically. He believes that the cost of a Falcon Heavy launch would be less than $100 million, compared with more than more than $400 million for its main rival.

One of the other main talking points about the launch was the choice of payload for this inaugural venture: Musk's Tesla sports car with a space-suited dummy in the driver's seat and a David Bowie soundtrack.

www.spacex.com/falcon-heavy

Government aims to make the UK the 'most innovative nation'

The Government launched its Industrial Strategy White Paper on 27 November 2017, setting out its vision for how Britain can build on its economic strengths, address its productivity performance, embrace technological change and boost the earning power of people across the UK.

With the aim of making the UK the world's most innovative nation by 2030, the Government plans to invest £725 million over the next three years through its Industrial Strategy Challenge Fund to respond to some of the major global challenges and the opportunities faced by the UK. This will include £170 million to help transform the construction sector helping to create places to live and work that are affordable, safer, healthier and which use less energy.

There will also be up to £210 million to improve early diagnosis of illnesses and develop precision medicine for patients across the UK.

The White Paper also confirmed that the Government would be pressing ahead with a series of Sector Deals. The first of these sectors to participate in these strategic and long-term partnerships with Government are construction, life sciences, automotive and AI. The partnerships will be backed by private sector co-investment.

• See also page 7 of this issue.

www.gov.uk/government/topical-events/the-uks-industrial-strategy

Latest research finds global ozone levels 'not recovering'

The ozone layer is recovering at the poles, but unexpected decreases in part of the atmosphere may be preventing recovery at lower latitudes, between 60°N and 60°S (London is at 51°N), according to new research.

Global ozone has been declining since the 1970s owing to certain man-made chemicals. Since these were banned, parts of the layer have been recovering, particularly at the poles. The new result, published in the European Geosciences Union journal *Atmospheric Chemistry and Physics*, finds that the bottom part of the ozone layer at more populated latitudes is not recovering.

The cause of this decline is not certain, although the authors suggest a couple of possibilities. One is that climate change is altering the pattern of atmospheric circulation, causing more ozone to be carried away from the tropics.

The other possibility is that very short-lived substances (VSLSs), which contain chlorine and bromine, could be destroying ozone in the lower stratosphere. VSLSs include chemicals used as solvents, paint strippers, and as degreasing agents: one is even used in the production of an ozone-friendly replacement for CFCs.

Study co-author Professor Joanna Haigh, Co-Director of the Grantham Institute for Climate Change and the Environment at Imperial College London, said: "The potential for harm in lower latitudes may actually be worse than at the poles. The decreases in ozone are less than we saw at the poles before the Montreal Protocol was enacted, but UV radiation is more intense in these regions and more people live there."

www.atmos-chem-phys.net/18/1379/2018

The role of the Academies in providing independent advice to Government

David Cannadine

Professor Sir David Cannadine PBA FRSL FSA FRHistS is an historian of modern British history from 1800 to 2000. He succeeded Lord Stern as President of the British Academy in July 2017. He is Dodge Professor of History at Princeton University, a Visiting Professor of History at Oxford University and Editor of the Oxford Dictionary of National Biography. He has previously taught at the University of Cambridge and Columbia University, New York. He was Director and Professor of History at the Institute of Historical Research from 1998-2003. (Picture courtesy Benedict Johnson)

Among other things, governments are in the business of serious decision making. To do this in the absence of good evidence and advice is foolhardy at best, at worst it can be disastrous. History is littered with examples of where governments have proceeded without these, with significant adverse consequences. For example, in the 1990s there were major failings in the way evidence was sought and used in tackling the BSE crisis: by 2000 this had cost the government £3.7 billion and damaged public trust[1]. Many other examples can be found in the devastating book co-authored by Anthony King and Ivor Crewe, alarmingly and appropriately entitled *The Blunders of our Governments*[2].

We are living in an age of vast and fast-moving technological change. Our world is increasingly complex and across the next five years the Government will be taking some momentous and far-reaching decisions in relation to a number of issues. These range from withdrawal from the EU, responding to the forces of globalisation, climate change and dealing with the disruption brought about by technological transformation. The stakes of poor decision making by Government have rarely been higher.

The good news is that there is a rich resource of high quality evidence available for politicians and civil servants to use, as the UK has a long and distinguished track record of research excellence on which Government can draw. Discovery and innovation helped the UK become an economic powerhouse during the Enlightenment and the Industrial Revolution. As the recently published Industrial Strategy[3] notes, the UK is still recognised as a global leader in science and research, top in measures of research excellence and home to four of the top 10 universities in the world.

There is a rich resource of high quality evidence available, as the UK has a long and distinguished track record of research excellence.

The Academies

One of the important functions of the British Academy and the other national academies is to champion and strengthen our respective disciplines as well as to promote their public value and the contribution they can make to policy making. We did just this during the passage of the Higher Education and Research Bill through Parliament in 2016-17. The Bill presented a critical opportunity to revisit the principles and structures which underpin the funding of the UK's world leading research base. We engaged with parliamentarians in both Houses. We emphasised both the importance of the Haldane Principle in enabling academic expertise in decision making about funding of research as well as the need to limit the Secretary of State's powers to change the remit or name of the Research Councils without consultation. These points were addressed in amendments tabled to the Bill, thereby helping ensure that UK Research and Innovation (UKRI) will continue to recognise the value of research across the disciplinary spread.

A target

We are pleased that the Government recognises the importance of investing in this excellence and has committed to achieving a target of 2.4% of GDP invested in UK R&D within 10 years, as well as a longer-term goal of 3% – something that the national academies have jointly been calling for[4].

So, while there is no shortage of high-quality, diverse and excellent research being carried out in the UK across all academic disciplines, there is a need to ensure that this excellence is used effectively by Government, and that is where the Academies, including the British Academy, also have a key role to play. We at the British Academy, alongside our colleagues at the three other national academies, The Royal Society, The Royal Academy of Engineering and The Academy of Medical Sciences, play a vital and unique role in providing evidence and independent advice to Government.

The British Academy is the UK's independent national academy representing the humanities

MIKE PEEL (WWW.MIKEPEEL.NET) / (CC-BY-SA-4.0)

The British Academy has hosted roundtables on a number of pertinent issues, including industrial strategy.

and social sciences. It is first and foremost a fellowship of distinguished academics selected for their excellent research. Through the breadth and depth of expertise of more than 1,000 Fellows across the UK and internationally, we offer a unique and valuable resource to Government as it seeks (or should be seeking) to understand many of the great questions facing humanity today.

Our Fellows have spent their lives studying everything from how individuals behave to how nations are governed, how economies operate, and how cultures evolve. Taken together, the subjects our Fellows study put the whole of human experience in context. Whatever the challenge policy makers are grappling with, or whichever opportunity they want to open up, our Fellows can bring to bear independent perspectives, relevant insights and robust evidence.

Supporting research

We do not only offer the wisdom and insight of our Fellows as a resource from which policy makers can draw. For over a century we have supported and celebrated the best in UK and international research. We fund outstanding academics at key stages of their careers undertaking innovative research – all of which excellence we can, and do, put at the disposal of Government on a regular basis.

Our research touches every corner of the world, helping us to understand our society today, where it came from and how it might change in the future. Because we seek, in all of our activities, to safeguard scholarly interests and academic freedom we can provide truly independent advice to Government in a way which is difficult for other organisations to emulate in quite the same manner.

Like the British Academy, all the national academies can draw upon both the expertise of their Fellows and the research they fund in order to provide independent advice to Government. Between us we represent a hugely valuable resource for politicians and civil servants alike. This is especially the case when we join together, as we often do, and pool our collective wisdom and insights from a range of disciplines. A good example of this is the work that The British Academy has done over the past year with The Royal Society on the governance of data management and use.

Data

The rate at which data is accumulating, and the inferences that can be drawn from it, are both increasing at exponential rates and this is likely to continue at a breath-taking pace. There are huge benefits to be gained from a data-driven economy, but to realise these benefits societies must navigate significant choices and dilemmas. In this fast-moving landscape, governance challenges need to be addressed in a timely manner if the system for oversight of data management and use is to retain public trust.

This is exactly the sort of complex and multi-faceted issue to which the national academies can make a significant contribution. By collaborating across many of our disciplines, the

There are huge benefits from a data-driven economy, but to realise these benefits societies must navigate significant choices and dilemmas.

TOM MORRIS / (CC BY-SA 3.0)

Over the past year The Royal Society has worked with the British Academy on the governance of data management and use.

academies were able to pull together a working group drawn from a wide range of academic subjects, including law, computing and data science, anthropology and ethics.

By working in this multi-disciplinary way, we were able to set out some high-level principles for data governance in the 21st century and recommended the setting up of a body to steward the governance landscape. In essence, we made the intellectual case, which enabled the Government to act. They have now done so through their commitment to establish a new Centre for Data Ethics and Innovation.

The academies also have a unique power to bring policy makers, Fellows and other experts together to provide focussed, evidence-based advice on a range of current policy issues. Over the past year, The British Academy has hosted roundtables on a number of pertinent issues, including industrial strategy.

International cooperation

We work with colleagues from other countries' national academies and have recently joined with the Royal Irish Academy to harness expertise across our islands on some of the thorny and complicated issues that we now face in the context of the UK leaving the EU. To date we have jointly published four briefings related to the land border, the Common Travel Area and the Good Friday Agreement. These briefings raise awareness on these topics and the questions that need consideration and/or response, as the UK negotiates its withdrawal from the EU and beyond that period.

We hope that they may help build broader policy and public reflection on the need to address such questions and the various ramifications that they might incur. The briefings provide an informed and impartial arena for the understanding of these complex matters, illustrating items that need policymakers' consideration, often in ways that they may not have considered.

Independent advice

These examples illustrate just some of the ways in which the academies assist in providing independent advice to Government as well as the breadth of issues on which we can and do offer advice. As I mentioned at the beginning of this article, we are living in a time of huge change so we need to keep pace with the vexed issues that are coming our way so rapidly and those generational issues that remain unsolved. But to do this successfully there must be more respect for, and appreciation of, evidence-based learning, as well as for truth, reason and ideas. There also needs to be a greater eagerness on the part of policy makers to engage with those who are the experts on subjects of such vital contemporary concern.

We must approach these questions with rigour and by drawing on all disciplines. The challenges we are facing today are as much human and societal as they are technical and scientific ones. The combination of the humanities and social sciences working together with science and technology can help us all to understand and shape our economic and social future. It will take fresh perspectives and many minds to respond to the complex and interconnected questions that face our society and inform the debate about our future. The British Academy, alongside our colleagues at the other academies stand ready, willing and able to provide essential and independent advice to Government. □

The academies have a unique power to bring policy makers, Fellows and other experts together to provide focussed, evidence-based advice.

1. Building a stronger future, Royal Society, British Academy, Royal Academy of Engineering and the Academy of Medical Sciences, 2015
2. The Blunders of our Governments, Anthony King and Ivor Crewe, One World 2013
3. Industrial Strategy, BEIS, Nov 2017
4. https://www.britac.ac.uk/sites/default/files/Investing%20in%20UK%20R%26D%2022.01%20%28web%29.pdf

There have been a number of science and innovation strategies since the end of the Second World War. The present Government has been developing its own. A meeting of the Foundation for Science and Technology on 18 October 2017 considered what light history could shed on different approaches to industrial strategy.

Searching for a strategy that makes a difference

Peter Hennessy

The Lord Hennessy FBA started his career as a journalist working on The Times, The Financial Times and The Economist, unearthing the hidden wiring of the constitution and the power of the machinery of Government in Britain. Those themes remained at the heart of his research and teaching at Queen Mary when he moved from journalism to academia in 1992. Since then, it has been his aim to write the history of the country, in his own times, for academic and public audiences alike. Lord Hennessy is a member of the Council of the Foundation for Science and Technology. (Photo © Layton Thompson www.laytonthompson.com)

SUMMARY

- There have been more than 20 science and innovation initiatives by Government since 1945
- The UK must now surpass the performance levels achieved by previous strategies
- Successive governments have struggled to meet funding aspirations for research and innovation
- Transforming research insights into commercial success has been a continuing challenge
- The productivity gap between the UK and its international competitors remains a serious concern.

Reviews can be very revealing about areas of public policy. By my calculation, the current so-called 'capability review of the 2015 strategic defence and security review' is the 13th defence review since the Second World War. The current industrial strategy is the eighth since 1945. There has, by contrast, been only one comprehensive review of welfare and deprivation in the past 75 years: the Beveridge report of 1942.

In a contribution to the debate about the latest industrial strategy, the Foundation for Science and Technology has undertaken an exercise in 'documentary cartography', identifying at least 20 science and innovation initiatives of various kinds since 1945 (see page 16) – and that does not include those mounted by individual Government Departments. A quick glance shows that their frequency has picked up since the early 1990s. Suffice it to say that several generations of our best political, scientific and official minds have pitted themselves against this particular bundle of problems.

The challenge

Given the uncertainty we are facing as a major manufacturing, trading, thinking and innovating nation, this time we must somehow surpass the performance levels of the past on several fronts. Happily, there may be an embryonic political consensus on several aspects.

The first of these strategies was the Barlow Report on Scientific Man-power of May 1946[1]. It was quite a committee that produced it, members including Edward Appleton, Patrick Blackett and Solly Zuckerman, with C.P. Snow as assessor.

The opening paragraph states: "We do not think it is necessary to preface our report by stating at length the case for developing our scientific resources. Never before has the importance of science been more widely recognised or so many hopes for future progress and welfare founded upon the scientist. By way of introduction therefore, we can find ourselves pointing out that, least of all nations can Great Britain afford to neglect whatever benefits the scientists can confer upon her. If we are to maintain our position in the world and restore and improve our standard of living, we have no alternative but to strive for that scientific achievement without which our trade will wither, our colonial empire will remain undeveloped and our lives and freedom will be at the mercy of a potential aggressor." Take out the colonial reference and that could still serve pretty well today.

Abiding concerns

There are three crucial themes that run through our score of reviews.

First, there is the question of funding. A thread that runs through the post-war period has been the difficulty in meeting the stated aspirations of successive governments to raise spending on science and innovation as a percentage of GDP and, in addition, to encourage the private sector to follow suit.

The second one is commercialisation. There has been a continual struggle to take to market the world-class ideas created in UK science and

The productivity gaps between ourselves and our chief competitors are a prime anxiety in all the industrial strategies since the Attlee Government.

innovation through conversion into patents and thence to commercial opportunities. We have not done well in comparison to many of our leading international competitors – both longstanding and more recent ones.

The third theme that runs through this period concerns skills, education and productivity. The productivity gaps between ourselves and our chief competitors ring out as a prime anxiety in all the industrial strategies since the surveys produced by the Attlee Government's Central Economic Planning Staff. The same drumbeat of anxiety booms out from the latest industrial strategy and the OECD has highlighted the problem too.

Huge efforts have been put into skills training. The Robbins Report on Higher Education[2] in 1963 stressed the need for more science and technology courses. Today, scientific and technical education elements remain a prime concern. Enhanced performance is ever more vital.

In their recent examination of the latest industrial strategy, the House of Lords Select Committee on Science and Technology[3] stressed the potential benefits of a vigorous industrial strategy with science and innovation as 'pervasive themes'.

The big picture

While there has been a variety of reports on aspects of the science and technology landscape, there has never been a Beveridge-style examination, embracing in one sweep the whole breadth of these issues and isolating the concerted and simultaneous action required to break through the crust of under-performance. The closest is Lord Heseltine's 2012 report[4] on growth entitled *No Stone Unturned*.

The key to Beveridge was its focus on the slaying of what he called the 'five giants on the road to reconstruction' – Ignorance, Idleness, Squalor, Disease, Want. Beveridge's argument was that unless all of those five giants were smitten simultaneously, the crust of poverty would not yield. A Beveridge for science, technology and innovation could take a similar, over-arching approach.

Beveridge used a particularly buoyant, perhaps almost poetic, language. All too often Whitehall reviews concentrate, understandably, on the plumbing rather than the poetry. The substance of a policy rarely appeals to the imagination. I remember a wonderful line of R.H. Tawney: "Only those institutions that are loved appeal to the imagination." The same applies to White Papers.

There has been a variety of reports on aspects of the science and technology landscape, but there has never been a Beveridge-style examination.

Getting this right, though, has been and must remain a great national endeavour. Knowing just a little about how we got to where we are today can help. Mark Twain put it rather well when he said: "History may not repeat itself but sometimes it rhymes."

Significant milestones

Several strategies stand out as significant milestones over the past 50 years. The recommendations of the Rothschild and Dainton reports[5] were accepted by the Heath Government and implemented in the 1972 Framework for Government Research and Development. The customer-contractor approach remains contentious today. The question of who should decide the priorities for Government-funded research is a continuing debate.

Dr Miles Parker, the former Defra Deputy Chief Scientific Adviser, reviewed the impact of the Rothschild Report of 1971 on *The Organisation and Management of Government Research and Development*, as well as the role of scientists in policy development[6]. Rothschild had recommended the appointment of Chief Scientists to act as the customer for research in Government Departments, rather than Chief Scientific Advisers who have an explicit role in advising Ministers.

Miles Parker concluded that: "Rothschild never really addressed the question of the function of scientists in Government policy-making Departments. His mind was wholly focussed on research, not only because of the question put to him and the Central Policy Review Staff (Ted Heath's creation in the Cabinet Office) but also because of his previous Shell experience as Director of Research.

"Industry actually is very forward-looking and willing to wait for research results to flow in, but policy makers in general cannot afford to wait for the slow products of research to emerge. Politicians need the best available advice now, to take action on the policy problems of today."

The 1993 *Realising our Potential: a Strategy for Science, Engineering and Technology*[7] document refocussed attention on cross-cutting funding of research to improve competitiveness and the quality of life. A spin-off from the review was the establishment by John Major of the Office of Science and Technology in the Cabinet Office and the Technology Foresight process which

successfully brought together end-users to articulate what they wanted.

In 2000, the seminal House of Lords Select Committee inquiry on *Science and Society*[8], chaired by Lord Jenkin, promoted the idea of a two-way dialogue between scientists and the public, which of course is still a political theme.

The 2006 *Next Steps* report on the science and innovation framework set out the arguments for companies to stimulate investment in innovation and recommended the establishment of the Technology Strategy Board which has since become Innovate UK.

As Minister for Science in the Blair Government, Lord Sainsbury stressed the importance of funding for science and innovation during the financial crisis with his *Race to the Top* report[9]. The recommendations were accepted and the *Innovation Nation* strategy with it.

Lord Willetts, as Science Minister in the Coalition, successfully defended research and innovation funding at a time when all Departmental budgets were being cut by 20-30%. Paul Nurse's review set out recommendations for radical reform of the Research Councils which were put into law in the *Higher Education and Research Act* of 2017[10]. On 1 April 2018, UK Research and Innovation (UKRI) will be up and running, bringing together the seven Research Councils, Innovate UK and Research England.

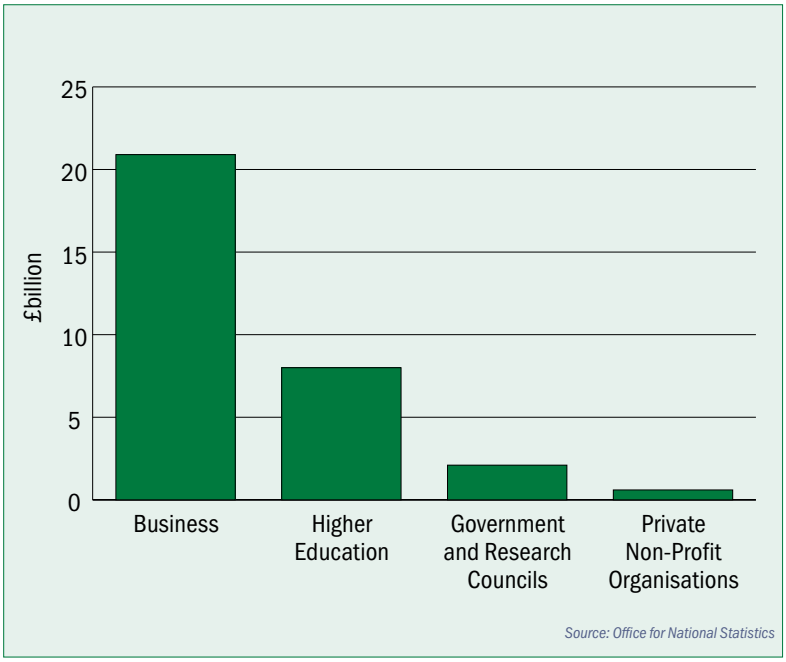
However, discussion of how Departments are managing their own research programmes should not be forgotten.

