Future risk

How technology could make or break our world

Centenary Future Risk Series: Report 4

100 1912–2012 A CENTURY OF PROFESSIONALISM

CII

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Foreword

This year the Chartered Insurance Institute celebrates its centenary year as a chartered professional body. To mark this achievement, we are publishing a series of seven reports, each of which explores some of the risks and opportunities that might face us in the decades to come, drawing on the assessment of commentators across various fields of expertise.

Whilst 'future gazing' doesn't always lead to accurate predictions, it is an important exercise for the insurance industry to undertake as understanding and assessing potential risks is at the heart of what we do. Indeed, central to the role of insurance is the ability to make informed, professional judgments about the relative risks of various hazards occurring over a particular period of time. By planning for the long-term and challenging assumptions about what the future might look like, the profession will be well placed to provide expertise and insight on the risks that lie ahead.

This report is the fourth in our centenary series and focuses on possible technological futures. Within the report, four leading experts provide their views about future risks in this area. Using the expert analysis, the report seeks to outline three possible technological scenarios and their potential implications for the insurance sector.

Tony Emms
Chair, CII Claims Faculty

Introduction

The rate of technological change over the last hundred years, and the last fifty in particular, has been remarkable and it has driven significant improvements in many areas of our lives. Advancements in technology related to healthcare, for example, has dramatically increased our chances of surviving illness and disease, and enhanced our ability to live following organ failure or the loss of a limb.

Technology has also permeated through our normal daily routines changing the way we cook and eat, the way we travel from A to B and the way we work and interact with one another. What's more, the rate of change appears to be increasing – especially in the world of telecommunications. Never before has so much information been accessible to so many people around the world.

But with new technological developments, come risks as well as opportunities; for example, with the widespread dissemination of the motor-car came traffic accidents, whilst the growth in ownership of personal computers and access to the internet has led to the possibility of cyber crime and internet fraud. Understanding the risks attached to new technology will, therefore, be crucial to ensuring that opportunities are maximised and technological change is embraced rather than feared in the years ahead.

It is also important to note that the benefits of technological change have been unequally felt around the world. Whilst many across the more advanced economies take "new" developments like internet access and mobile phone technology for granted, in other countries the infrastructure may not even allow for phone lines, and poverty is such that many do not have the capacity to afford mobile phones or personal computers. Incentivising improvements in access for the poorest people and those living in the remotest regions is, therefore, another key challenge facing governments and industries.

The insurance sector can help people face up to some of these challenges. For example, it played a key role in bringing forward seatbelts in cars and fire safety standards in buildings. By understanding the risks attached to technology and pricing insurance products accordingly, the industry has been able to raise awareness of some of the downside risks associated with certain technologies stimulating improvements in safety for users. Insurance can also play a role in stimulating investment in technology – providing protection in case technology backfires provides an incentive for growth and innovation. And finally, insurers are themselves embracing new forms of technology – particularly ICT to help with their core business functions.

But what are likely to be the big technological opportunities and risks over the next few decades and what can the industry do to mitigate them? This latest report within the centenary series will be dedicated to answering this question.

Overall approach to the Future Risk series

In early February we published the first in the centenary series – ***Future Risk: Learning from History***. It set the scene for the entire CII Future Risk series by reflecting on some of the most dynamic trends of the past and their potential implications as well as discussing some initial findings from a global survey into the risk perceptions of members of the public from across the globe.

A central point made by the report was that in such a rapidly changing international environment, it is vitally important to question underlying assumptions about the world around us and re-evaluate prevailing wisdom. We qualified this statement by noting that whilst a healthy level of scepticism about prevailing wisdom and future forecasting is a good thing, it should not prevent us from developing some scenarios on the long-term to help us prepare for some of the opportunities and risks that lie ahead. Rather, it should ensure that we do not become overly confident and dependent upon any single narrative. In this context, the fourth in our series of reports looks at some possible technological futures and their implications for the insurance sector and society as a whole. Crucially it also seeks to identify what role the industry can play in incentivising a secure technological future. Our next report in the series will look at future demographic risks.

Summary

The report begins by presenting a number of **specially commissioned essays** on future technological risks from leading experts in the field. The authors and their topics include:

- **David Willetts MP** – The UK's Science and Universities Minister discusses the importance of investing in science and technology and notes some of the key links between new technology and the insurance industry.
- **Professor James Woudhuysen** – Professor of Forecasting and Innovation at De Montfort University, considers the types of innovative industries in which the UK can build a strong comparative advantage.
- **Professor Dave Cliff** – Director of Large Scale Complex IT Systems, University of Bristol, reflects on the risks of "cascade failure" in large IT systems, some of their implications, and how failure can be avoided.
- **Dr Peter Taylor** – Research Fellow at Oxford University and risk specialist, Dr Taylor considers the ways in which it is possible to be driven by computational models of the world that are not always reliable and which can lead to poor decision making.

These essays represent compellingly argued visions of the future which can provide the basis for the construction of three illustrative scenarios – all of which could have important implications for the insurance sector and beyond.

In our most optimistic scenario, there is substantial investment in new technology underpinning economic growth by shifting the supply curve. Insurance firms are able to capitalise on new technology to better understand customers, market products and underwrite risks. The limitations of technology are understood and the risks are carefully assessed – though this does not deter progress and innovation. Indeed, helped by the industry's pricing of risk, innovation stimulates the development of increasingly safe and effective technology providing real benefits to people's lives.