A vision for the future

The past 70 years have been a story of high intentions, great expectations and sustained attempts to find the Holy Grail of a science and innovation strategy, a solution that would somehow bring about a shining synthesis and close the ever-stubborn productivity gap, a solution that would transmit waves of stimulus into the research and development community and the private sector.

That was always a tall order and remains so today. Money is tight and every ounce of value has to be squeezed out of the science budget and particularly the extra £4.7 billion over five years announced in the 2016 Autumn Statement. Government, as Nye Bevan once said of socialism, is all about the language of priorities and setting them is always stretching.

So, we must build on what has already been achieved but reach for a new way of working together, striving for a new national trajectory and indeed a great national endeavour in pursuit of a more vibrant economy, rising productivity and a sustained betterment of our society. □



Composition of UK gross domestic expenditure on research and development by performing sector, 2015 (£billion)

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Establishing a strategy for the whole economy

Michael Heseltine

The Rt Hon the Lord Heseltine CH was elected an MP in 1966. He served on the front bench as a Minister with briefs for transport, industry, environment, and defence. Under John Major, he returned to the Cabinet as Secretary of State for the Environment, President of the Board of Trade, and between 1995 and 1997 he was First Secretary of State and Deputy Prime Minister.

SUMMARY

- The current global market place is not one of free trade and open competition
- Companies need a stable home market in order to successfully compete internationally
- We need some standard metrics to show just how competitive British business is in the world
- Government strategy should focus on wealth creation across the whole economy, not just traditional manufacturing sectors
- Excellence needs to be driven through all levels of our economy if we are to succeed against our international competitors.

One of the last initiatives I introduced in my company before I became a Minister was to bring in a regime to approve every expenditure over 50p. Three weeks and an election campaign later and I was a Minister in the Department of Transport. I was welcomed with a request to authorise £6 million investment in the electrification of a branch line in Essex. When I asked to see the managers and ask a few questions, I received the reply: "Oh, no, Parliamentary Secretary, if you start querying the details of every £6 million we put in front of you, we will never get anything done in this department." I had joined the public sector! Within three years I had been responsible for the rescue of Rolls-Royce and for persuading my European colleagues to create the European Space Agency. I had masterminded the sales campaign for Concorde.

In 1983, US General Abrahamson came to see me to tell me about a £29 billion research and development programme for which he was responsible. He was going to build an impenetrable defence system against missiles – it was to be called Star Wars. He came to see me because he had £100 million earmarked for Heriot-Watt University in Edinburgh.

He explained that in this particular field of research the University was a world pace-setter and we would become a partner in the programme. He was expecting me to say: "Well that's amazingly generous." However, I knew that all that commissioned research would be transferred, at our taxpayers' expense, back to the American industrial base.

If anyone comes to me and says "just have open competition and free trade: that will really solve your problems," I think back to Rolls-Royce. They tried to compete with an American defence project called the CF6 engine financed by the US taxpayer. Rolls-Royce had no defence project with which to pay for the development of the RB211 engine – and so they went bust.

Now I am in favour of free trade. I am in favour of competition and of reducing barriers. Yet, in my experience, that has very little to do with the world in which our companies operate. Time and again, when the Ministry of Defence wanted to acquire some sophisticated, high-tech weaponry, there would be a working American model available immediately off-the-shelf. So it is perfectly possible to source one's needs from overseas. But what happens to the industrial base when it does not have a reliable home market, allowing it to sell at marginal cost to the rest of the world?

The situation is complex. I know all the arguments about picking winners. But put simply, people by and large want to succeed and the responsibility of Government is to enable them to do just that.

A really serious attempt

The fascinating thing about the latest proposals for an industrial strategy is that they constitute a really serious attempt to do something more comprehensive, in my view, than any other Government has tried. They also have one absolutely essential ingredient – the Prime Minister is in charge and without that single ingredient, nothing works. So, she deserves credit for putting it on the agenda and for being the chairman of the committee that is going to make it work.

One interesting aspect is the enormous frankness in the way the initial Green Paper commits to large numbers of reviews. Clearly there is no need for a review when the answer is already known. So every promised review is a clear indication of what we do not know. Why not? Because Whitehall has not taken the trouble to find out.

One of my criticisms of the proposals concerns the attempt to focus the debate away from the total picture to those areas that suit the Government. I want to widen the debate, particularly on the issue

Bodies like the Port of London Authority could help to generate wealth for the country

of competitiveness. Underlying everything else is the need to know just how good you are and, just as important, how good that evaluation is in a competitive global market place. Any worthwhile company regularly carries out a SWOT analysis (strengths, weaknesses, opportunities, threats) in order to determine whether it is ahead of the competition, whether it is behind, what is coming up, what the challenges are.

Yet this does not happen in Government. There is no reservoir of worldwide comparisons. Get into the detail, though, and the scale of the problem becomes clear. We all know the statistic – if American and German workers stopped work on Thursday evening, we in Britain would have to continue to the end of Friday to produce as much.

Competitive position

Knowing our competitive position is absolutely fundamental. There should be an institutional process to do just that. At the heart of the competitiveness committee the Prime Minister has set up, there has to be a means by which, when Department A says: "We are winning out here Prime Minister," a still, small voice can interject: "Prime Minister, I am afraid it is not quite as rosy as you are being told."

That will create tension which people will not like because it disrupts and it challenges – but it is essential. In the private sector it happens every day.

Another problem is that this country is over-centralised: I cannot think of a single advanced economy that is so functionally centralised in its capital city. In the vast majority of cases, Government Departments carry out their functions within a narrow definition of their purpose. Someone does housing, someone does services, someone does transport, someone does law and order. In large measure, they also execute the policies with associated agencies doing as they are told. So Government consists of 20 or 25 functional monopolies – and monopolies are dangerous.

I believe that every Government Department should have its own responsibility for wealth creation. The word 'industrial' should be abandoned because traditional manufacturing industry only accounts for 10% of the economy. The emphasis should be on a 'whole economy' approach: many of the most exciting growth areas lie outside the industrial manufacturing base. Not only that but we must go beyond the traditional Departmental monopolies. Will the Department responsible for education talk to educational publishers (who report to another Department) about the huge opportunities in high-technology, individually-tailored learning? It certainly does not happen now.

Unless Departments are forced to explain their contribution to wealth creation to Ministers other than their own, little will change.

The Royal Commission on Local Government in England, 1966-1969 (more generally known as the Redcliffe-Maud report after its chairman) looked at the devolutionary situation in this country. There were at the time 1,400 local authorities – perfectly understandable because when they were designed the only way to get anywhere was by walking or on horse, so you needed a lot of local authorities. By the time of Redcliffe-Maud, the motor car and the railways had arrived.

The report proposed about 60 unitary authorities and in East Anglia the four were Norfolk, Suffolk, Peterborough and Cambridge. Today, though, there are five counties, the combined authority of Cambridge/Peterborough, 15 district authorities as well as three independent study groups (one looking at the corridor from Cambridge to Norfolk, one at the corridor from Cambridge to Stanstead and onto London and one at

I cannot think of a single advanced economy that is so functionally centralised in its capital city.

the corridor from Cambridge to Milton Keynes and Oxford). Is it possible to design anything more likely to delay development around one of the world's great universities?

The great thing about quasi-autonomous non-governmental organisations (quangos) is that they are autonomous and are potentially huge wealth creators. Think of the Port of London Authority – what could be more capable of improving the trade on the Thames? Some of the environmental agencies have huge ability to influence tourism – although that is not currently within their remit.

Today, though, there is a multi-layered local authority environment, with quangos and functional Departments just interested in their own narrow roles. It is not the way to run a ship.

In the end nothing matters as much as the skill, ability and energy of people. So where is the UK in the world education league? Depending upon which statistics are chosen, the ranking comes in at 21st, 29th or something of that order. Some 20% of our young people are being educated in schools which the Department for Education itself knows are not good enough and yet this is tolerated. Why is it tolerated? The inevitable consequence will be unemployment queues in the ever more competitive and technological world of tomorrow.

There is always a tension here. I know just how good so much of this country is. However, while there is a great amount of excellence, it does not permeate to those areas where it is needed if the average is to be raised. This patchiness reveals itself in the problem of productivity. It is also the cause of not exporting enough, of selling too many of our companies too cheaply and too quickly. We do not follow through in the depth that competitor nations seem to do. That must change – and that is our challenge. □

• *Lord Heseltine has written a response to the Government's Green Paper. More details at: www.themagazineshop.com/bookazines/industrial-strategy-by-michael-heseltine*

A tension at the heart of Government activity

David Willetts

The Rt Hon the Lord Willetts served as Minister for Universities and Science from 2010 to 2014. He is the Executive Chair of the Resolution Foundation and a member of the Council of the Foundation for Science and Technology. He served as the Member of Parliament for Havant from 1992 to 2015. Prior to his appointment as a Minister, he worked at HM Treasury and the No 10 Policy Unit. Lord Willetts is a visiting Professor at King's College London, Governor of the Ditchley Foundation, Chair of the British Science Association and a member of the Council of the Institute for Fiscal Studies.

SUMMARY

- Many of the research funding arrangements that we recognise today were originally devised during the First World War
- There has been continuing tensions between Ministerial aspirations and pre-existing science and research frameworks
- The current dual-funding system obscures a gap in funding for institutions that are not universities
- The UK is unusual in that its universities are not in the public sector
- Industrial strategies should be disruptive and not merely reward incumbents.

When Britain was lobbying America to enter the First World War, the realisation dawned that all America's leading universities were staffed by people who had studied in Germany. Nine of the 25 professors heading departments at Harvard had been to Germany. There was no comparable opportunity for them to study in the UK.

The doctorate, a 19th century German innovation, was therefore established in Britain in 1917 so that there was something to offer American students. At the same time, rather ingeniously, the universities argued that if they were to deliver such services they needed funding: so the Higher Education Funding Council for England (HEFCE) came into being in 1918.

The Department for Science and Industrial Research, the progenitor of the Research Councils, was instigated in 1918 following the Haldane report. Universities UK had its origins in the meetings of the Committee of Vice Chancellors and Principals which began in 1918. In all, a flurry of institutional creativity, trying to catch up with what Germany and the USA were doing.

There followed 50 years of close links between research and industrial policy because it was realised that to be a serious military and imperial power in the 20th century required an organised research effort.

But confidence in that model waned. In 1964, the Wilson Government had been elected around the principle of the 'white heat' of technological

revolution, but by 1970 Tony Benn thought the country was spending too much on R&D of insufficient quality. Both main parties became wary of the massive R&D-based, industrial effort. Many of the research associations created after the war were closed down. Over the past 20 years, though, there has been a revival, with industrial strategies in some form or other.

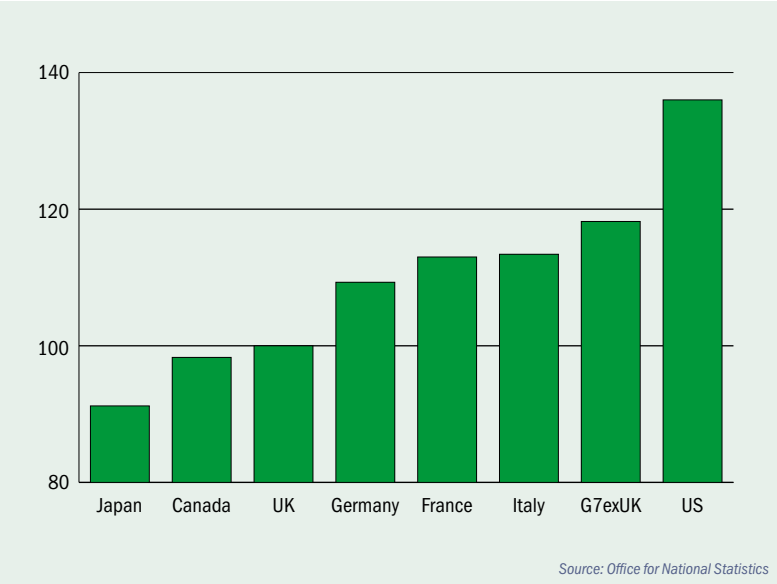
Yet these strategies have consistently been frustrated by the tension between what Ministers were trying to achieve and the existing science and research framework which was based on:

- an ambitious and successful strategy of maintaining research excellence across a whole range of disciplines. Britain has an exceptionally wide range of areas where we score very high citation rates, way above the average achieved by other similar-sized economies;
- rewarding research excellence, even at the expense of objectives like geographical distribution or indeed industrial relevance. So Nobel Prizes, academic citations and the prestige of the universities became the focus;
- a university-based research system. Looking at the distribution of publicly-funded R&D in advanced western countries shows Britain as one of the outliers, with an unusually high proportion based in universities.

Another peculiar feature of our education system – one I regard as a fundamental weakness – is that students choose to focus on a narrow range of subjects (normally opting for either arts or sciences) at age 16. They then go to university to study these subjects. The universities in turn are staffed to teach those subjects and research focusses on them too. In essence, university research is heavily influenced by the subject preferences of 16-year olds.

Our system is also very decentralised, with very high levels of institutional autonomy. While that has many strengths, it is built on three crucial doctrines which make it very hard to reconcile science strategy with the ambitions of industrial strategy. These are: the way in which dual funding works; the Rothschild doctrine; and the particular position of universities.

Dual funding appears to have a satisfying completeness. Essentially, there is Research Council funding, which is project-based and not dependent on universities (though the people capable of doing that research are usually found in universities). Then there is HEFCE funding to universities through the Research Excellence Framework (REF), whose roots go back to the argument that the Red Brick universities needed compensation as they did not have endowments like the Oxbridge colleges.



Source: Office for National Statistics

2016 UK productivity per hour compared with other G7 nations (UK=100)

Although there are two flows of funding, there is an omission: there is no reliable flow of funding for institutions outside universities. So it can be tough for The Welding Institute, for example, (the last survivor from the post-war creation of research associations) because it does not slot neatly into this regime. The same goes for the National Institute of Agricultural Botany. In fact, those that do survive tend to have prior and independent charitable status. One of the reasons I was keen to create the Catapult institutes was because we needed to sustain and fund research establishments linking public and private sectors outside universities.

So, behind the dual funding model, there is a gap in funding.

The Rothschild doctrine

Lord Rothschild was crucial in shaping our current research model. He argued in his report that the science budget should be reserved for blue skies 'pure' research. However, applied research should be funded on a customer-contractor model and there was an obvious place to do so – central Government Departments. So, some of the funding for the Research Councils was re-directed to Departments who would be the customers contracting to purchase research.

The Departments proved to be appalling custodians of this responsibility. Whenever there was budgetary pressure they cut funding, so the

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The ambition of successive governments – to create an industrial strategy that included a focus on R&D – has been very hard to deliver in practice.

science budget languished and then diminished over time. It is fascinating to see Margaret Thatcher's role in this. As Education and Science Minister, she supported the approach. However, when she came back into office as Prime Minister, with Rothschild as Head of the Central Policy Review Staff (CPRS), she said that the obvious customer for applied research was the business sector. That again left an enormous gap in the system because business was not willing to do this. It is not that British businesses are unusually risk averse, rather that in other countries public funding for research goes closer to market.

So, in Britain we ended up with the 'Valley of Death', the result of a particular set of institutional arrangements not repeated in other countries. To counter this, a further set of intermediate institutions or funding arrangements were needed: Lord Sainsbury's ingenious solution was the creation of what became Innovate UK. I added to that with the Catapults.

Universities and research institutes

Universities are private sector bodies which gives them an advantage over research institutes in the public sector. It is one reason why such a high proportion of R&D in Britain is done in universities. Internationally, research institutes have historically been in the public sector and most countries have a proud network of them. Germany has the Max Planck and Fraunhofer Institutes, while the USA has the Argonne and Lawrence Livermore National Laboratories, just to quote a few examples. The UK has never been successful in sustaining anything similar. Such institutions would here be subject to public sector rules on recruitment and on how they should function, so the private sector in general and universities in particular has looked a better bet for research. Departments themselves were uninterested in such mechanisms.

British agricultural productivity has barely grown in the past 10-20 years, precisely because of Defra's failure to support institutions intermediate between pure research bodies and farmers. The former Department of Energy has hardly been more successful. The National Nuclear Laboratory (NNL) shrank until it survived just on funding for individual projects. So, as the new civil nuclear programme gets underway, there is no core capability in this country.

During all the discussions on privatising nationalised industries, I cannot recall any that considered what would happen to their R&D capabilities. That was, in fact, where a lot of the energy and water research had previously taken place. Yet, the financial framework chosen for these privatised bodies was price competition. Years later as Science Minister, I would talk to privatised utilities about R&D and they would respond that the regulators were opposed to what was regarded as 'gold plating' or 'non-essential' expenditure: price-regulation was the focus.

So, the UK has a very different model of research from almost any other advanced western country. That is why the ambition of successive governments in the past 20 or 30 years – to create an industrial strategy that included a focus on R&D – has been very hard to deliver in practice.

Concerns around 'picking winners' hang over this debate, but in reality all Governments make these judgements. The purists say Government should only have horizontal policies that operate across the economy as a whole. But if you extend the Jubilee Line into Canary Wharf to enable the City of London to expand, why not build a railway line linking the east and west coasts in the north of England to boost industry there? But one goes ahead and the other does not. It is impossible to have a pure horizontal strategy.

In the Coalition Government, an industrial strategy emerged out of four different approaches. The Business Secretary Vince Cable focussed on industrial sectors like aerospace and automotive which were self-organised, ones where it was possible for a Minister to have a conversation with 'the industry'.

Second, you can focus on places – and of course Michael Heseltine has been an eloquent advocate of that. It has a powerful logic: if investment is based on a cost-benefit analysis that is itself founded on where people are already living and where there is an identified need, then that essentially provides a responsive strategy. It is also possible to take a strategic view on what could happen through bold investments in particular places, as Greg Clark has been doing with his city deals and George Osborne has been attempting with his agenda for the North.

There is an excitement in tackling big challenges and this constitutes a third approach. David Cameron was excited by the challenge of antimicrobial resistance and by the challenge of sequencing the genome of 100,000 NHS patients. Under his administration, Number 10's agenda was to bring strategies to life by setting challenges.

And then, fourth, my focus was on technologies. One of the first tests I applied when approached by people with a set of particular

technologies was whether I could remember the list: too many were random, there needed to be some conceptual framework. What we tried to do with the Eight Great Technologies was to start with digital, IT-based technologies. That covered e-infrastructure, autonomous systems and robotics. It meant satellites as increasingly important collectors and transmitters of data. Next was to look at the life sciences: Britain is the home of genetic sequencing, of fantastic advances in life sciences. By extraordinary coincidence, biological information now comes in digital form, as genetic code. Particular applications include synthetic biology and agri-science.

Then, there are the areas like energy storage and advanced materials without which it is very hard to make progress in other areas.

One criticism of previous industrial strategies is that they have rewarded incumbents. My view is that these technologies are inherently disruptive. They should also be general purpose technologies, so it is not possible to predict which business sector will take them up.

Today's industrial strategy has the backing of the Prime Minister. UK Research and Innovation (UKRI) is a body that could step up to the plate to resolve some of the obstacles that have stopped us hitherto linking R&D strategy and industrial strategy coherently.

I believe we will now see a sustained focus on industrial strategy in order to address the challenges facing the UK economy. □

The debate

The new UK Research and Innovation (UKRI) should use its new structures to think strategically about how to get best value from the additional £4.7 billion of funding. It should also look at encouraging researchers to work more closely with industry to boost growth.

Years of pressure on public spending have meant that overall funding for research, as a percentage of GDP, has remained static at 0.7% between 1997 and 2010, largely due to declining Departmental spending. Those same pressures, this time on applied technology spending, mean that restoring the funding of Innovate UK should be a priority.

Disruptive technologies, including machine learning, autonomous vehicles, block chain and smart contracts, as well as synthetic biology (where the costs of gene synthesis are falling rapidly) need to be identified and supported. So an industrial strategy must be quick to respond and be flexible. For example, the car industry's value model is shifting rapidly towards companies providing transport as a service rather than one where vehicles are owned by the customer.

In terms of place, Cambridge now has a research ecosystem, building connections between research parks, innovative graduates, and entrepreneurs. Academics need these networks to build good ideas into companies.

Smart, flexible regulation has a role in driving innovation. Research excellence can help the UK set future standards in areas such as embryology, or 5G telecoms (if Ofcom prioritises density of coverage over competition).

The UK is short of R&D-intensive companies able to buy innovative research and scale it up for the market. Patient capital is also in short supply, with no real equivalent of the German KfW government-owned development bank. One role of Government is to bear risk that no commercial entity can take, and the UK is not strategic in this area. Without such a proactive strategy, then letting innovative companies be sold abroad with the guarantee of a continuing research focus in the UK may be the best available option to keep value at home.

Polarisation between political parties is not conducive to maximising the value of our research effort, though there is some underlying consensus on what needs to be done. While the German system is not the Holy Grail, it avoids short-term and confusing changes in the research and innovation landscape by modernising within familiar existing structures.

Measuring success

Measuring university success in innovation should not be measured by start-ups alone: there should be more focus on scale-ups and the best business models for the future. The neglect of technical education has to end.

There is an important and continuing role for foreign direct investment, but it would be naïve to think some overseas governments would not want to move resulting advanced technologies back to their own base.

Within Government, Ministers should avoid short-term decision-making, and civil servants should build more expertise in key issues by remaining in post longer. There is a case for making all public bodies report annually on how they have supported innovation and wealth creation. □

In the debate following the formal presentations, the invited audience raised a number of issues including: the role of UKRI in achieving best value on investment; the function of disruptive technologies; the need for strategic, patient capital; and the place of political consensus.

SCIENCE AND INNOVATION STRATEGIES SINCE 1946

As a contribution to the debate on the new Industrial Strategy set out in the Government's Green Paper at the beginning of 2017, the Foundation for Science and Technology prepared a cartography covering initiatives to promote science, research, innovation and technology since the Second World War.

Looking back 25 years, there has been a multitude of science and innovation strategies as well as supporting reviews and guidance. Each was set in the context of the time, e.g. in 2017 the themes are Brexit and continued financial pressures. Financial pressures were a feature of the 2008-2014 strategies. In Lord Sainsbury's review in 2007 the theme was globalisation.

The strategies since 1993 have contained many notable similarities on the contribution of science and innovation to the UK's prosperity, funding (government and private funds), setting priorities, skills and education.

Recent strategies have noted that the UK has ring-fenced and prioritised funding for science and innovation at a time when other public spending has been reduced. However, other nations have been increasing their spending on these areas during the same period.

The full text of *Science and Innovation Strategies since 1946: a cartography* can be downloaded from the Foundation website at: www.foundation.org.uk/Events/pdf/20171018_Summary.pdf. It can be found at the end of the summary of the meeting.

UK science and innovation strategies – a timeline

2017 Industrial Strategy: building a Britain fit for the future, White Paper, November
2017 Building our Industrial Strategy, Green Paper, January
2014 Our plan for growth: science and innovation (Cm 8980)
2013 Government response to the Heseltine Review
2012 Heseltine Review - No Stone Unturned in pursuit of Growth
2012 DECC Science and innovation strategy
2011 BIS Innovation and Research Strategy for Growth
2008 Innovation Nation: Department of Innovation, Universities & Skills (White Paper)
2008 Implementing "The Race to the Top" Lord Sainsbury's Review of Government's Science and Innovation Policies
2007 Lord Sainsbury Review of the UK Science and Innovation system
2006 Science and innovation investment framework 2004-2014: next steps
2005, 2006, 2007 The ten-year science & innovation investment framework annual reports
2004 Science and Innovation investment framework, 2004-2014
2003 21st Century Skills: Realising Our Potential
2003 Innovation Report – Competing in the global economy: the innovation challenge, DTI
2002 Investing in Innovation: A strategy for science, engineering and technology, DTI, HMT, DES
2001 Opportunity for all in a world of change, A White Paper on Enterprise, Skills and Innovation, Cm 5052
2000 Excellence and Opportunity: a science and innovation policy for the 21st century
1998 Our Competitive Future – Building a Knowledge Driven Economy, White Paper
1996 Information Society Initiative (ISI)
1996 UK Government: Green Paper, "Government Direct": A Prospectus for the Electronic Delivery of Government Services
1993 Realising our Potential: A strategy for science, engineering and technology (White Paper)
1972 A Framework for Government Research and Development, Cm 5046
(contains the Rothschild report and Dainton report – see below)
1971 The Organisation and Management of Government Research and Development (the 'Rothschild Report')
1971 The future of the Research Council System (the 'Dainton Report'), Cm 4814
1968 Report by the Committee on Manpower Resources for Science and Technology on the Flow into Employment of Scientists, Engineers, and Technologists, Cm 3760
1965 Science and Technology Act
1963 Committee of Enquiry into the Organisation of Civil Science, Cm 2171 (The Trend Report)
1946 Barlow Report of 1946 on Scientific Man-Power

How should the funding of research and innovation by Government and private enterprise be channelled in support of businesses in Scotland? That question was debated in a joint meeting of the Foundation and the Royal Society of Edinburgh on 6 November 2017.

Translating research excellence into economic benefit

Iain Gray

SUMMARY

- Despite its reputation for excellent science, Scotland's expenditure on research and development lags significantly behind that of other countries
- Current economic strategy focusses on investing in people and infrastructure, fostering innovation, promoting growth and opportunities for all, and boosting international trade
- Enterprise funding has been increased and innovation centres have been developed to bring universities and businesses closer together
- Growth needs to be inclusive, covering all geographical areas and harnessing digital technology
- The future of the Scottish economy should be viewed in both a UK and an international context.

Scotland has an international reputation for excellent science and research. Five of its universities are in the top 200 in world university rankings. In the 2014 Research Excellence Framework, 77% of Scotland's university research was deemed 'world leading or internationally excellent'.

Despite this, expenditure on research and development is significantly below that of the UK and even further below the OECD average, at a little over half that of the USA and Germany. How can we better translate our research excellence into economic benefit?

Current initiatives

Scotland's economic strategy focusses on the two mutually supportive goals of increasing competitiveness and tackling inequality. The Scottish Government has based its future growth plan on four priorities:

- investing in people and infrastructure in a sustainable way;
- fostering a culture of innovation, research and development;
- promoting growth and creating opportunity through a fair and inclusive jobs market and regional cohesion;
- promoting Scotland on the international stage to boost our trade and investment and extend our influence and networks.

To support this strategy, a number of initiatives have been launched. The Scottish Funding Council has funded the development of innovation centres that will seek to bring Scottish universities and businesses closer together. Funding through Scottish Enterprise Agencies has been increased.

The RSE Enterprise Fellowship scheme, supported by Scottish Enterprise, three of the UK Research Councils and Quantic, has supported many talented scientists and engineers in developing business and entrepreneurial skills.

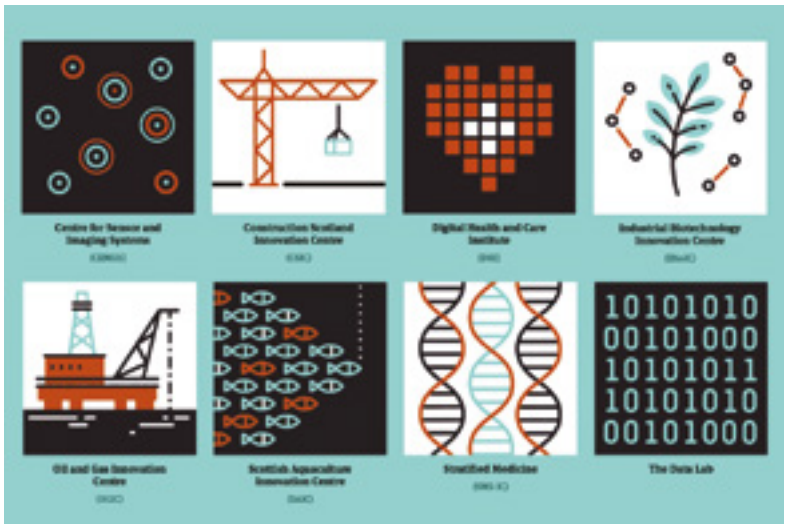
The RSE has contributed to the UK Government's consultation on Industrial Strategy[1] and has engaged with the Scottish Government on the future of the economic and skills agencies[2]. In addition, the Royal Society of Edinburgh's Business Innovation Forum has agreed to commission studies on three areas that are critical for economic growth: commercialisation, productivity and skills.

Fostering inclusive growth

We must ensure that all our citizens have access to training and knowledge throughout their lives. Inclusive growth also means seeking to involve all geographical areas of Scotland. Currently the highest concentrations of economic and research activity are around our major cities.

One of the ways we can seek to address this is by harnessing the opportunities presented by digital communications. Another is by providing greater opportunities for people in more rural parts of Scotland to learn and train within their

Professor Iain Gray CBE FREng FRSE is Vice-President for Business of The Royal Society of Edinburgh and Director of Aerospace at Cranfield University. He spent his early career as an engineer working for Airbus rising to become the Managing Director and General Manager for Airbus in the UK. In 2007 he became the first Chief Executive of the Technology Strategy Board later renamed Innovate UK.



The Innovation Centre programme was launched in 2012 to support transformational collaboration between universities and businesses.

own communities. The University of the Highlands & Islands is a prime example of this.

The skills necessary to support inclusive growth are not simply about scientific or technical knowledge. It is also critical that we seek to incorporate business and entrepreneurial thinking into all levels of education.

We cannot afford to be parochial – we must consider the future of the Scottish economy in a UK and global context. The UK Government is close to publishing a new Industrial Strategy (published in November 2017[3]). It is important that this strategy reflects the needs of Scotland, and equally important that the Scottish Government leverages the full opportunities provided by the UK strategy. The newly established UK Research and Innovation (UKRI) has a budget of more than £6 billion a year. Scottish universities and businesses need to ensure that they engage effectively with UKRI.

A good Brexit

Internationally, in my view the highest priority should be to negotiate a positive outcome to the Brexit negotiations with our current partners within the European Union. By a positive outcome I mean one that maintains our relationship with the European research community and enables researchers throughout the European Economic Area to continue to work collaboratively and move between countries.

The RSE has produced advice on the economic impacts of Brexit, including a recent submission to the Migration Advisory Committee[4].

At the same time, Scotland should seek to extend its trade beyond Europe, particularly to the fast-growing economies of Asia, and to the USA. We have some large global companies investing in Scotland, such as Toshiba Medical, who were attracted by Scotland's science base and incentives from Scottish Enterprise. We also have some promising emerging companies, for example Clyde Space, which is Europe's largest micro-satellite manufacturer, based in Glasgow. We need to develop policies and an economic environment that will nurture such companies and enable them to grow into large-scale enterprises.

Improving future strategy

To help improve Scotland's business strategy further, the RSE will be devoting considerable resources to finding the answers to some key questions, including:

- Why is business investment so low?
- Why is business research and development investment so persistently low?
- What are the obstacles to commercialisation?
- What is our place in partnership with others?

We will use the expertise of our Fellowship, together with that of other economic and business experts, as well as support from our staff. We have been discussing this proposed work with the country's leading business organisations. I hope and expect that many of them will contribute their knowledge and help us engage with their membership. We will also welcome evidence-based contributions from individuals and organisations.

Shining a light

Scotland has to get its economic policy right if it is to proper. To do this, we must start by shining a light on why our previous actions have not worked. In collaboration with partners from universities and business, as well as the UK and Scottish Governments, we aim to develop a strong and productive strategy for business, and hence the economy, across the country. Scotland's research base is among the best in world – whatever we do, we must build on this. □

We cannot afford to be parochial – we must consider the future of the Scottish economy in a UK and global context.

1. www.rse.org.uk/wp-content/uploads/2017/04/AP17_09.pdf
2. www.rse.org.uk/advice-papers/phase-two-review-enterprise-skills-agencies
3. www.gov.uk/government/topical-events/the-uks-industrial-strategy
4. www.rse.org.uk/advice-papers/rse-response-to-mac-inquiry-into-eea-workers-in-uk-labour-market

Plugging gaps in performance

Nora Senior

SUMMARY

- Identifying and addressing performance gaps is vital to bring Scotland into the top quartile of OECD countries
- Workforce training, including management training, needs to be improved across Scottish business
- Digital technology needs to be used much more widely by businesses
- Businesses need to be supported to do more research and development
- The Strategic Board for Enterprise and Skills is well placed to create new partnerships between businesses, educators and Government agencies.

The Scottish Government aims to move the country into the top quartile of OECD countries for productivity, equality, wellbeing and sustainability. Business strategy must put in place the elements needed to achieve that goal.

To develop a meaningful strategy, it is vital to understand where the gaps in performance lie. Scotland's level of productivity is near the bottom of the second quartile and needs to improve by at least 27%. Capital investment needs to rise by £10 billion, an increase of 95%. The country needs at least 6,000 more exporting companies.

Innovation imperative

Scotland has to become three times more innovative, tripling our investment in research and development (an increase of £1.9 billion). Currently, in companies with 10 or more employees, only 56% of those employees are actively involved in innovation.

Finally, we need to reduce the proportion of the population with no or low qualifications, currently 12% of those aged 16-24 (and 25% in the most disadvantaged parts of the country). The people of Scotland face difficult challenges, but the economy has strengths in many areas, including life sciences and financial services.

The Strategic Board for Enterprise and Skills encompasses five agencies (Scottish Enterprise, Skill Development Scotland, Highlands and Islands Enterprise, South of Scotland Enterprise and the Scottish Funding Council) and representatives of business, economics and local authorities. This membership allows business strategy to be considered from a broad range of viewpoints, and it has an important role in finding ways to plug gaps in Scotland's business performance.

Successful competitors in other OECD countries are aggressively and affordably up-skilling their workforces, with a focus on the competences needed to advance themselves and their companies. I believe training budgets should become a key focus for Scottish businesses. Much of what our delivery agencies in this area are doing at the moment could be taken on by businesses themselves. Part of any new enterprise and skills strategy has to be a call to arms to businesses, encouraging them to engage much more fully in the training dialogue, alongside the research and innovation as well as technology dialogues.

The quality of management can be a key differentiator in economic performance. Poor management, poor managerial practices and poor attitudes have a direct impact on productivity. There is evidence that the right type of upskilling and re-training leads to significant improvements in organisations, particularly in productivity. All the research shows that by improving standards of management, even by a small margin, substantial gains in efficiencies can be made. Too many Scottish companies do not regard management training, re-training or up-skilling as priorities in their workforces and so they do not invest enough in this area.

Digital technologies

Scottish businesses tend to perform poorly in terms of the take-up and use of digital business tools. Although 87% of businesses use websites and email, only 6% employ tools such as resource planning, which are used by 43% of businesses in Sweden. For example, only 19% of Scottish businesses use customer relationship management (CRM) tools, and even fewer, just 8%, use digital tools to manage their supply chains.

A key part of our strategy is to look at how to embed technology into our businesses and develop skills in the use of data and analytics. Investment in the use of digital technology is crucial. It is worth noting that the UK will need to fill 750,000 new digital jobs by 2020. In Scotland we will need people trained to fill 11,000 jobs that

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It will be crucial to further embed innovative practices, generate efficiencies and create new markets. This will not happen through investment alone.

will be created in the fintech (financial technology) industry alone.

We need to increase the awareness of sources of innovation support in Scotland. Research and development has a well-documented positive impact on growth and productivity, but R&D remains a high-risk activity for firms. It entails significant investment, it has uncertain outcomes and it creates knowledge spill-over which goes to other firms and organisations.

Essential incentives

Since firms are not able to capture all the benefits of their investment for themselves, they perform less R&D than would be socially optimal. So Government incentives to stimulate increased activity, particularly among businesses, are justified and need to be explored.

The Strategic Board for Enterprise and Skills will be looking at innovation support for different business sectors, including cross-cutting opportunities to offer access to academic expertise and facilities across Scotland. One of the key problems is the lack of data or real insight into Scotland's asset base. By analysing such information, we could see where our competitive advantages might lie. We also lack insight into the business or investment priorities of companies and universities. These insights are needed in order to prioritise investments in research and development.

It will be crucial to further embed innovative practices, generate efficiencies and create new markets. This will not happen through investment alone. It will also depend on having people with the right skills.

We are leaving behind the days when employers were passive consumers of the education and skills system. The way forward must include an increase in the partnerships between educators, businesses and official agencies. My aim, as Chair of the Strategic Board, will be to move towards a model in which our agencies work together for the benefit of the user, rather than as a collection of parts or a selection of silos. Their activities should be combined into a coherent system that is easy for users to navigate. ❐

An ecosystem for business

Susan Rice

Dame Susan Rice is a banker by profession. She was Chief Executive and then Chairman of Lloyds TSB Scotland and a Managing Director of Lloyds Banking Group. She now pursues a career as a non-executive director, and trustee committee member. She is the Chair of Scottish Water, of Scotland's first Fiscal Commission and has chaired the Edinburgh International Book Festival.

SUMMARY

- Business operates most successfully in a mutually supportive ecosystem
- Ongoing education is a key component of a successful business strategy
- We need a diverse workforce with opportunities for international collaboration
- New regulatory or consumer pressures create new opportunities for innovation, such as carbon-neutral solutions
- Large and small companies can be mutually supportive, and both should be encouraged.

There are a number of strands to a successful business strategy, and the key to developing a strong and effective strategy is to link these together into a mutually supportive system. For example, innovation and investment hubs could be aligned. Digital energy and transport strategy could be positioned to support each other. We need to think of our businesses as operating within an ecosystem, and determine what we can do to support this.

Education

Although a high value is rightly placed on having a skilled workforce, we also need a well-educated workforce. This goes beyond literacy and numeracy, and extends to communication, problem-solving and questioning. We may teach business or entrepreneurship but a successful worker, whether in a large organisation, self-employment or as a serial entrepreneur, is one who has been educated to think and analyse. Education should be continuous, beginning at school age, continuing through further and higher institutions and on into the workplace, throughout the span of an individual's working life.

We also need a diverse workforce in the widest sense – one that includes people from different backgrounds, demographics, countries and career routes. They can have a strong positive impact because they see things in the workplace through a different lens – keeping each other alert and imaginative, and potentially more creative. A business strategy that keeps the doors open for people to come and go is essential.

We need to recognise the importance of the international element and avoid separating

investment into inward or outward flows. Collaboration in research, investment, test sites and markets should be encouraged, with all flowing easily across borders.

Companies, whatever their size, have no choice but to respond to growing regulatory and consumer pressures. The impact of climate change on business is fast becoming apparent through extreme environmental events on the one hand and ever more stringent regulation and investment constraints on the other. Businesses have to examine their own models, their markets and their place within supply chains more critically now.

Opportunities abound

As the economy is progressively decoupled from a carbon-intensive model, some businesses are finding new opportunities. That is especially true of the small and medium sized businesses (SMEs) that are such a critical part of our economy here in Scotland.

For example, Edinburgh-based Vegware develops, manufactures and distributes a range of completely compostable food packaging. Although they are a local business, they work with some of the largest contract caterers and distributors, Government offices, NHS trusts, tourist attractions, food retailers and events organisers. These clients all demand zero-waste solutions. Vegware has grown nine-fold over the past five years and is the third fastest-growing firm in Scotland.

Another example is John Lawrie Ltd, an exporter of mainly tubular metal for recycling and reuse. Their business model is based on the circular economy – re-use what you have again and again. It has brought them great success in recent years, leading to 90 jobs here and around the world, as well as trade with North America, Europe, the Middle East and China. Not bad for a scrap metal merchant that started out in Aberdeen in the 1930s!

Businesses like Vegware and John Lawrie will thrive if transport and communications within the country work well and if there are agencies and organisations to provide support, such as Entrepreneurial Scotland and the Scottish Innovation Centres. The Edinburgh Centre for Carbon Innovation, for example, delivers support and funds to help good low-carbon businesses get off the ground. It also hosts the Climate Knowledge and Innovation Programme.

Large companies also innovate. Scottish Water is using robots to travel through underground pipes and detect potential stresses and leaks: this avoids the need to dig up all the pipes. Drones are being used to investigate above ground in order to find out where pipework might or might not be put. We turn to smaller companies to get this work done, which helps them to become more innovative and thus more marketable and successful.

We need to support the start-ups, the gazelles and the unicorns, knowing that when they interact with the big boys – the elephants – there will be success.

Having large companies close at hand enables smaller companies to gain early customers who are making new demands that require innovation and change. So it is important that a business strategy keeps the doors open for larger businesses as well as smaller ones. An environment that is attractive to larger businesses, as well as sustaining small ones, would be the best outcome because this approach would support the whole market.

Scotland has a wealth of universities for a country of its size. Some are research universities and a number of them regularly produce new spin-off businesses and start-ups. Many of these new businesses grow from science and technology. In these spheres, scientists need to be able to collaborate without borders or other artificial constraints. So a business strategy should enable or enhance international research links among institutions and with industry.

Leading role

Edinburgh University, for example, plays a leading role in the field of informatics and technology. It gave birth to Dolly the sheep and the research behind the Higgs Boson. Not only do universities create spin-off businesses, but the quality of their research also attracts business and this can be significant. Skyscanner was attracted to Scotland because of Edinburgh University's strengths. FanDuel of Fantasy Sports Company grew out of an Edinburgh spin-off.

Business unicorns are start-ups worth a billion pounds. Business gazelles are fast-growing companies that start with a million pounds and increase their revenue at least 20% annually for four years. That means they have doubled their revenue over four years and typically have had a disproportionately positive impact on job creation. More jobs may lead to a growing population, which is one of the characteristics of a thriving national economy.

We need to support the start-ups, the gazelles and the unicorns, knowing that when they interact with the big boys – the elephants – there will be success. As for the elephants themselves, we should never discourage them! □

Driving innovation

Paul Wheelhouse

Paul Wheelhouse MSP is Minister for Business, Innovation and Energy in the Scottish Government. He has been in post since May 2016. He is a professional economist and, since 1992, had specialised in Higher and Further Education markets, as well as policy evaluation, economic appraisal and impact assessment of capital projects. He has served on the Scottish Parliament's Finance Committee and the Standards, Procedures and Public Appointments Committee.

SUMMARY

- The Scottish economy is strengthening, although growth is slower than desired
- Businesses need practical help to realise their growth potential and an additional £45 million has been made available for R&D
- Strengthening links with universities and colleges through innovation centres will enable Scotland to better align research with the needs of the economy
- Improving digital connectivity and skills is vital to speed up the innovation cycle
- Public sector collaboration with technology start-ups provides a route for entrepreneurs and businesses to win public sector contracts.

The fundamentals of the Scottish economy are strong – employment is above its pre-recession peak and international exports increased by 41% between 2007 and 2015. In the first half of 2017 the number of people in employment rose to 2.6 million. However, economic growth is still slower than we would like.

Our major trading partners are the rest of the UK. We have been vocal in telling Westminster that we and our agencies, and indeed the other devolved nations, need to be engaged fully in the development and delivery of the UK Industrial Strategy. Yet Government engagement is only part of the answer. We need to encourage and facilitate businesses to drive us forward.

Small and medium-sized businesses with high growth potential need practical support that includes access to finance. To this end, the Scottish Government announced an additional £45 million in research and development grants over the next three years. This uplift in support will enable more ambitious businesses to invest in research and development. The aim is to double business expenditure on R&D to £1.75 billion by 2025. We expect the Government investment of £45 million to be topped up with business adding a further £222 million. That gives an idea of the scale of the leverage anticipated from this investment.

Business catalyst

The Government is also investing in delivering a national manufacturing institute for Scotland to facilitate innovation and to catalyse our businesses. This will not only contribute to business growth but will also help to boost Scotland's overall innovation performance. There are many small and medium-sized businesses (SMEs) that lack access to the special equipment and necessary skills needed to develop prototypes, so this will play a very important role in meeting these requirements.

We need to strengthen the links between our business and academic communities. Scottish universities are the envy of the world – not only do they provide excellent teaching to the innovators and entrepreneurs of tomorrow, they also produce some of the best research. Many institutions have knowledge and experience that are internationally recognised. For example, a recent report on global innovation identified the University of Dundee as the world's most influential scientific research institution in pharmaceuticals. By better harnessing our world-leading research and making sure that wherever possible it is aligned with the needs of our economy, we can drive major innovation, investment and growth in the economy.

This does not just apply to universities. Colleges also play a vital role in supporting innovation, engaging with large numbers of businesses on a weekly basis. We are looking to support this work through the College Innovation Fund pilot. There are still many SMEs across the economy which are not yet engaged. The Government has committed up to £120 million to support a network of eight innovation centres over a six-year period.

Digital connectivity and skills

Scotland's digital economy has made great strides. Digital technology allows us to speed up cycles of innovation and to link rural and urban economies. We are on track to have 95% of Scottish premises able to benefit from fibre-broadband thanks to continued funding and support from the Scottish Government and hard work by local authorities. But we are not stopping there: our ambition is for 100% coverage by 2020.

Digital connectivity is vital, but to fully capitalise on it we must have digital skills as well. These skills are the key to opportunities and success in the global economy. We are therefore committed to expanding our pool of digital skills and capabilities. We are building upon foundations already laid, such as the STEM programme and the CodeClan digital skills academy, both of which are

helping to accelerate Scotland's progress in building a high-performing digital economy.

We are also aiming to embed digital literacy from early years onwards by expanding the number of coding clubs in schools and boosting teacher numbers in computing. We are working with industry to tackle skills shortages and to increase the number of pathways into the workplace.

It is imperative to address the gender gap that continues to blight the digital sector. The proportion of women in digital technology roles in our country is only 18%. Clearly that is far below what it should be, and limits both our talent pool and our ability to understand the needs of our users.

Ground-breaking programme

Government has to practise what it preaches. I am therefore very pleased with the CivTech pilot that was launched last September. CivTech is a ground-breaking programme that is harnessing new technologies to drive innovation into the public sector. It is bringing together private sector innovation, public sector organisations and citizens to develop more efficient products and services.

FURTHER INFORMATION

Royal Society of Edinburgh
www.royalsoced.org.uk

Strategic Board for Enterprise and Skills
beta.gov.scot/groups/enterprise-and-skills-strategic-board

It will also provide a route for entrepreneurs, start-ups, SMEs and others to take forward digital transformation in the public sector. CivTech will offer a rapid and secure pathway for businesses to win public sector contracts. Through collaboration with technology start-ups as well as the brightest and best in the private sector, the public sector will benefit from improved service delivery and outcomes. We have doubled the funding to £1.2 million to allow this programme to be scaled up. Working together, we can create a more prosperous, innovative and inclusive society. We want a Scotland where people have the opportunity to flourish, no matter where they were born or who they are. □

The debate

The STEM subjects (science, technology, engineering and mathematics) are important to any business strategy, as is the need to attract more women into them. However, the arts and humanities should not be ignored: some STEM graduates move into careers in other work areas.

Universities can make a fundamental contribution to commercialisation by turning out good-quality graduates. There is, though, a more general need for a skilled and well-educated workforce at all levels, and in this context tackling current under-achievement in Scottish education is a priority.

The Government could give greater direction to universities on recognising the needs of business. Although strong links between universities and business are important, there are other approaches that are needed to create better links. For example, parents could be made more aware of business career opportunities at the stage when they are advising children on subject choices.

Encouraging graduates to remain in Scotland after graduation is important which may have implications for the Scottish Government's taxation policy. The availability of high-quality jobs and public services, together with a good quality of life generally, are among the factors that influence graduate retention.

There are excellent examples of innovation in Scotland but not all areas have benefitted. Efforts to embed the digital economy could help to improve the career prospects of young people.

SME challenge

There is a particular challenge regarding small and medium-sized enterprises, since they account for the vast majority of Scottish businesses. In these, innovation usually needs to be incremental and takes time. Tax credits for research and development to encourage SMEs to work with universities should be considered. The nurturing of medium-sized companies is especially important since some of them have real potential to grow and contribute to the Scottish economy.

Scotland's relatively poor business productivity needs attention. Greater investment by businesses in technology is important. Equally, there is a need for management in some sectors to communicate more effectively and work more closely with the workforce in introducing technologically-driven change.

In the debate following the presentations, a number of topics were raised, including: the importance of STEM; the skills agenda; encouraging graduates to remain in Scotland; and digital technologies.

What needs to be done to meet urban air quality targets and what are the consequences if the targets are not met? These issues were debated at a meeting of the Foundation, held at The Royal Society in London, on 26 April 2017.

The energy emissions challenge

Steve Bryce

Dr Stephen Bryce is Vice-President, Fuels Technology, Shell Projects and Technology. He is an expert in future and specialist fuels and manages the research and development that supports Shell's technical partnerships. In 2008, he became President of Shell Cansolv, an innovative, technology-centred company that offers high-efficiency capture solutions for the removal of sulphur dioxide and carbon dioxide from gas streams in various industrial applications.

There are about 7.4 billion people in the world today, and this number is expected to rise to 10 billion by 2050. About 54% of us live in cities, but this is expected to increase to 70% by that date. The amount of energy we will need is expected to increase by 67% by 2060. This is partly due to an expected increase in the number of vehicles, from 800 million today to 2 billion by then.

Renewable energies will become more of the 'norm', although there will still be a significant role for hydrocarbons. Currently more than 50% of the world's energy is supplied by oil and gas, with 29% from coal. It is perhaps surprising that 30% of the world's domestic and commercial energy is still supplied by traditional biomass, including the burning of wood, charcoal and animal dung.

Urban air quality needs to be addressed as part of a broader view of sustainability from an environmental perspective. While that includes CO_2, it is important not to focus just on one aspect to the exclusion of others. We also need to look at air quality from the perspectives of energy accessibility, affordability and sustainability. We should not optimise one priority at the expense of the others. To reach the best overall solution we need to look at these three aspects together.

Transport-related energy consumption varies considerably across the cities of the world. For example, the US city of Atlanta is geographically spread out and has a high level of car ownership. It uses more energy for transport than New York, which is less spread out, has a lower level of car ownership and a more comprehensive public transport system.

There are changes in models of car ownership, however, and in the numbers of people who want to own a car. Where I live in Hamburg, car ownership is becoming less popular and car sharing is increasingly prevalent. The cost of car ownership is also rising. There are now limits on the entry of vehicles into inner cities. In some cities such as Singapore, the cost of obtaining a licence is very high, and in others such as Beijing it is very difficult. These policies are all, in one way or another, driven by the need to reduce air pollution.

SUMMARY

- The world's energy needs are expected to increase by 67% by 2060
- Urban air quality needs to be addressed as part of a broader perspective that includes energy accessibility, affordability and sustainability
- There is no 'one size fits all' solution – different cities will need different solutions
- Changes in lifestyle, such as more car sharing and reduced car ownership – as well as the advent of new technologies – have the potential to reduce transport energy use
- New energy sources will require partnerships between Government and industry, for example to provide hydrogen refuelling stations or ensure that charging points for electric cars are standardised.

New technology, new opportunities

In addition, new technology is opening up new opportunities. Autonomous vehicles available on call might reduce the need for individual car ownership in the future. Heavy goods vehicles can travel close together in platoons – lines of 10 – coupled electronically and benefiting from more efficient aerodynamics. New developments such as these and others will have an impact on urban air quality.

We use the term 'mosaic of potential solutions' to describe how energy demand can be met at the same time as improving air quality. Different cities will need different solutions. Our mosaic still includes fossil fuels, but increasingly will rely on alternatives including renewable fuels, solar energy, batteries and hydrogen. Their role will vary depending on local circumstances. What is good for Manila will not be good for Manchester and what is good for London may not be good for Los Angeles. So we need to be very mindful of those local circumstances.

The issues must be looked at from a broad perspective; we must not solve one problem by creat-

ing another – for example, creating a problem with electricity demand by switching to electric vehicles.

The pathways from energy sources through to final products, whether they be fuels, electrons or something else, are very complex. Creating successful pathways will require partnerships between governments at local, regional and national levels, businesses and society as a whole. This includes making sure that end users are informed about energy issues and can take these into account when deciding how they want to live.

One area where a joined up pathway is urgently required concerns electric charging for cars. At the moment, there are at least three different connection types, which clearly limits uptake of electric cars. The industry needs to work with governments to quickly establish a standard for electric charging. For this reason we are working together with companies such as Daimler in the Charging Interface Initiative to promote the standardised Combined Charging System.

A joined up pathway is urgently required for electric charging for cars. The industry needs to work with governments to quickly establish a standard.

Another example is hydrogen refuelling. Germany is developing a number of hydrogen refuelling sites. Working in partnership with the government, vehicle equipment manufacturers and energy providers, this programme will provide 400 hydrogen refuelling sites across Germany by 2023. This has been made possible only because of these working partnerships. It is essential to have all the pieces of the puzzle in place when trying to develop a new energy source. If one piece of the puzzle is missing it will not be sustainable.

We believe that improvements in urban air quality are certainly attainable. However, they will depend on partnerships between governments and industry, and a broad-based approach that takes account of energy affordability and availability. ❐

The health consequences of air pollution

Frank Kelly

SUMMARY

- WHO issues targets for air quality in Europe, including target levels of $PM_{2.5}$ and NO_2
- In many UK cities including London these targets are regularly exceeded
- There is diverse and extensive evidence from studies in the laboratory and in the field that air pollution damages health
- Much of the problem is caused by modern lifestyles
- We can improve the quality of our air, and our health, by adopting measures to tackle $PM_{2.5}$ and NO_2, in much the same way the 1956 *Clean Air Act* successfully tackled black smoke and sulphur dioxide.

Targets for air quality in Europe are based on guidelines issued by the World Health Organisation (WHO), derived from reviews of the health literature available at the time. The guidelines were first issued in 1987, and were revised in 1997 and 2005. The next update is in progress and is scheduled for publication in 2019.

The WHO guidelines cover key pollutants such as NO_2 and $PM_{2.5}$ (fine particulates less than 2.5 micrometres in diameter, which can enter the lungs). The 2005 target for NO_2 is 40μg/m^3. For $PM_{2.5}$ it is 10μg/m^3. In London the level of $PM_{2.5}$ is around 14-15μg/m^3 – about 50% higher than the WHO target.

Breathing this quality of air over a long period of time leads to health problems for many people. In 2010 the Department of Health Committee on the Medical Effects of Air Pollution reported that poor air quality, measured as levels of $PM_{2.5}$, was associated with the loss of 340,000 life-years across the population – equal to 6 months for every person in the UK, or equivalent to 29,000 premature deaths per year.

But of course death is the extreme outcome. It sits at the top of a pyramid of health problems (see Figure 1, page 26). We know that on high air pollution days there are more hospital admissions, A&E attendances and GP visits to treat respiratory and cardiovascular problems. Episodes of high air pollution occur regularly; during

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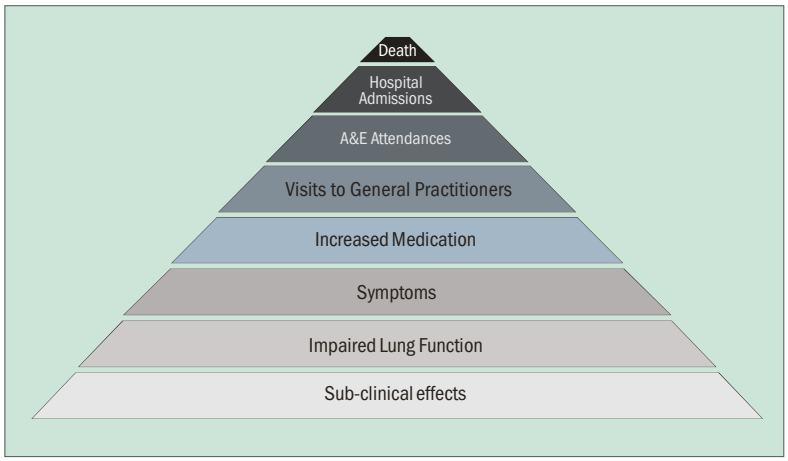

Figure 1. The impact of air pollution on health

the first four months of 2017 we had an episode lasting a few days in each month. People with health conditions suffer more consequences during these episodes.

Poor-quality air does not just affect people with existing health conditions. Laboratory experiments in healthy volunteers in Sweden have shown that two hours of exposure to diesel fumes – roughly equivalent to the levels found on London's Oxford Street – produced an inflammatory response in the lungs, indicating that the lungs were struggling to combat the fumes.

We also have evidence from studies conducted in the real world. A study about 10 years ago on people with asthma looked at their lung function when they were walking in Hyde Park and compared it with their lung function when walking on the much more polluted Oxford Street. Lung function was measured using FEV1, (forced expiratory volume), which is the volume of air that can be forcefully exhaled in one second.

Impact on children

The study volunteers walked for two hours and their FEV1 was measured for 24 hours afterwards. After the Hyde Park walk their FEV1 had decreased by about 2%, but after walking on Oxford Street for the same amount of time, their FEV1 had dropped by about 6%. The reduction in lung function lasted for up to 24 hours afterwards. This would happen to most people with asthma every time they experience high levels of pollution.

To find out what impact London's air pollution is having on children's health, we did a six-year study called the Exhale Study. This looked at the effects of exposure to NO_2 on about 2,000 school children in east London. Most of these children live in areas or streets that exceed the WHO target for NO_2 of 40μg/m^3. We found that children with an annual exposure of 35μg/m^3 had about 5% less lung volume than expected. The children who were exposed to a higher level – 55μg/m^3 – were losing up to about 9% of their lung volume.

The implications for these children are lifelong, because lung growth continues only until the age of 18. From about age 30 we start to lose lung volume, which is why we find it increasingly difficult to carry out exercise such as running up stairs as we get older. The tragedy for these children is that they might reach age 18 without full lung development, and will carry that burden for the rest of their lives. So it is crucial to better understand this issue and stop this generation of children being affected in this way.

It has been known for a long time that breathing air of poor quality affects our lungs. But what we now appreciate is that the health effects go beyond the lung. There are also now strong links with cardiovascular disease. In the report *Every Breath We Take*[1], chaired by Professor Steven Holgate, it was shown that air pollution affects nearly every tissue in the body at every stage of life, including the unborn child in the womb. Studies have shown that mothers in areas with high air pollution have smaller babies. Effects on young children, in particular lower airway respiratory tract infections and, in some instances, effects on lung growth, have been shown in some polluted environments.

As we move into adulthood we may start to develop chronic conditions such as diabetes, and later neurodegenerative conditions such as Alzheimer's or Parkinson's disease. In the past, we have viewed these as inevitable consequences of ageing. Yet, increasing it seems that air pollution is contributing to the development of these conditions. The evidence base linking poor air quality and poor health is now diverse and extensive, consisting of thousands of studies done across the world.

Seeking solutions

We all contribute to the problem in one way or another – driving our cars, jumping into taxis, lighting our woodstoves at the weekend. Although we do not think about it, these actions are all adding to the problem. However, we know it can be solved, in the same way that the problems of black smoke and sulphur dioxide were solved in the 1950s. The concentrations of both pollutants fell dramatically after the 1956 *Clean Air Act* was enacted. We now need to find similar solutions to deal with the modern air pollutants $PM_{2.5}$ and NO_2. □

Air pollution affects nearly every tissue in the body at every stage of life, including in the womb. Studies have shown that mothers in areas with high air pollution have smaller babies.

[1] Royal College of Physicians: *Every breath we take*: the lifelong impact of air pollution www.rcplondon.ac.uk/projects/outputs/every-breath-we-take-lifelong-impact-air-pollution

The debate

It is vital to widen public awareness of the scale of the air pollution problem, the nature of its adverse impacts, and the part everyone plays in creating the problem and could play in solving it. Politicians need to be persuaded that action to deal with air quality should be given higher priority. For that to happen there needs to be much greater popular pressure (stimulated by professional public relations activity and by the media) as well as firm political leadership of the kind being shown by the Mayor of London.

Comparative regulation

It is useful to look at the different regulatory policies and practices of other countries such as Japan (which, unlike the UK, has not incentivised the use of diesel power), Hamburg, Los Angeles and Madrid, as well as the Netherlands which has many similarities to the UK but a better air quality record. We should do more to help cities in the developing world, such as Calcutta and Kathmandu, to avoid the mistakes made elsewhere.

One cause of increased traffic in London and other urban centres could be the growth of journeys delivering online purchases. Possible solutions to this could be consolidation of drop-off points or the use of new technology to optimise delivery systems.

Although some progress has been made toward the development of nationally available forecasts of air quality, more needs to be done.

We need to ensure we give enough attention to reducing sources of pollution outside large urban areas, where the lack of public transport leads to greater use of private transport and financial constraints preclude measures to increase the use of bicycles.

Taxi drivers in London, who are heavily exposed to air pollution, are well aware of the need to clean up London's air. It is therefore regrettable that the minicab lobby has succeeded in persuading the authorities to allow continued use of diesel-powered vehicles until 2023. □

The discussion that followed the formal presentations considered a wide range of issues, including public awareness, political will, international experiences and forecasting.

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Taxi drivers in London are heavily exposed to air pollution

FURTHER INFORMATION

City of London Air Quality Strategy 2015-2020
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***Clearing the Air*: The Mayor's Air Quality Strategy**
www.london.gov.uk/sites/default/files/air_quality_strategy_v3.pdf

Hansard Report on Urgent Question on Air Quality Strategy
hansard.parliament.uk/commons/2017-04-24/debates/4E0AFC5E-6B08-4A88-AE5E-AACC3F1C47D9/AirQualityStrategy

IARC: Outdoor air pollution a leading environmental cause of cancer deaths
www.iarc.fr/en/media-centre/iarcnews/pdf/pr221_E.pdf

Monitoring the implementation of London Plan energy policies in 2015
www.london.gov.uk/sites/default/files/2015_monitoring_report_-_final_nov_2016.pdf

Royal College of Physicians: *Every breath we take: the lifelong impact of air pollution*
www.rcplondon.ac.uk/projects/outputs/every-breath-we-take-lifelong-impact-air-pollution

Studies on the Impacts of Air Pollution on Human Health, the Environment, and Global Economies
www.niehs.nih.gov/health/topics/agents/air-pollution

World Bank Report: The Cost of Air Pollution: Strengthening the Economic Case for Action
www.openknowledge.worldbank.org/handle/10986/25013

Can cancer be diagnosed earlier and if so what are the implications for patients and the health system? The challenge was debated at a meeting of the Foundation held at The Royal Society on 11 July 2017.

Early diagnosis has the potential to transform patient outcomes

Harpal Kumar

Sir Harpal Kumar is Chief Executive of Cancer Research UK. He worked for four years in the London office of McKinsey and Co, specialising in healthcare. He then became CEO of The Papworth Trust. He left Papworth in 1997 to become founding CEO of Nexan Group, a venture-capital-backed medical device company, creating and marketing novel cardio-respiratory monitoring technologies to reduce premature mortality in patients with congestive heart failure.

SUMMARY

- Early diagnosis is vitally important if patient outcomes are to be improved
- Early diagnosis and treatment is much less expensive than late-stage intervention
- The UK lags behind other countries in cancer treatment resources
- Early diagnosis technologies have their own challenges, including over-diagnosis
- Shifting the focus to early detection will require a re-assessment of funding for different elements of the health system.

For most types of cancer, early diagnosis can greatly improve outcomes. For example, if bowel cancer can be detected early, the survival rate is higher than 90%. The rate is much lower in the case of late detection, in fact less than 10%.

The story is similar for lung cancer – outcomes are much better with early detection. Indeed, this is the case for most types of cancer: the earlier it is diagnosed, the more we can improve outcomes in terms of survival.

On average, half of all cancers are diagnosed at stages 1 or 2 and the remainder at stages 3 or 4 although the picture varies for different types (see table, page 29). With breast cancer, somewhere between 80-90% of cases are diagnosed at an early stage: the UK is in line with the best countries around the world on this. On the other hand, less than half of bowel cancers are diagnosed at an early stage – which is behind many other countries – so there is an evident opportunity for improvement, even with no new technology development.

On average, if a colon cancer is diagnosed at stage 1, the cost of the entire treatment journey averages just over £3,000. If, on the other hand, it is diagnosed late that rises to more than £12,000. So there is a real imperative, both in terms of outcomes and in terms of NHS resource utilisation, to diagnose earlier.

There are a number of ways to do this. First, though, it is important to recognise that diagnosis itself is complex with a whole range of inter-related factors that determine how quickly or late a patient is diagnosed. There are different ways in which patients interact with their GPs or the health system, for example. In fact, there are a whole range of system issues and a further set of challenges about the quality or otherwise of the tests available.

Screening

There are three national screening programmes in the UK, but bowel screening continues to have much lower take-up than breast or cervical programmes. Sadly, there has been a decline in cervical screening over the last several years.

For those who do take part in bowel screening, there has been a significant impact on mortality – 25% lower in those who have taken part in screening compared with those who have not. While there are undoubtedly a whole range of reasons why screening uptake is not as high as it could be, the need to improve this picture is clear: it would make a significant difference to survival and mortality rates.

Yet the challenge is not solely about screening. The proportion of cancer patients who are diagnosed early compared with those that are diagnosed late varies across the country. In some areas, as little as 44% are diagnosed late, whereas in other parts it can be as high as 55%. That variation (11% or so) represents an enormous number of patients – about 40,000 a year.

The past several years have seen a steady increase in delays caused by the lack of diagnostic capacity. Figure 1 (page 29) compares radiology resources globally – both the level of equipment and the number of trained radiologists. The UK scores poorly in national comparisons of the resources available for diagnosis. That of course then translates into patients being diagnosed later.

The 2015 Cancer Strategy[1] highlights some of the system issues and proposes a target of four weeks between a patient presenting with symp-

Stages in cancer development
Stage 1: the cancer is small and within the original organ.
Stage 2: the tumour is larger, but has not started to spread into the surrounding tissues. With some types of disease, cancer cells may have spread into lymph nodes close to the tumour.
Stage 3: the cancer is larger. It may have spread into surrounding tissues with cancer cells in nearby lymph nodes.
Stage 4: the cancer has spread from where it started to another body organ (also called secondary or metastatic cancer).

toms to actually getting a definitive yes/no diagnosis. There are a whole series of elements to examine in the way the diagnostic pathway works. For example, if a patient presents with relatively non-specific symptoms – abdominal pain, headaches, persistent coughs – they often go round and round the system with several presentations to their GP and different diagnostic sciences. This is a waste of resources as well as a waste of time and often it results in a later diagnosis. A number of organisations are examining the possibility of changing some of those pathways, particularly where the symptoms might not be clear or obvious. Multi-Disciplinary Centres (MDCs) such as those established in Denmark provide examples of this approach. A number of these changes can be made with no new technology and no new tests.

Other possibilities include developing a better understanding of those groups with the highest risk of cancer and then monitoring and/or intervening more frequently.

One of the most exciting things about the present situation is the myriad possibilities of new technologies, with both pre-clinical and clinical applications. These may facilitate a significant shift in the stage at which a whole series of patients are diagnosed. There are some very interesting possibilities in terms of examining existing data sets as well the use of machine learning and artificial intelligence to search for patterns that might enable earlier detection of cancers.

False positives and negatives

So those are all opportunities, but what are the implications? One is the possibility, as indeed with any test, of false positives and false negatives. There has been a very large study carried out in the USA, looking at low-dose helical CT scanning for earlier detection of lung cancers. That study showed a 20% reduction in mortality. What is not generally talked about is the false positive rate in that study was 96%.

As a result of that particular technology being used in this way, large numbers of people underwent quite significant interventions – in many cases bronchoscopy, but in some cases more extensive investigations. Now those tests have significant levels of morbidity associated with them. So the headline numbers of a 20% reduction in mortality have to be considered in context.

There is, in fact, a great deal of activity underway to improve the false positive rate through the

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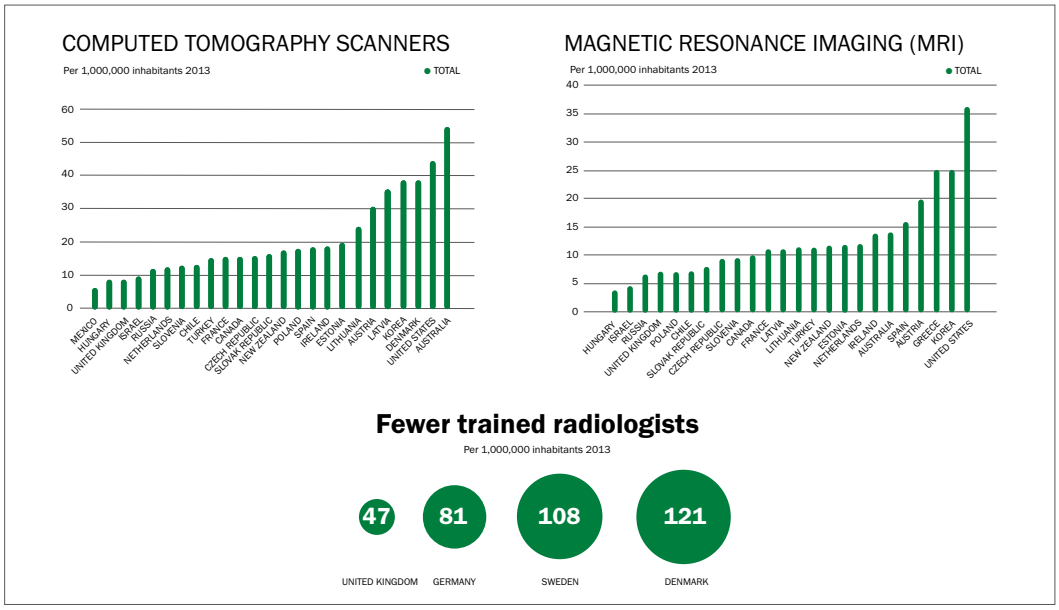

Figure 1. Comparisons of cancer detection resources

DEVELOPMENTS IN CANCER DIAGNOSTICS

Billy Boyle, Chief Executive Officer of Owlstone Medical, outlined some of the developments in cancer diagnostics. His company has developed what is essentially a breathalyser for disease: every time a person exhales, there are thousands of chemicals on their breath. Some of these are biomarkers – of conditions from cancer to infectious disease. Chemical sensor technology can be programmed to detect specific markers.

While a person's genome indicates the theoretical risk of disease it is the downstream metabolism that provides the best real-time snapshot of actual disease state. In regard to cancer, this has been known for about 75 years. Cancer alters metabolism, even at the very early stage. Using breath markers has the obvious advantage of being non-invasive, but the tests can be more effective as well.

One in two people will get cancer. There is still a very uneven picture in terms of outcomes for patients. In some cases, treatments work and in other cases screening works. In addition, some of the cancers are extremely deadly but the incidence rate is relatively low.

Even relatively modest improvements in the rate of early detection can have a really significant impact on patient survival as well as reducing the cost of treatments.

It is not a question of throwing out existing strategies but of using technologies in conjunction with each other. The breath test, for instance, offers an opportunity to reduce the number of false positives when used in combination with existing screening. There is also the important question of resource efficiencies – if the number of CT scanners and radiologists is limited, how can the best use be made of these?

The nature of the test really matters. In colorectal cancer screening using a faecal-based test, up to 50% of people do not turn up for the appointment and so risk developing late-stage disease. As well as the choice of technologies themselves, there is the broader picture of acceptability to patients.

In his talk, Boyle agreed with the conclusion of the other speakers that the field of early detection offers significant benefits to society, both in terms of patient outcomes and in the efficient use of scarce health-service resources and funding.

addition of other tests that may be used as a triage into a low-dose CT screening programme.

The contrasting possibility of false negatives is potentially very serious. If a technology has a relatively low sensitivity as indeed several do, cancers will be missed. If the patient goes away thinking there is nothing wrong, it might prevent them from coming back if their symptoms become worse. This is another factor we need to take very, very seriously and why sensitivity is really important.

Saving lives

A third critically important area concerns over-diagnosis, i.e. the possibility of detecting quite slow-growing cancers which might not cause a problem for the individual in their lifetime. The best current example is the breast screening programme. There is no doubt that this saves lives, between 1300-1500 a year in the UK. A recent study estimated that for every woman's life saved through the programme around three are diagnosed with a cancer that would not cause the woman a problem in her lifetime. Almost always, these women have treatment – sometimes quite extensive treatment.

We need to get much better at distinguishing cancers which are lethal and need treating from those that are not lethal. At present we do not have the ability to do that. With some of the newer technologies looking at circulating biomarkers, it can be difficult to determine where the cancer arose in the first place. Of course, these technologies are in an early stage of development and it is quite possible that they will offer greater opportunities as they progress, but as yet this is not clear.

There are significant implications for the health system. With new technologies coming along and in the light of the challenges to diagnostic capacity, more funds will have to be invested to get a higher proportion of people diagnosed at an earlier stage. The corollary is that it should be possible to shift investment from other aspects – so less resources and less money may need to be spent on treating late-stage disease.

What role will primary care play in the future? Some would argue for a bigger role and some for smaller. If symptoms that are known to be red flags for cancer can be identified earlier, it might be possible to put in place a mechanism by which patients go straight to test, rather than via GP referral which introduces delay. Why waste a GP's time if someone has had persistent rectal bleeding for a number of weeks?

On the other hand, some of the technologies that are in current (or future) use in secondary and tertiary care might be carried out in a community setting. A very large programme of work is now underway to see if this is possible. So, the jury is out on future activity in the primary care setting.

The key message in all this is the real potential for transforming outcomes and getting much higher levels of survival than we have seen previously, as well as better utilisation of resources. It is so much less expensive to treat a patient with early-stage cancer than to treat one with late-stage cancer. □

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[1] Cancer Strategy Implementation Plan. www.england.nhs.uk/cancer/strategy

Using genetics to combat cancer

Clare Turnbull

SUMMARY

- Stratification using genetic risk can improve targeting resources on early detection and prevention
- The majority of cancers occur in the minority of individuals who are at elevated genetic risk
- Identification of individuals who carry mutations in high-penetrance cancer susceptibility genes is a priority; the impact of screening/preventative interventions is highest in these individuals
- Individuals at high and moderate cancer risk can also be identified using risk modelling that combines genetic and non-genetic factors.

The majority of patients who present with advanced cancer die from their cancer. In addition, they incur very high treatment costs for investigations, drugs and prolonged in-patient stays. There are targeted drugs that have been developed to treat cancer which are typically used in the advanced setting. These drugs do not cure patients but may extend their life. However, this may only be for a matter of a few months. As these drugs have very high development costs (in excess of $1 billion to bring a drug to market), 'per patient' costs often come to more than £10,000 per treatment round.

Tumours

Tumours are not homogeneous, they are clonal. They are made up of sub-clones of cells which have different molecular characteristics. Thus a targetable mutation which the expensive drug is designed to treat may only be present in a sub-set of the cancer cells. The disease itself is ruthlessly Darwinian – treating it with a drug, creating a selective pressure, will drive development of resistance mutations. The resistant clone has a selective advantage which means that the clone expands, predominates and the tumour continues to progress. Hence the limited period of effectiveness of targeted drugs in the advanced setting.

Mathematical modelling of cancers suggests that for many tumour types there may be a catastrophic molecular event at some point in cancer development and after that there is aggressive, unbridled replication of the tumour with the normal mechanisms of cell defence becoming increasingly futile. Overall, between tumour evolution and cataclysmic molecular events, developing measures that meaningfully impact on cancer control in the advanced setting is a real challenge. Therefore, it remains the case that 'curing' cancer still relies on timely physical removal of the tumour. In the vast majority of tumour types this is achieved through surgery. Effective surgery to cure the cancer is contingent upon getting to that tumour when it is small and localised – and before the catastrophic molecular event has caused 'bolting' of the tumour.

Considering this at population level, a 'leftwards shift' of the average time of cancer diagnosis will also shift the stage at which cancers are operated on, with commensurate improvement in the proportion of tumours effectively cured by surgery.

Detection and prevention

National screening programmes for breast, colorectal and cervical cancer are already in place: behavioural research, public education and evolved participant tools are vital to better understand and improve uptake.

Coupled very closely with, but even better than, early detection is prevention. Preventative approaches may comprise modification of lifestyle exposures (e.g. to sunlight or tobacco), chemo-prevention (e.g. aspirin to prevent colorectal cancer) or surgical prevention such as risk-reducing bilateral salpingo-oopherectomy (removal of the ovaries and fallopian tubes to prevent ovarian cancer).

Expansion of vaccine programmes is another area of prevention that warrants attention. HPV vaccinations save lives, but they are only administered to girls. Yet this can prevent, in addition to cervical cancer, other HPV-driven cancers such as anal cancer or head-and-neck cancers. So urgent evaluation of vaccination of boys is also indicated.

Then there is chemo-prevention – drugs that cost pennies but which reduce the incidence of cancers. Aspirin, statins, metformin – these are

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Cancer itself is ruthlessly Darwinian – treating it with a drug, creating a selective pressure, will drive development of resistance mutations.

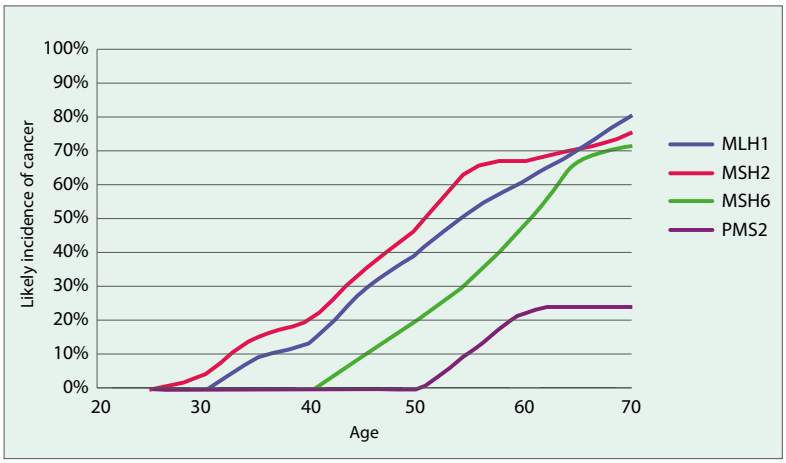


Figure 1. Lynch Syndrome: cancer susceptibility due to mutations in base excision repair pathways.

not being used systematically and that is another missed opportunity.

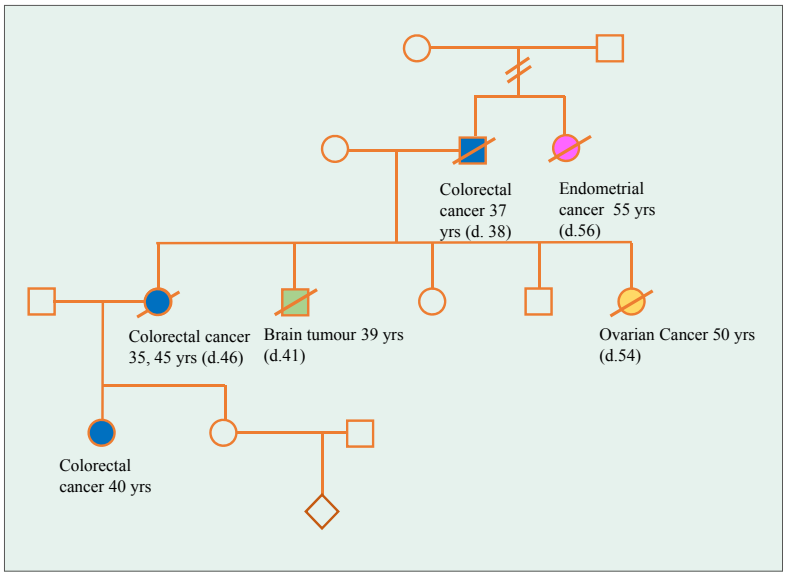
Education is also needed about public health interventions and lifestyle change – earlier action on obesity, smoking and other public health indices will have substantial impact on cancer incidence.

Targeting

When considering screening and prevention, it is logical to target the populations most likely to have the cancer in question. The two filters normally used are age and gender: so the three current screening programmes (breast, cervical and colorectal) use these basic demographic factors to identify the people most likely to have prevalent cancers. Could we use genetics and non-genetic factors to refine and better target screening and preventive measures to sub-populations who are at a prior highest risk?

Genetic susceptibility to cancer has been recognised since Roman times when there was documentation on familial clustering of breast cancer. Dr Aldred Scott Warthin wrote a paper in 1913 detailing the family of his seamstress in which he observed a marked excess of cancers of the gastro-intestinal tract and of the gynaecological tract. However, he foolishly did not put his name to the condition and in 1966 Professor Henry Lynch documented a couple more such families while giving his name to the now eponymous 'Lynch Syndrome'.

Figure 2. Lynch Syndrome: a typical pedigree.



In the 1990s, four genes underpinning Lynch Syndrome were identified (MLH1, MSH2, MSH6 and PMS2) and the biological mechanism causing this cancer susceptibility was identified as defects in base excision repair pathways. Studies of individuals and families carrying mutations in these genes indicated a lifetime risk of 70-80% of developing cancer (and some of these cancers develop young).

Figure 1 shows a curve accelerating from age 30: by 40 there is a substantial accrued incidence of cancer. Figure 2 shows a typical Lynch Syndrome pedigree. There are two cases of colorectal cancer – they died young. There is a brain tumour, an ovarian cancer, another colorectal cancer and an endometrial cancer.

Until recently the patient who had come to my genetics clinic might have been a woman on the lowest line of the tree. She would be concerned that her sister had recently been diagnosed with bowel cancer at a young age and that there was a dreadful family history of cancer.

I would contact the sister's clinician and advise referral of the sister to genetics. The genetics service would proceed to identify the cause of genetic mutation in her. They would write back to me, I would test my patient for it and institute measures to address her high risk of cancer.

Yet, all those other people had to die of cancer before we were able to ascertain the family risk. Supposing genetic testing had been available to those earlier generations. The first to suffer from colorectal cancer could have been tested for mutation. That might in turn have changed the course of the history of this family: everyone would have their genetic test as they reached early adulthood and they would know if they were at high risk of cancer or if they were 'off the hook'. Preventative surgery could have allowed them to live long, full, cancer-free lives. My patient could come along knowing that she carries the causative mutation and have IVF embryo selection to make sure her child does not carry the mutation.

Historically, though, it was not feasible to deliver genetic testing routinely in clinical cancer care: 'screening' of genes for mutations was arduous, low throughput, slow and relatively insensitive. However, in the last decade there has been a renaissance in technology. 'Next generation sequencing' has been a game-changer in identifying mutations in patients. Sequencing is now

cheap with high throughput; it is very quick and very sensitive. It offers the possibility of expanding the populations and patients that are offered genetic testing.

Knowing about Lynch Syndrome mutations is really useful for early detection and prevention of cancer. Those at risk can be given regular colonoscopy from age 25, picking up these cancers while they are still polyps. They can then have preventative surgery before they develop cancer. Aspirin is really effective in these patients: it reduces the incidence of bowel cancer very substantially (there is a dosing study underway being led by Professor Sir John Burn).

There is also interesting work taking place on immuno-modulating drugs which appear promising in terms of chemo-prevention and of reducing cancer in Lynch Syndrome patients. This is the population in which we may see the first successful non-virus-related cancer vaccine, based on the immune-genetics of how these tumours arise.

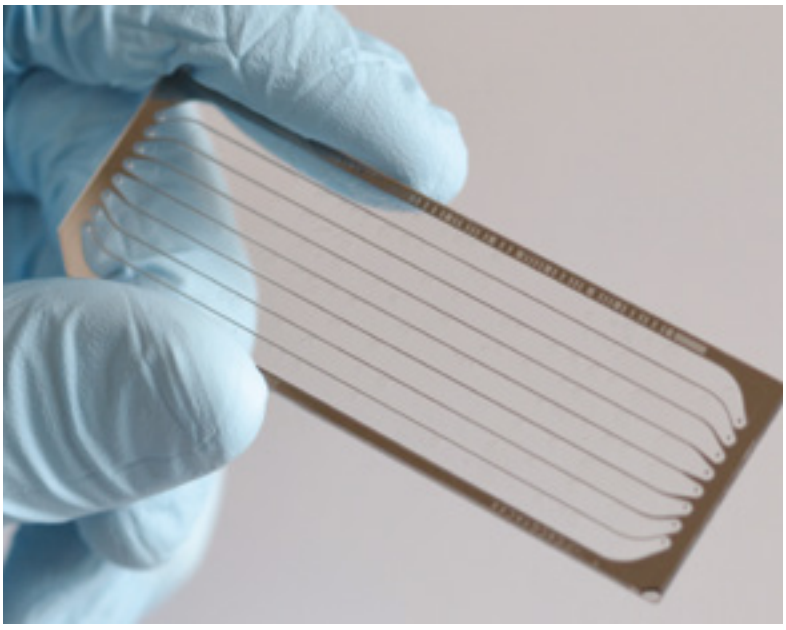
Breast/ovarian cancer

In a similar way, if we can ascertain the mutation causing hereditary breast or ovarian cancers early on, we change the natural history of the cancer pattern in the family. Once again genetic testing gives us this knowledge, allowing us to catch cancer much earlier or even intervene before the cancer happens. Rather than dying of ovarian cancer, these women can have preventative surgery. Rather than developing fatal breast cancer, a woman might have screening with MRI mammography to afford early detection or else prophylactic mastectomy to prevent the disease developing.

Another option is chemo-prophylaxis: five years of tamoxifen reduces the incidence of breast cancer in women by 30%. There is also promising work around RANK ligand inhibitors for chemo-prophylaxis and these are under trial in the United States.

If the patient does develop cancer, knowledge of the underlying genetic cause means the cancer can be managed accordingly, with selection of chemotherapeutic agents based on its underlying molecular characteristics, so-called 'precision oncology'.

There is a spectrum of genetic factors that underpin each tumour type varying from 'high-penetrance' mutations in genes such as BRCA1 to common genetic variants which each confer a tiny additional increment of risk. For nearly all tumour types studied, common susceptibility variants of this have been identified. For any given tumour type it is likely that hundreds, if not thousands, of these variants exist. In breast cancer, there are over 170 common susceptibility variants published, each of which confers a additional risk of developing the condition. All women carry some of them, but how many depends upon the individual. 'Polygenic risk profiling', summing the totality of common variants carried by a specific woman, can be used to estimate her genetic risk of breast cancer, thus identifying an additional subset of the population at high risk.



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Next generation sequencing offers the possibility of expanding the populations and patients that are offered genetic testing.

Non-genetic factors

Non-genetic factors can also be added in to improve the accuracy of the breast cancer risk prediction. These factors include family history, body mass index, age at first period, number of children, breast feeding and so forth. By including the common variants and the breast density on first mammogram, a risk profile can be derived. Using this model (with 94 breast cancer susceptibility variants included in the analysis), the top third in terms of risk contains two-thirds of the cases of breast cancer. So by using this 'non-genetic and polygenic risk profiling' model, breast screening could be focussed more closely.

The average risk of breast cancer in the total population of women being screened between ages 47 and 70 is 2.5% per ten years. This figure increases with age. However, the two bottom quintiles of risk (using our 'non-genetic and polygenic risk profiling' model) never even hit that average. So, rather than screen on the basis of age alone, this tripartite model (of non-genetic factors, combined with the 94 risk variants and breast

If the patient does develop cancer, knowledge of the underlying genetic cause means it can be managed using precision oncology.

density) could more accurately target women at genuine elevated risk of breast cancer. It is estimated that such an approach could reduce the number of women being screened by 31% while lowering detection by just 2%. The resources saved could be redirected to offer more screening to those at really high risk.

Combining these two approaches, (i) identifying individuals carrying high risk mutations and (ii) applying 'non-genetic and polygenic risk profiling' risk modelling will enable us to identify individuals at elevated risk of cancer and better target our resources for screening, early detection and prevention. Colorectal cancer is an exemplar cancer in which screening is highly effective: approaches to better target screening based on prior risk would be strongly impactful in improving outcomes. Furthermore, there is massive potential gain in cancer outcomes and survival from improvements in population-level uptake of screening in combination with more systematic administration of aspirin, a drug of proven chemo-preventative efficacy for this (and potentially other) tumour types. ❐

The debate

A range of points were put forward by the invited audience after the formal presentations, including: gene therapies; reducing the time for diagnosis; resource constraints; and access to capital.

Sequencing tumour material is a complex process and the number of mutations that can currently be targeted by drugs is limited. However, as research on the whole genome develops there is clear potential for progress. There are promising signs that targeted therapy can work at a molecular level. In addition, new technologies combining effective monitoring with combinations of therapies to treat re-occurrence offer promise for the future.

Private sector role

Does the private sector have a role to play in risk-profiling for health? There may be scope for collaboration with companies involved in gathering genetic information at the population level, but this is very unlikely to be directly helpful to an individual.

The introduction of 'one-stop-shops' on the Danish model (which Cancer Research UK has championed for some time) would provide rapid access to diagnostic assessment for individuals with non-specific symptoms. This would reduce multiple, separate and consecutive testing for such individuals and support earlier diagnosis. Five pilot centres have been established and the results should known in the coming months.

There is no link between preventive surgery to cure inherited cancer in an individual and subsequent inheritability. Reproductive interventions on the other hand could guarantee that high risk mutations were not passed on; but IVF is expensive and carries other risks.

Radiology and radiography are crucial to cancer diagnosis and treatment, but current services are over-stretched and under-resourced. Workforce and technology issues have to be addressed. Artificial Intelligence (AI) and machine learning have real potential for interpreting data, in genetic screening and to support radiology (Singapore is already using AI effectively).

Access to capital for innovations in this field is recognised as a limiting factor – and not just in the UK. However, the NHS, arguably, sets a higher bar for wide-scale adoption than, for example, the healthcare system in the USA, because of a requirement for value across the whole chain – from screening through testing to treatment. However, momentum on prioritising research and funding for early detection is unquestionably building. The Chief Medical Officer has, for example, prioritised the issue in her 2016 annual report.

More collaboration is needed to develop bigger data sets to support risk stratification as well as better targeting. These developments could reduce the burden on the health system and improve clinical effectiveness. Longitudinal research studies would be particularly important. ❐

FURTHER INFORMATION

Diagnosing Cancer Earlier: Evidence for a National Awareness and Early Diagnosis Initiative.
www.cancerresearchuk.org/prod_consump/groups/cr_common/@nre/@hea/documents/generalcontent/ cr_044142.pdf

Annual Report of the Chief Medical Officer 2016: Generation Genome.
www.gov.uk/government/publications/chief-medical-officer-annual-report-2016-generation-genome

Cancer Research UK. www.cancerresearchuk.org

Genomics England. www.genomicsengland.co.uk

Owlstone Medical. www.owlstonemedical.com

Can we control the way machine learning is steering the course of our everyday lives, ensuring that we maximise the benefits while minimising potential risks? The issue was discussed at a meeting of the Foundation held at The Royal Society on 14 November 2017.

An opportunity or a threat to society?

Mike Lynch

SUMMARY

- Machine learning will have a profound impact on society
- Machine learning is based on learning from examples
- The fundamentals of machine learning can be quite counter-intuitive
- The power of machine learning comes from the technology's ability to adapt to the variation we see in the world
- We need to absorb the implications of living in a probabilistic world.

The easiest way to think about the promise of machine learning is to compare it with a fairy-tale genie. It can grant wonderful wishes but you have to be very, very careful what you ask for: it will deliver precisely that, which may not be what you intended.

Machine learning will have a profound impact. The industrial revolution replaced muscle, while the IT revolution which started at the end of the 1960s replaced simple repetitive mental tasks like calculating the payroll ledger. Today there is a new revolution which is replacing more advanced cognitive tasks, including many that people undertake at the moment. Machines do not get bored, they can often deal with more information, they can now out-perform humans in some key areas in terms of accuracy.

I started working on machine learning in the late 1980s. The easiest way to understand it is to compare it with learning French. There are two methods: either sit in a classroom as a student with a grammar book, or go and live in Paris as an infant. The latter tends to give better results. You will learn the realities and the idioms, as well as slang. When you are five and someone asks why you have constructed a sentence in a particular way, you will have very little idea – you will just know French.

The situation is similar with machine learning. Rather than trying to programme a computer, modern machine learning is based on learning by example. Before modern machine learning, many problems were not solvable by machines. A simple example might be to ask a computer what is in an arbitrary photograph: no amount of programming will get very far with that, whereas machine learning systems will give a pretty good assessment.

Problems where performance was getting better little by little, such as voice recognition, have recently seen significant leaps in a very short amount of time. A recent set of papers claimed speech recognition by machines is more accurate than humans. If true, that is a very significant milestone.

Other areas which have seen advances are computer vision and machine translation.

Societal impact

In the early days, this subject was only discussed by people working in this area. Now, it seems you cannot open a newspaper without seeing something on it.

The difficulty is that much of the commentary does not understand the fundamentals of machine learning which are actually quite counter-intuitive. The danger is that ill-informed speculation could lead to regulation which might not work.

There are three main themes in much of the coverage. The first, coming even from quite highly-educated people, concerns the fear of machines taking over and killing humans. Those working in the field know that there is very little to fear at the moment. Putting aside the point that we may have far more to fear from evil people with machines, rather than evil machines themselves, it actually shows a misunderstanding of where the subject is at this point in time.

Recent advances have been in what has been called 'narrow AI'. This is the ability to resolve a narrowly-defined problem like recognising what

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A machine can probably be as accurate as a fox in determining whether there is a rabbit in your garden. But try and build a fox with current AI and it would get run over by the night bus

is in a photograph. There is, on the other hand, a whole class of problems which are 'broad AI': to give just a single, simple example, a machine can probably be as accurate as a fox in determining whether there is a rabbit in your garden. But try and build a fox with current AI and it would get run over by the night bus because it would not be able to deal with the generalities that a real animal encounters.

It is easy to assume from the progress of narrow AI that something similar will happen on broad AI. Yet there is no scientific basis for this.

I believe that there will be a significant impact on jobs, but perhaps more important will be the requirement for skills and adaptability within the workforce. Some of the knowledge-based tasks in society will be automated, but wisdom-based tasks are less likely to be affected.

Then there is the economic aspect. These technologies are going to affect pretty much every area of commerce and they are going to have significant effects on existing industries.

Reality and hype

I often read about people who over-clean their data, believing that everything must be cleaned before it goes into a machine-learning algorithm. The power of these algorithms actually comes from their ability to deal with the variation in the real world, so the last thing you want to do is take out that variation – that is the real benefit.

One thing that will happen might be termed a 'hype curve'. Already, almost every start-up asking for funding claims to be doing machine learning. Very few are actually doing so which means that a lot of money will be wasted. Investors do not understand the difference between a demonstration model and a useable system.

Demonstrating something in the lab with machine learning is pretty much useless. Doing it at the side of the road in Peckham, dealing with all the real-world variation is what is important. Again we are not seeing people that really understand those differences.

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The skill sets required will be quite specific. Obviously there will be some people with the mathematical processing skills that go into modern machine learning, but getting the best out of the algorithm may involve coupling technical abilities with more human skills.

The biggest challenge concerns exception-processing. There is a wonderful road along the Amalfi Coast in Italy where buses regularly meet head-on. It seems physically impossible for them to pass, but by a process involving a barrage of medieval Italian, they somehow do! There is no way a machine-learning algorithm is going to manage that, so the arrival of autonomous vehicles in that part of Italy is like to lead to gridlock! Problem-solving is not the issue: exception-processing is crucial in these situations.

Data

Machine learning needs data. Whoever gets the data first produces the best system. They can then get more data and probably end up with a monopoly. This is a question about strategic data rather than open data.

If we want the UK to be strong in this field, how are we using our data? If we are providing data, what do we get in return? Does the NHS get back products at competitive prices because its data was used to create them?

Mr Putin claims that these technologies will create domination in the future, so in that sense data could be strategic in a true geo-political sense. Cyber attacks are starting to be based on machine learning, which is making them a lot more difficult to counter.

In terms of economics, there will probably be over-investment in this area – and therefore some disappointment. A skills-base will have to develop and there will be big effects on other industries. When machine learning techniques are applied, imperfect pricing structures in markets are quickly exposed and so margins in many industries will come under pressure.

Societal challenges

Machine learning has great promise for some of the great challenges facing society. For example, it may assist early-stage dementia patients to remain at home for longer, adjusting for some of the variations in cognitive level. Another application might be better optimisation of traffic flows, maximising the use of existing transport infrastructure, rather than commissioning a new piece of motorway.

The airline industry functions because planes can be insured, even though one of them might go down over central London (and that risk anal-

ysis is an interesting one given there are no precedents). There is plenty of evidence about the risk profile of human car drivers, but none for autonomous vehicles even if it is believed they are intrinsically safer. There are issues about derived works: if my data is used in an algorithm, do I own the algorithm?

People may get very excited about CCTV surveillance, but if no one is looking at the cameras it does not really matter. With machine learning, though, all the cameras will be monitored and the data analysed, so many of our current concerns will become much worse.

If an algorithm calculates that Ruritanians are more likely to default on their mortgages, is that acceptable or fair? At present, using that kind of information is probably against the law. How can society make sure that decisions are being made on the right basis yet take into account cultural and legal acceptability?

We need to understand that we live in a probabilistic world. Really good drivers crash cars – and so will really good autonomous vehicle algorithms. Is the algorithm at fault?

We will certainly go through a period of hype. There will be many machine learning systems that will not work. There will be lots of promises that are not delivered, but underneath all of that there is a real revolution going on. I think we will see society's time-honoured approach of under-estimating how long the change will take, while also underestimating how deep the effect will be. □

Giving society the confidence to embrace the opportunities

Claire Craig

SUMMARY

- Machine learning and AI are about much more than robots replacing humans, presenting a massive opportunity to promote human flourishing
- The challenge is to deliver benefits quickly, safely and sustainably
- Governance should not focus on technology, but on its applications, and should be based on sectoral governance
- Existing frameworks governing the use of data will not work in this new and developing landscape
- A new stewardship body, with oversight across the whole range of applications, is needed.

Machine learning offers massive opportunities to promote human flourishing, in fields ranging from health and home efficiency to the conduct of science itself. The UK is well placed to lead in the development of this technology. It has an excellent science base in both academia and business. It also has a long history of successful governance of new technologies, as well as a more recent history of promoting open data.

The challenge today is to deliver benefits quickly, safely and sustainably, without any adverse effects that result in a loss of public confidence and slow progress.

The Royal Society published a report on machine learning in 2017[1]. Led by Peter Donnelly, Professor of Statistical Science at Oxford, there were 15 scientists from academia and business on the working group. Around 500 practitioners were involved in workshops. The project looked at the effects of machine learning in sectors such as pharmaceuticals, law and manufacturing.

Extensive public engagement and public dialogue were undertaken. Around 15,000 people participated in a range of ways, with Professor Brian Cox and an expert panel attracting a capacity audience at the Royal Festival Hall.

The report's conclusions included five areas for action:

1. **Data** – the creation of a suitable data environment, through incentives and funding, to enable not just open or accessible data, but machine-readable data. This will require data curation and the training of specialists with the necessary skills, as well as open standards for data.
2. **Business** – embedding machine learning in industrial strategy. This will include US 'DARPA-style' funding, as well as support and advice for businesses via Growth Hubs, for example.
3. **Skills** – ranging across: achieving digital liter-

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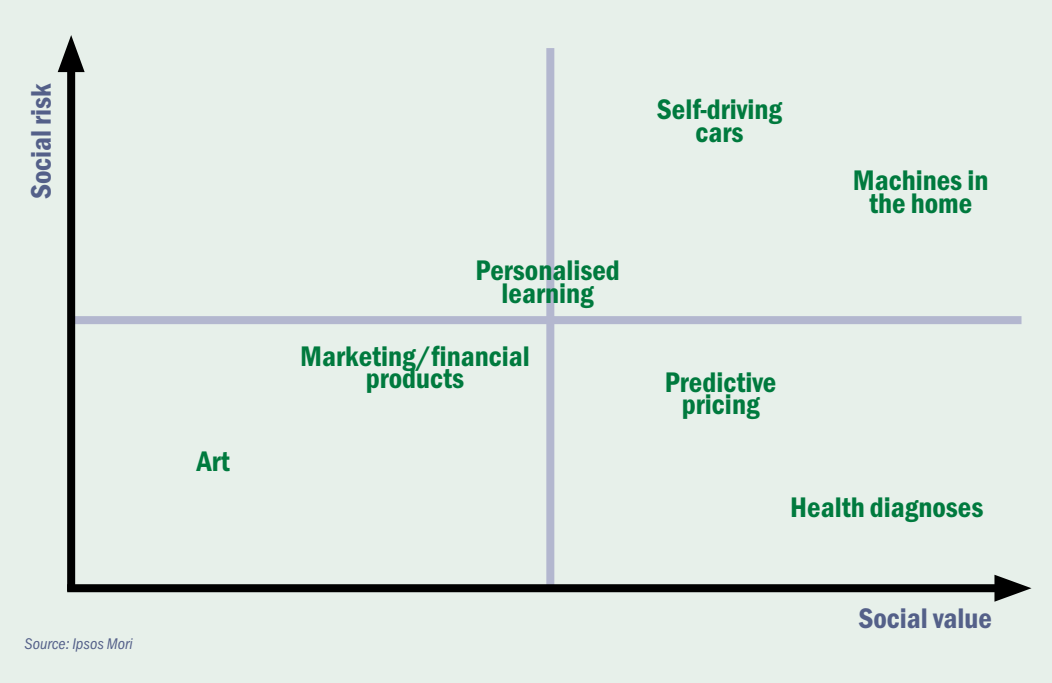

Figure 1. Perception of value/risk in machine learning applications. Source: Ipsos MORI.

acy in the primary school curriculum; embedding the importance of machine learning within data science, mathematics and other subjects through to age 18; and specific support for advanced courses such as Masters. The Royal Society is starting further work on the barriers and enablers to keep the UK at the leading edge of research.

These first three areas are addressed in the AI Review (see page 41), but there are two others:

4. Engagement with society
5. The next wave of research

Engaging with society

The 2014 annual report of the UK Government's Chief Scientific Adviser[2] focussed on innovation and risk. The concerns citizens have about machine learning are typical of previous emerging technologies such as stem cells or nanotechnologies.

People want to understand a technology and the purpose behind its development. They want to know how the benefits and risks will be distributed, who pays, what the alternatives are, who they can trust and so on. As a technology is used and applied, these questions become more context-specific. It is no longer the technology itself, but its context-specific applications on which judgements are made.

Ipsos Mori carried out a quantitative survey which showed, among other things, that only 9% of respondents had heard the term 'machine learning', although most were familiar with applications that use it, such as predictive text or consumer recommendation systems.

They also carried out structured public dialogue. The results showed that people had broadly four typical initial reactions, ranging from 'I can relate to this technology', through suspicion, to a denial that it could be made to work. Interestingly, we repeated the work with young people who have grown up immersed in digital technologies. They had much more rapid and intuitive understanding of what machine learning might do and mean, but their interests and concerns were fundamentally the same as the previous participants.

As the dialogue deepened, and people thought through potential applications, their aspirations and concerns varied by context. Figure 1 shows a schematic representation of a discussion. Note that the axes are not quantitative, the point is simply that in terms of risk and benefit the different applications are seen very differently.

This public dialogue alongside the expert work led the report to two conclusions. The first is that existing frameworks governing the use of data will not be sufficient in the future. The second is that it would be wrong to govern this as a technology *per se*. There are many reasons for this, one being the impracticality of trying, in effect, to regulate maths. But perhaps more importantly, in many (or most) contexts, machine learning is generally uncontroversial and does not need new governance.

The benefits and risks of different applications vary widely: a major health or financial decision is different from a customer recommendation. Issues around safety and proper testing in transport applications are likely to be better handled by existing bodies in that sector. Similarly, questions about the validation of machine learning in medical applications should be overseen by existing medical regu-

The benefits and risks of different applications vary widely: a major health or financial decision is different from a customer recommendation.

latory bodies, while applications in personal finance would fall within the purview of the financial regulators.

To take one specific example, views on the use of machine learning in diagnostic systems in GPs' surgeries were influenced by a range of assumptions, including how such systems would actually be put to use, how they would be tested for safety and accuracy, which patient groups would have access to them if they were beneficial, and what the alternatives or consequences might be. People might, for instance, be happy to have a machine learning diagnosis where that was shown in some way to be better than a human one, but they might still want a human 'in the loop' to discuss major decisions affecting them personally.

Data management and use

The Royal Society had already begun work on the wider governance issues of proliferating data and its uses, including – but not solely – machine learning. In 2017 it published, jointly with the British Academy, a report on governance in the 21st century[3]. Led by Ottoline Leyser and Genevra Richardson, the project brought together historians, philosophers and other scholars with cross-over membership to the Machine Learning group.

This report argued that, in order to have a principled and connected set of discussions about the future of governance, while at the same time accepting that individual governance decisions need to be taken in context, two new elements were needed. First, very high level principles for governance of data use, and second, a stewardship function operating across the governance landscape as a whole.

Because existing words come with 20th century connotations, the report recommends the introduction of an overarching principle 'to promote human flourishing' (the term is deliberately not defined, nor is it capable of being measured). The purpose is, at least in part, to force people to consider what flourishing might mean in different contexts. New uses of data may create new trade-offs between individual and collective benefits and risks.

A governance system has a range of critical functions, from anticipation to enforcement. While many of these are already being carried out, there is no-one with responsibility for oversight of the entire landscape. Thus, the system risks losing transferable learning, falling behind the ways that the technology itself is interconnecting. For example, definitions of health data may not be meaningful when health facts can be deduced from retail or transport information.

The report therefore recommended the introduction of a new stewardship body to oversee and deliver a clear set of functions – but with the specific form left deliberately open. Its functions would include ensuring that emerging gaps in governance are identified and addressed, and issues are anticipated wherever possible. It would conduct inclusive dialogue and expert investigation into new questions and issues, attempt to anticipate future consequences of today's decisions, and spread learning from one sector to another.

The Nuffield Foundation has since announced that it will work with others to create a new Convention addressing the longer term ethical and governance implications of new uses of data.

The next wave of research

There are areas of research that will help ensure machine learning can promote human flourishing. They include urgent questions of verification and validation, as well as security and robustness. In addition, work is needed on ways to create systems that can be better interrogated by users, so that they can used more effectively in public or private decision-making, and result in better human-computer interfaces. Machine learning is, in a real sense, creating its own research agenda about the things we need to know in order for it to fulfil its potential safely and rapidly.

The impact of machine learning will vary depending upon the sector. Timing will also be important, especially for SMEs looking to exploit opportunities.

Machine learning, and AI more generally, is likely to have significant implications for employment, both threats and opportunities. The professions – such as the law, medicine and accountancy – will have to address these challenges to their career structures, and to their attitudes about continuing professional development (CPD). Experiences in the transport sector illustrate issues that have broader relevance: questions of accountability, liability, and the 'public licence to act'.

A fundamental issue is the need to get beyond thinking only in simple terms of robots replacing humans. It is much more complex than that: machine learning and AI have the potential to change business models, create new opportunities, and result in structures that augment or collaborate with humans. □

There are areas of research that will help ensure machine learning can promote human flourishing.

1. https://royalsociety.org/~/media/policy/projects/machine-learning/publications/machine-learning-report.pdf
2. www.gov.uk/government/uploads/system/uploads/attachment_data/file/381905/14-1190a-innovation-managing-risk-report.pdf
3. https://royalsociety.org/~/media/policy/projects/data-governance/data-management-

The potential to augment human efforts

Amir Saffari

Amir Saffari is Director of Applied AI at BenevolentAI. He has been working in the field of Artificial Intelligence for more than 15 years, researching and developing machine learning (ML) theory, applications and industrial products. He was part of Sony's Computer Vision R&D team working on ML technology for Augmented Reality and Virtual Reality applications. He joined BenevolentAI in early 2017 where he heads the AI team, focussing on creating machine learning technologies to accelerate scientific discovery.

SUMMARY

- Rediscovery of neural networks at the beginning of this decade has accelerated the progress of AI
- Speech, computer vision, and natural language processing are widely used applications today
- Increasingly, machine learning is being used to accelerate scientific research in areas like drug discovery
- AI has a large role to play in education, making it more interactive and personalised
- In the near future, AI has enormous potential for augmenting human activity.

The Artificial Intelligence journey began in the 1950s. It was thought to be a very easy technology to develop and, famously, some professors thought the challenge would be solved within three months – well, it has been a very long three months! Then came the 70s and 80s, what was known as the 'AI winter', when funding was cut and development stagnated. But things picked up again in the 90s and on into the new century.

About seven years ago, researchers rediscovered neural networks. These were rebranded as 'deep learning' and led to massive improvements in what machines were capable of doing. At the same time, large data sets and high-powered graphics processing units (GPUs) started to be used. Most of the current public and media interest has resulted from that renewed focus on neural networks.

In 2007, Image Net was developed to classify images into about 1,000 categories. By 2010, the best systems had an error rate of about 25% which was not good enough for any serious applications. By comparison, humans have a 5% error rate on this type of task. Even for humans, the number of different categories makes such detailed classification a very challenging task.

Fast-forward to 2017 and neural networks can achieve a 2.5% error on these datasets. That makes it possible to build applications, solid applications. Combine these developments with others in computer vision systems and the possibility of self-driving cars looks much more realisable.

Other applications include speech recognition, taking a sound wave and transcribing the language, or using machine translation from one language to another – in fact, any mix-and-match of data modalities. In image captioning, it is possible to take an image and ask the system to describe the content. There is good progress being made on the accuracy of such tasks. This in turn opens up new applications in industry and elsewhere.

With all the successes inevitably comes the hype. It often happens with new technologies that people over-estimate the capabilities. Then suddenly a change happens after which people actually underestimate the capability. The public's image of AI – given the fuzzy language – probably comes from science fiction, with killer robots and bad things happening to people. Current media coverage does not help.

The public's image of AI – given the fuzzy language – probably comes from science fiction, with killer robots and bad stuff happening to people.

People typically fall into one of two misconceptions about AI. Either they think that AI is here to take over the world and we are doomed, or else AI is all hype, all smoke and mirrors. The truth lies somewhere in between. Some people also think that progress in AI will lead to more automation, more unemployment and our replacement by soulless machines. This, too, is not true. In terms of full automation, we are still far away from being replaced by robots. However, the technology may soon allow humans to work collaboratively with software – with AI – and help us to become better at what we do.

AI augmentation

BenevolentAI is an artificial intelligence company based in London. It specialises in using AI for advancing scientific discovery. For the past three years the focus has been on drug discovery. The rationale is this: there is one research paper published every 30 seconds, so a scientist would only be able to digest a fraction of the amount of knowledge available. This is exactly where machine learning can help because it can read all this material. Machine learning can turn that data

into knowledge that our scientists can use: we have discovery scientists in the company who can take this knowledge and accelerate their discovery. Potentially, this can help find treatments for very difficult diseases more quickly than would otherwise be possible.

One area of machine learning that is progressing rapidly is that of generative models. These techniques are now capable of creating images that look very authentic. Content creators and artists can interact with these systems to become better or faster. This extends to other areas such as generative design – where machine learning and generative algorithms produce better designs.

I have been involved in a project over the past year applying machine learning to music. This has led to the creation of a model that can compose polyphonic music. We linked it to Twitter: tweeting at it generates a small music audio clip. This is another way of exploring humans and machines working together, in this case to compose music. The majority of people would like to make music if they could, so by lowering the barrier to entry, more people can be creative – and that is a very good thing.

AI also has a role in education – and specifically personalised education, making it interactive and fun to learn. One example is Sonic Pi, from the University of Cambridge Computer Laboratory. The software, created by Sam Aaron, is very interactive and he uses it to teach very small children programming. Because it is interactive and fun, people learn programming much faster than they could otherwise.

AI has enormous potential in terms of augmenting us and helping us to become better. There is a great deal published about AI but some of the good news stories often get overlooked. People often are not aware of the way in which machine learning could be used for the good of society. □

The opportunities for the UK

Wendy Hall

SUMMARY

- Realising the opportunities arising from AI is a priority for governments around the world
- Access to data is a critical enabler for small businesses and researchers in this area
- Higher Education courses to help people acquire AI skills will help to extend the technology across industry
- It is important to build confidence across society about AI
- The UK computing industry must make sustained efforts to increase diversity in what remains an overwhelmingly male environment.

I co-chaired with Jerome Presenti, the Chief Executive of BenevolentAI, a review on *Growing the AI industry in the UK*[1] for the Government. We took some inspiration from what was happening in other countries. In the USA, the Obama administration produced two very good reports on AI, addressing threats, job losses and opportunities. Canada has set up a strategy for AI and there are programmes in Europe. China has said it is aiming to be the leading country in AI in the next decade, something they stand a very good chance of achieving. Russia is also pursuing this technology. And it is not just the larger powers that are showing interest: Singapore, a small nation, is developing an ambitious AI strategy as are many others.

The scope of our review was closely-drawn: it was to look at the opportunities for the UK. That included job creation and economic growth. It was envisaged that this would lead the way to one of the Sector Deals set within the Industrial Strategy. That is very exciting because of course there is no easily-defined AI sector. It is quite ambitious of the Government to consider it in those terms. AI is an emerging technology, not a traditional, established industry sector like automotive, aerospace or pharmaceuticals.

In the four months we had to complete the review, it was not possible to cover everything. However, others were also working on this subject. The Royal Society and the British Academy were developing their Data Governance report. I do not think we could have produced our review without knowing that these other efforts were underway: our scope was very firmly on job creation and economic growth. There are huge issues about ethics and accountability that we did not have time to consider but they are well covered by the academies.

The vital thing is to create a level playing field. For small companies to grow they have must have

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FURTHER INFORMATION

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www.nature.com/articles/nature24270

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Machine Learning information from The Royal Society website
https://royalsociety.org/topics-policy/projects/machine-learning/videos-and-background-information

Machine Learning Education
www.coursera.org/learn/machine-learning

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The Royal Society project on machine learning
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The Royal Society and British Academy Report on data governance
https://royalsociety.org/~/media/policy/projects/data-governance/data-management-governance.pdf

White House Report on AI
https://obamawhitehouse.archives.gov/blog/2016/10/12/administrations-report-future-artificial-intelligence

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access to the data they need to create the algorithms and test that they work.

We developed the idea of data trusts. These are places to get legal advice on how to talk to big companies, local councils, universities and research labs about access to data, as well as the ways in which this data can be used. Then, at the end, who owns what? Who owns the rights to what deliverables?

This is really complicated. There is no one answer that fits everything. So the report addresses this challenge and it proposes the setting up of a data trust support organisation.

A large section of the report is concerned with skills. One message that was conveyed very clearly by the companies in the AI industry was that they need people with skills. They need undergraduates studying this subject and they need PhD students with machine learning skills, for example.

The report puts forward the idea of industry-funded Masters courses, which take students with a maths, computer science or statistics background and turn them into machine learning programmers. A 15-month course is proposed, the normal 12-month university course and then a 3-month internship at the company funding the studentship.

More generally, there is a need to up-skill the whole of industry in terms of AI (and the Government service too). That does not mean everyone has to be a machine learning programmer, but a 'conversion Masters' could train people with all sorts of different disciplinary backgrounds to become cognisant with AI or even to be able to take AI to their own industry.

The economy needs a lot more PhD students if it is to have the skilled researchers needed for AI to grow in this country. Online courses and CPD have an important part to play here, if whole sections of society are not to lose out as we move to greater automation.

We also talked about the development of fellowships to be offered through the Alan Turing Institute to attract the best researchers into the UK and to retain the ones we already have here. Of course, every developed country in the world is trying to do that, so there is major competition.

At the moment, a graduate leaving university with machine learning skills can almost name their price, I have been told. It is not clear how long that will last, but there is a great scarcity of people with the right skills at present. Of course, it is not possible just to train hundreds more PhD students: they need supervisors in the universities and these people too are in danger of being poached. It is very hard to keep academics who are paid a university salary when they have the skills to work in industry.

To maximise AI research in the UK, there are plans to turn the Alan Turing Institute into the national institute for artificial intelligence as well as for data science. It ought to be easier for industry to license IP from universities. Small companies and research labs should have easier access to improved computer capacity, either to cloud services or to high performance computer services.

The report makes a number of recommendations to support the uptake of AI in the UK. It recommends the setting up of an AI Council to take proposals forward and to look at accountability issues. UK AI skills could be exported through the Department for International Trade.

The report also proposes developing practical guidance for UK companies who want to use AI.

We hope the Government will be an early adopter, both in terms of encouraging AI skills and also of developing challenge funds that have AI as their core purpose.

There are major ethical issues surrounding AI. It is important that society has trust in what the industry is doing. Companies are in the business of making money, but at the same time they must be accountable for the algorithms they develop. Some aspects of the technology will need to be Government-regulated and some will need to be self-regulated. Personally, I believe companies should state on their websites the principles under which they are using data and developing their algorithms.

They could be asked to publish this information as part of their annual reports. It is a matter of building public confidence. Leading on the discussion in these areas will be the role of the new Centre for Data Ethics and Innovation that is being set up in parallel with the AI Council.

I have been in the computing world for over 30 years and the number of women in this industry has actually decreased over that time. A short-term stimulus to introduce AI skills into industry will have to rely on the computer scientists, mathematicians, etc, leaving university today. There will be hardly any women, so we are producing a workforce which will not be diverse, by definition.

Diversity is, though, a key feature of the review. It proposes coordinated, on-going action which has to start in schools, reaching girls in particular and encouraging them to go into fields that will lead to a career in AI – and it has to be recognised that this will take many years to achieve.

If action is not taken, the AI industry will be one where all the algorithms are written by one half of society and no matter how much you try, those algorithms will be biased. 'Bias in and bias out' is how it is with algorithms and the datasets used to train them.

This has to be addressed. One way to do so is to require the involvement of interdisciplinary teams in the development of the algorithms from the very beginning; something similar to health service practice. This helps ensure an holistic view of the project, reducing bias as much as possible. It should be remembered that gender is not the only bias that can creep in: we should also consider age, race, ethnicity, culture and many others. Bias in all its form has to be tackled head-on.

As a society, we also have to decide how we are going to treat the people who are going to lose their jobs but cannot be retrained into this type of work. What does a 'welfare state' involve in a world with AI? ❐

[1] www.gov.uk/government/publications/growing-the-artificial-intelligence-industry-in-the-uk

The debate

How many jobs will be lost or affected by machine learning? Broad estimates have been considered by the Council for Science & Technology, but none can be regarded as definitive. The impact on employment may be most significant for those aged 40-60, so the potential to retrain in this age group should not be neglected.

If NHS data is used in new ways, the NHS itself should receive a benefit, at least by obtaining access to the relevant products at a discount. Individuals who obtain their own health data could contribute that data into curated records, which could be used for wider benefit. The manner in which the Met Office has been forced to offer its data free to competitors has weakened it in an unhelpful way.

There is a healthy overlap between AI and traditional neuroscience, which goes back to the origins of AI. These synergies will continue to be fruitful. Developments in AI could widen global inequalities: perhaps this should be investigated by the World Health Organisation. The deployment of healthcare advances to patients could be widened through the widespread use of AI-driven apps on phones. These would make good quality medical advice more readily available to communities lacking access to doctors.

Mathematics (including probability) will be key to the pace of further progress. However, this needs to be coupled with an understanding of how real data could incorporate bias. New techniques to avoid bias are needed.

Although machine learning could eliminate the need for human involvement in many tasks, human understanding of the outcomes from AI will still be fundamental. Those responsible for the expansion of apprenticeships should consider how jobs in AI could be served. Universities could create degree apprenticeships in AI.

Greater efforts must be made to enthuse young people about the potential of AI and the recent initiatives to increase the teaching of computer science in schools are most welcome. ❐

After the main presentations, the audience was invited to give their views. Topics raised included: the impact on employment; benefits to data providers; avoiding bias; and the human element.

The future of social care

Norman Lamb

The Rt Hon Norman Lamb MP is a member of the Council of the Foundation for Science and Technology as well as Chair of the House of Commons Select Committee on Science and Technology. He has been the Liberal Democrat MP for North Norfolk since 2001. In 2005 he was appointed Shadow Secretary of State for Trade and Industry. In 2006, he became Liberal Democrat Shadow Health Secretary. Following the 2010 General Election, he served first as Chief Parliamentary Adviser to Nick Clegg, the Deputy Prime Minister, and then as a junior minister at the Department of Business, Innovation and Skills (BIS), before he was promoted to Minister of State for Care and Support at the Department of Health.

Social care, and its interactions with the health service, has been a political 'hot potato' for decades. Yet the UK has still not been able to settle on a coherent strategy. Instead, many people find themselves feeling terribly let-down and vulnerable just when they need access to these services. How can we move forward as a society on this urgent issue? Technology and innovation have vital parts to play in addressing the challenge, yet they are not the only elements in an effective solution.

For me, the aim of social care is to enable our citizens to lead good, happy and fulfilling lives – in the way they want to lead them. That involves people having power and control, rather than having things done to them. Then, at the end of life, the really important priority is for individuals to have a dignified death. This is denied to many people.

Our society has made enormous advances in keeping people alive with medical technologies and therapeutics. However, at times the maintenance of life seems to have become the sole aim, sometimes irrespective of the dismal quality of that life. Just staying alive is not what I or, I suspect, most of us want.

Atul Gawande is a surgeon living and working in the USA but his book, Being Mortal, has universal relevance. It presents a stark critique of where we have gone wrong; approaches are too often focussed on minimising risk, restricting the lives of vulnerable people, often institutionalising them. He makes the point that we permit children to take more risks than a person approaching the end of their life.

The history of the past two decades indicates a very clear public policy failure in the UK. The omens looked good when, coming into office in 1997, the first Blair Government delivered on a key manifesto commitment by establishing a Royal Commission on the funding of long-term care.

The Commission identified a range of failings in the social care system: "It is too complex and provides no clarity as to what people can expect. It too often causes people to move into residential care when this might not be the best outcome. Help is available to the poorest, but the system leads to the impoverishment of people with moderate assets before they get any help."

These words could be written today.

For all its merits, though, the Royal Commission ultimately failed to resolve these fundamental issues. Its chief recommendation – of free personal care on the basis of need – divided its members and was rejected by the Labour Government on the grounds that it would carry "a very substantial cost" and "would not necessarily improve services".

Further proposals were developed during the Labour years; in particular, more generous means-testing, a 'National Care Service', a two-year cap on paying for social care from 2014, and care free-at-the-point-of-use at some point after 2015.

Personal budgets

On other fronts, changes had started to happen. Personal budgets, a concept which had its origins in the United States, were introduced and the right to a personal budget was later enshrined in legislation by the Care Act of 2014.

With the arrival of the Coalition came a new initiative. The Dilnot Commission was established to consider a partnership model between individuals and the state. Its report concluded that "the current system is confusing, unfair and unsustainable". It highlighted that people were left "unable to plan ahead to meet their future care needs". Echoing one of the conclusions of the Royal Commission, it said that "a major problem is that people are unable to protect themselves against very high care costs" in old age.

Dilnot's central recommendations were for a £35,000 lifetime cap for over 65s and lower caps for those in younger age groups, along with a more generous means-test.

The Care Act, which I took through Parliament, enshrined the three principles of choice, independence and prevention. Promoting the individual's wellbeing must be at the heart of all decision-making by the local authority (and, for the first time, that was to include the wellbeing of the carer).

The cap on care costs was initially set as a lifetime cap of £72,000 for everyone over the age of 25 with a more generous means-test for support for those who had not reached the cap. This meant that more people could get a contribution towards the cost of care. All this was due to be implemented in April 2016.

Within weeks of the election of a Conservative Government in May 2015, the cap was postponed until 2020. The Conservative General Election Manifesto in 2017 abandoned the cap and, instead, proposed protection for just the last £100,000 of a person's assets. There was to be no pooling of risk. This was immediately dubbed a 'dementia tax'. The proposal was changed just a few days later.

The Budget in November 2017 failed even to mention social care. The process is expected to start all over again with a Green Paper in the summer.

It is worth reflecting on the extraordinary demographic changes since the late 18th century which are still gathering pace. In 1982, there were about 600,000 people over the age of 85. By 2007, this had more than doubled to 1.3 million and by 2032 it will be 3.1 million.

Half of people over the age of 75 live alone. Social isolation is known to affect health and wellbeing. Loneliness is said to be more damaging to health than smoking 15 cigarettes a day. In the past, a family would all live on the same street while now people are left stranded as extended families are dispersed far and wide.

The economy's ability to fund services is also increasingly difficult. The ratio of people of working age (those who work and pay taxes) to people in retirement is changing. For every 1,000 people of working age, the number in retirement is projected to rise from 305 in mid-2016 to 370 by mid-2041.

In addition, around 300,000 working-age adults rely on the social care system today. Financial pressure from the increasing care needs of younger adults with disabilities or mental health problems is rising.

Social care has always lost out to the National Health Service. Since 2010, first under the Coalition and then under the Conservatives, cuts to local authority funding has resulted in social care being cut by 8% from a peak in 2009-10. This has put the sector under immense pressure – and the impact on those in need of care, some of the most vulnerable in our society, is stark and distressing.

These pressures show no signs of abating. The King's Fund, The Nuffield Trust and the Health Foundation have all warned of a looming £2.5 billion annual funding gap in adult social care by the end of this decade.

Faced with such a dismal landscape, it would be easy to conclude that this is an intractable problem. That, though, would be the wrong conclusion. Crucially, though, this will not be solved through the normal process of partisan politics. A cross-party process is needed to develop a sustainable, long term settlement for the NHS and social care. Such an approach also has to engage with the public and with staff.

Necessary additional resources have to be raised in a progressive way, based on ability to pay, but it must also be fair between the generations. Serious consideration should be given to a hypothecated Health and Care Tax, perhaps based on a reformed National Insurance system. Reform of NI would be necessary to ensure that people on high earnings above retirement age make a fair contribution. Those in younger adult life – starting a family, trying to buy their first home or renting – cannot be expected to meet the full burden.

Kate Barker's Commission for the King's Fund has suggested a range of ways of raising extra resources. Many of these have merit.

Critically, additional resources for health and care must be used to shift the emphasis to preventing ill-health and so potentially reducing the increase in demand for health services.

An irrational divide

There is an irrational and highly damaging divide between health and social care budgets. Too many people fall through the gap, caught in the crossfire between the NHS and local government. The drive for a pooled budget in places like Greater Manchester has massive potential to deliver better outcomes for people. Pooled budgets for localities, with a single commissioner for local services who has some democratic legitimacy (accountable to the community rather than to Whitehall) would be a significant step in the right direction.

We also need to see greater local experimentation, giving regions the freedom to innovate and shape a health and care system that works for local populations.

Pooling of risk (as proposed by Dilnot) through a partnership model – shared responsibility between the individual and the state – makes eminent sense. It also reduces the divide between the free NHS and means-tested social care.

A recent report from Stanford University School of Medicine argues that "a focus on data in the coming years has the potential to make health care more preventive, predictive and personalised, meaningfully reduce health costs and lead to better patient outcomes." Data has the potential to transform the future of health and social care. Information is becoming easier to collect, analyse and understand, opening the door for major advances in preventive care, quality of care and cost of care. At both the individual and population level, data is helping to prevent ill-health, provide earlier diagnosis and more effective treatment.

One example is in the dramatic increase in the use of wearable devices which collect healthcare data. Globally, there were an estimated 274 million sold last year. Fitness bands are the most popular. Data produced can be linked directly to health professionals. We have the ability to track temperature, pain and stress through thermo-electric pulses. The promise of wearables is that they will help to detect and treat illness at an earlier stage.

Faced with such a dismal landscape, it would be easy to conclude that this is an intractable problem. That, though, would be the wrong conclusion.

At both the individual and population level, data is helping to prevent ill-health, provide earlier diagnosis and more effective treatment.

At present the market is dominated by recreational technology and fitness companies but health and care organisations are already seeing the potential to make use of medically robust and relevant data. Remote home monitoring is growing, although the adoption of technologies in the UK is very slow.

Some other European countries are further ahead – Norway has developed a national programme to drive the use of technology. Spain is exploring the use of incentives to make it worthwhile for providers to invest in technology. It is initiating the procurement of a service over a four-year period that includes risk sharing.

The UK could learn from this. When the Government gets behind a technology, such as electric cars, it makes things happen. We could see dramatic advances in health and care if the Government similarly got behind assistive technologies in these sectors. There is potential to empower people to take control of their lives, maintain independence for longer and stave off dependency.

Technology is not the whole answer, though. Ultimately, human contact, kindness and attention are essential for making life meaningful. While half of over 75-year olds live alone, couples can be lonely too – particularly where someone is caring for a loved one perhaps with dementia.

We surely all have a responsibility to each other. On every street, there are people living alone. In Potter Heigham on the Norfolk Broads, a group of local people make sure that no one in the village need be lonely. They take people to the doctor or to hospital. They get people out of their homes. They do the shopping. Another brilliant example of the power of communities is Shared Lives Plus. Families take people with a learning disability or mental ill-health into their homes. They are paid for the care they provide but the cost is a fraction of the cost of institutional care.

Within the membership of Shared Lives there are also community-based services which share the same values and ethos. This is a very different approach which helps put people in control and helps them lead ordinary lives.

There needs to be a recognition at all levels of society of the importance for people to be in control of their care and their lives. Although the Care Act enshrined in law the right to a personal budget, care provision is continually and relentlessly trimmed down to the bare basics. Too many councils still pay lip service to transferring power to citizens. This has to be challenged.

And at the end of life, people should be able to die where they want to, their priorities respected. Too many are trapped in the alien environment of a busy acute hospital. We have the ludicrous situation that care is free in the place the person generally least wants to be, while not free at home.

None of this is rocket science. This challenge is solvable. Yet today, many people feel horribly let down. Money is wasted. People are denied their dignity. As one of the biggest economies in the world, we can do better. □

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OBITUARY: THE RT HON SIR BRIAN NEILL

Council Member of the Foundation for Science and Technology and former Lord Justice of Appeal

2 August 1923 - 24 December 2017

To the world at large, Sir Brian Neill was best known as the barrister who represented the *Sunday Times* when the Government tried to prevent publication of an article about the drug thalidomide. However, his more enduring contribution to the legal system may prove to be his work in encouraging the use of computers and automation.

After serving in the Army during the Second World War, Brian Neill studied law at Oxford, being called to the bar at the Inner Temple in 1949 and becoming a QC in 1968. In addition to the thalidomide case, he represented the *Sunday Times* in its attempt to publish the diaries of the Labour minister Richard Crossman. He also worked on a series of high-profile libel cases.

In 1978 he was appointed a High Court judge and he served as Lord Justice of Appeal from 1985 to 1996. Shortly after, he became President of the Court of Appeal in Gibraltar, a position he held until 2005. Early on, though, he had recognised the possibilities that computing could bring to the legal world and he was one of the co-founders of the Society for Computers and Law (SCL), the inaugural meeting of which held in December 1973.

In May 1979, he set out some initial thoughts on 'Computers and the Courts' in the Society's newsletter. As the current President of the SCL, Professor Richard Susskind, remarked: "In that paper, he laid the foundations for decades of later effort in the field. For almost 40 years, Sir Brian led the charge for the modernisation and digitisation of the courts and the work of judges."

In 2003, to coincide with his 80th birthday, a festschrift was published entitled *Essays in Honour of Sir Brian Neill: The Quintessential Judge*. In a joint introduction, Lord Bingham (then Senior Law Lord) and Lord Woolf (then Lord Chief Justice) spoke of Sir Brian as "an advocate who was highly erudite, very intelligent, immensely well-prepared and so persuasive that it always seemed unreasonable to disagree with him". They went on to speak of his distinguished contribution as a judge whose "court was a showcase for the British system at its exemplary best".

Presentations and audio recordings from all meetings of the Foundation for Science and Technology are available at: **www.foundation.org.uk**

UKRI leaves the starting blocks: the management of government funding of research and innovation

28 February 2018

Sir Mark Walport FRS FMedSci HonFRSE, Chief Executive, UKRI
Sir Alan Wilson FBA FRS, Chief Executive, the Alan Turing Institute
Kirsten Bound, Executive Director of Research Analysis and Policy, NESTA [Panellist]
Jonathan Neale, Chief Operating Officer, McLaren Technology Group Ltd [Panellist]

The Hackitt Review of Building Regulations and Fire Safety

24 January 2018

Dame Judith Hackitt DBE FREng, Chair, Hackitt Inquiry into Building Regulations and Fire Safety
Graham Watts OBE, Chief Executive, Construction Industry Council (CIC)
Peter Baker, Director, Construction Division and Chief Inspector of Construction, Health and Safety Executive
Dr Peter Bonfield OBE FREng, Member, Grenfell Expert Panel, Ministry of Housing, Communities and Local Government and Chief Executive, BRE Group [Panellist]
Turlogh O'Brien CBE, Chairman of the Governing Board of the Chartered Institute of Housing and Post-Grenfell Expert Working Group, Construction Industry Council (CIC) [Panellist]

The impact on society of machine learning – an opportunity or a threat?

14 November 2017

Dr Mike Lynch OBE FRS FREng, Founder, Invoke Capital
Dr Claire Craig CBE, Director of Science Policy, The Royal Society
Amir Saffari, Head of AI, BenevolentAI
Dame Wendy Hall DBE FRS FREng, Regius Professor of Computer Science, University of Southampton
Professor Chris Bishop FRS FREng, Laboratory Director, Microsoft Research, Cambridge [Panellist]

A business strategy for Scotland

6 November 2017

Professor Iain Gray CBE FREng FRSE, Vice President for Business, The Royal Society of Edinburgh
Nora Senior CBE, Chair, Scottish Government's Strategic Board for Enterprise and Skills
Dame Susan Rice CBE FRSE, Chair, Scottish Water
Paul Wheelhouse MSP, Minister for Business, Innovation and Energy and Member for South Scotland, Scottish Parliament

Searching for the Holy Grail of a science and innovation strategy that makes a difference

18 October 2017

The Lord Hennessy of Nympsfield FBA, House of Lords
The Rt Hon the Lord Heseltine CH, House of Lords
The Rt Hon the Lord Willetts, Executive Chairman, The Resolution Foundation

Cancer diagnostics: can cancer be diagnosed earlier and if yes what are the consequences?

11 July 2017

Sir Harpal Kumar, Chief Executive, Cancer Research UK
Billy Boyle, Chief Executive Officer, Owlstone Medical
Dr Clare Turnbull, Clinical Lead, Genomics England 100,000 Genomes Cancer Programme
Dr Suzanne Jenkins, Diagnostics Expert (Director), Personalised Healthcare and Biomarkers, AstraZeneca [Panellist]
Sara Hiom, Director of Early Diagnosis and Health Professional Engagement, Cancer Research UK [Panellist]

The impact of demographic and medical trends on the health and social care systems of the UK

21 Jun 2017

Professor Chris Whitty CB FMedSci, Chief Scientific Adviser, Department of Health, Deputy Government Chief Scientific Adviser
Sir Robert Lechler PMedSci, President, Academy of Medical Sciences
Professor Marcel Levi, Chief Executive, University College London Hospitals NHS Foundation Trust

Making cities work - the application of technology, science and infrastructure improvements to create a place where citizens wish to live

24 May 2017

Professor The Lord Mair CBE FRS FREng, Sir Kirby Laing Professor of Civil Engineering, Department of Engineering, University of Cambridge
Tom Saunders, Principal Researcher, International Innovation, Nesta
Councillor Peter Marland, Leader, Milton Keynes Council

What constitutes an effective industrial strategy for the UK?

10 May 2017

Professor Graeme Reid, Specialist Adviser to the House of Lords Select Committee on Science and Technology
Professor Dame Ann Dowling DBE FRS FREng, President, Royal Academy of Engineering
Andrew Barker, Head of Investor Relations, International Airlines Group
Anthony Lilley OBE, Chief Executive and Chief Creative Officer, Magic Lantern
Dr Andrew Harter FREng FIET FBCS, Chair, Cambridge Network and Founder and CEO, RealVNC [Panellist]

What needs to be done to meet urban air quality targets and what are the consequences if the targets are not met?

26 Apr 2017

Eliott Treharne, Air Quality Manager, Greater London Authority
Dr Stephen Bryce, Vice-President, Fuels Technology, Shell Projects and Technology
Professor Frank Kelly, Professor of Environmental Health, King's College London
Dr Christa Hasenkopf, Chief Executive and Co-Founder, OpenEQ [Panellist]

How can skill levels be raised to meet the needs of society and the economy?

1 March 2017

Sir Mark Walport FRS FMedSci, Government Chief Scientific Adviser, Government Office for Science
Sir Adrian Smith FRS, Chair of the Smith Inquiry into mathematics education for 16 to 18 year olds and Vice Chancellor of the University of London
Dame Judith Hackitt DBE FREng, Chair, EEF (formerly the Engineering Employers' Federation)
Stephen Metcalfe MP, Chair, House of Commons Select Committee on Science and Technology [Panellist]

Making good use of science and innovation in overseas development programmes

14 December 2016

Professor Charlotte Watts FMedSci, Chief Scientific Adviser and Director Research and Evidence Division, Department for International Development
Jon Ridley, Head, M-KOPA Labs, M-KOPA Solar
Rowan Douglas CBE, Chief Executive, Capital, Science & Policy Practice and Chair, Willis Research Network, Willis Towers Watson

The opportunities for and threats to the research and innovation communities from Brexit
16 November 2016

Sir Venki Ramakrishnan PRS FMedSci, President, The Royal Society
Professor Louise Richardson FRSE, Vice-Chancellor, University of Oxford
The Rt Hon the Lord Willetts, House of Lords
Dr Hermann Hauser KBE FRS FREng, Co-Founder, Amadeus Capital Partners [Panellist]
Professor Madeleine Atkins CBE, Chief Executive, Higher Education Funding Council for England [Panellist]

The vision for UK Research and Innovation (UKRI)
9 November 2016

Sir John Kingman KCB, Chair, UK Research and Innovation, Department of Business, Energy and Industrial Strategy
Professor Dame Julia Goodfellow DBE FMedSci, President, Universities UK and Vice-Chancellor, University of Kent
Phil Smith, Chair, Cisco UK & Ireland, Chair, Innovate UK and Chair, The Tech Partnership

Health, happiness and wellbeing: supporting the transition from adolescence to adulthood
26 October 2016

Dr Joanne McLean, Research and Development Manager, Scotland, Mental Health Foundation
Dr Helen Sweeting, Reader, MRC/CSO Social and Political Health Sciences Unit, University of Glasgow
Lord Layard FBA, Director, Wellbeing Programme, Centre for Economic Performance, London School of Economics and Political Science
Catherine Calderwood FRCP, Chief Medical Officer for Scotland, Scottish Government [Panellist]

The National Flood Resilience Review: the lessons learned from recent flood events in the United Kingdom
12 October 2016

Professor Dame Julia Slingo DBE FRS, Chief Scientist, Met Office
Dr Doug Wilson, Director, Scientific & Evidence Services, Environment Agency
Simon Warsop, Chief Underwriting Officer, Personal Lines, Aviva
Professor Charles Godfray CBE FRS, Chair, Defra Science Advisory Council and University of Oxford
Professor Bas Jonkman, Professor of Integral Hydraulic Engineering, Delft University of Technology
Katharine Hammond, Director, Civil Contingencies Secretariat, Cabinet Office

What is the value to the economy of the finance and insurance sectors?
6 July 2016

Anne Richards CVO CBE FRSE, Chief Executive, M&G Investments
John Nelson, Chairman, Lloyd's of London
Professor John Kay CBE FRSE FBA, Economist and *Financial Times* Columnist

How should universities and Research Councils proactively respond to gender bias in success rates in grant applications?
22 June 2016

Professor Paul Boyle CBE FBA FRSE, President and Vice-Chancellor, University of Leicester
Professor Henrietta O'Connor, Deputy Head of College of Social Science, Arts and Humanities and Professor of Sociology, University of Leicester
Linda Holliday, Director of Capacity and Skills Development, Medical Research Council

Is a paradigm shift taking place in the ways individuals and organisations access, analyse and protect data?
25 May 2016

Professor Sir Nigel Shadbolt FREng, Chairman and Co-Founder, The Open Data Institute
Dr Mike Lynch OBE FRS FREng DL, Founder, Invoke Capital
Professor David Hand OBE FBA, Chief Scientific Adviser, Winton Capital
Baroness O'Neill of Bengarve CH CBE FBA HonFRS FMedSci, House of Lords [Panellist]

The pros and cons of EU membership for UK research programmes in private enterprises and public sector organisations
3 May 2016

The Lord Hennessy of Nympsfield FBA, Member, House of Lords Science and Technology Select Committee, House of Lords
Viscount Ridley FMedSci FRSL, Member, House of Lords Science and Technology Select Committee, House of Lords
Professor Dame Jocelyn Bell Burnell DBE FRS FRSE FRAS FInstP, President, The Royal Society of Edinburgh
Sir Emyr Jones Parry GCMG FInstP FLSW, President, The Learned Society of Wales

Building effective and efficient infrastructure for the UK
27 April 2016

Tony Meggs, Chief Executive, Infrastructure and Projects Authority, Cabinet Office
The Rt Hon The Lord Adonis, Chair, National Infrastructure Commission
Sir Terry Morgan CBE, Chairman, Crossrail
Darren James, Managing Director, Infrastructure, Costain [Panellist]

Using science to authenticate, verify or assure the identity of people and things
2 March 2016

Sir Mark Walport FRS FMedSci, Government Chief Scientific Adviser
Dr Derek Craston, Government Chemist and Managing Director of Science and Innovation at LGC
Professor Dame Sue Black DBE FRSE, Professor of Anatomy and Forensic Anthropology at the University of Dundee

Bringing science to the heart of government: the Nurse Review of the Research Councils
12 January 2016

Sir Paul Nurse FRS FMedSci, Chair, the Nurse Review of the Research Councils, and Director, The Francis Crick Institute
Professor Phil Nelson FREng, Chair, RCUK Executive Group and Chief Executive, Engineering and Physical Sciences Research Council
Gareth Davies, Director General, Business and Science, Department for Business, Innovation and Skills
Professor Dame Jocelyn Bell Burnell DBE FRS FRAS PRSE, President, The Royal Society of Edinburgh [Panellist]

Closing the US/UK productivity gap: connecting innovation and research to economic output
2 December 2015

Dr Ruth McKernan CBE, Chief Executive, Innovate UK
Professor Jonathan Haskel, Professor of Economics, Imperial College Business School
Tony Harper, Head of Research and Advanced Systems Engineering, Jaguar Land Rover

Responding to a changing Arctic: The House of Lords Arctic Select Committee Report
4 November 2015

The Lord Teverson, Chair, House of Lords Select Committee on the Arctic, House of Lords
Jane Rumble, Head, Polar Regions Department, Foreign and Commonwealth Office
Professor Dame Julia Slingo DBE FRS, Chief Scientist, Met Office

The Accelerated Access Review for the Department of Health (the Taylor Review)
26 October 2015

Sir Hugh Taylor KCB, Chair, Accelerated Access Review, Department of Health
Sir Leszek Borysiewicz FRS FRCP FMedSci FLSW, Vice-Chancellor, University of Cambridge

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IPA

J
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K
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King's College London
Knowledge Transfer Network Limited

L
Lloyd's Register Foundation

M
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Natural History Museum
Network Rail
Nottingham Trent University

O
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P
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Phrase
Plymouth University

Q
Queen's University Belfast

R
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Risk Solutions
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Royal Society of Chemistry
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