In our central scenario, whilst there is some investment in new technology, this is not as pronounced as in the first. In this environment, insurance firms do not fully utilise the opportunities afforded by technological change and fail to capitalise on potential benefits to marketing, underwriting and claims that technological advances can bring. Indeed, partly as a consequence, insurers place too much emphasis on outdated methods of modelling risk which lead to mispricing, ultimately affecting bottom line profit. "Black swan" events (that is broadly speaking, events that are rare but can have a very high impact) negatively affect the industry and the rest of society. They include the occasional failure of large scale IT systems, similar to the so-called "Flash Crash" of 2010, which cause sudden and widespread disruption.

At our most pessimistic, over reliance on old technology combined with complacency in the use of that technology has grave consequences. In the short-term, multiple systems failures are the result of 'normalisation of deviance' – where problems with technology are neglected and taken as normal rather faced up to and addressed. Failures of large scale systems are particularly prevalent in the financial services sector and energy sectors causing widespread and lasting disruption to the economy and society. A fear of technology results, with dire consequences for investment in innovation. Unfortunately, insurers are caught unprepared. An overriding obsession with modelling risk using out-of-date technology which contain spurious assumptions about the world, prevents the industry from preparing for "black swan" events. When the time comes, they are undercapitalised – technological failures put at risk the solvency of institutions.

In summary, there is a lot at stake with respect to our technological future. Depending on which path we take, technology can either help make or break us – and key to success is to embrace innovation but balance this with an appropriate consideration of some of the risks new technologies can bring. In this regard, insurance has a key role to play – both in terms of utilising new technology to improve its own business practices, and in highlighting some of the downside risks associated with technology to policyholders. Insurers are also well placed to identify possible "black swan" events related to the misuse of technology. In this regard, collaboration with government and other industries will be critical to success.

Past trends and possible futures

Our analysis of past trends from the first report within the centenary series identified a number of key risks posed by continuing technological change.[1] In this opening section, we briefly outline the kinds of insights that our expert authors provide in relation to these risks. This short discussion and the essays that follow, act as the building blocks for some simple technological scenarios set out later in this report.

It should be noted that the risks outlined below are in no way an exhaustive list. There are many technological risks not discussed in this report that might significantly affect our future. One of these is related to new developments in medical technology, which have the potential to dramatically extend lives and this will be discussed in detail, in our next report within the centenary series looking at demographic change.

The importance of investing in our technological future

In our first guest essay, **Minister of State for Universities and Science, Rt. Hon. David Willetts MP**, discusses the links between insurance and investment in technology and research and development in the UK. Willetts notes many of the ways in which science and technology are enhancing the ability of insurance to underwrite diverse risks like climate change, drug trafficking, oil spills and piracy by providing new and more accurate data streams from which to judge the likelihood and impact of the various hazards occurring. Willetts also notes the way in which advances in computational modelling are changing the way in which insurance brokers operate with the potential to deliver a “modern version of the classic broker function”.

In Willetts’ view, the UK’s current and future comparative advantage lies in the skill to programme computers to maximise their capabilities, and employ those capabilities to great effect in business. For this to happen, the government, industry and the scientific community must work together to ensure that technological developments are fully utilised across industry and for the benefit of the rest of society.

Our second guest essay by **James Woudhuysen, Professor of Forecasting and Innovation, at De Montfort University**, also discusses the importance of investing in technology. He argues that the recent pace of technological change has not been as great as many believe, and that there is a risk that a growing distrust of technology will prevent much needed investment in the years ahead. In this context, Woudhuysen identifies a number of key industries in which the UK could develop a comparative advantage in should sufficient investment be forthcoming. Examples include nanomaterials, electronic components and automotive systems amongst others. Woudhuysen notes that with new technologies come new risks, but that further technological advances are likely to lead to better mitigation of risk in the long run. He provides the example of fire engines, fire blankets and fire extinguishers. The biggest risk of all he implies, is not taking the risk to invest in new technology in the first place.

Reliance on technology – avoiding some of the pitfalls

Professor Dave Cliff, Director of UK Large-Scale Complex IT Systems Research and Training at the University of Bristol argues that the development of large scale IT systems or networked “systems-of-systems” has made something called “cascade failure” a possibility. This is where unanticipated interactions between the various moving parts in a complex system can cause a “domino effect” chain reaction. Professor Cliff argues that such events can be extremely serious and points to the example of the “Flash Crash” of May 2010 for evidence of this. There is, he argues, widespread speculation that the Flash Crash was caused by “robot traders that had been incorrectly programmed, or unexpected interactions between otherwise benign” robots. As a result the Dow Jones posted its biggest intraday loss – 600 basis points before recovering this loss in twenty minutes before the end of trading.

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1 For an in-depth analysis of past technological trends please read our first centenary report, ***Future Risk: Learning from history***, Centenary future risk series: report 1 (Feb 2012)

A key risk then, according to Professor Cliff, is that as societies become increasingly reliant on large scale systems, such events will occur with increasing regularity. To reduce the risk of cascade failure he argues that we must apply some of the approaches taken by so called "high reliability organisations" – organisations where the consequences of failure are so high (such as the aviation industry) that avoidance and mitigation of failure is deeply interwoven into business practices and culture. Cliff also calls for tighter regulation of such large-scale IT systems and greater political awareness and oversight of the risks associated with them.

Dr Peter Taylor, Research Fellow at Oxford University and risk specialist also considers some of the potential pitfalls of using technology and particularly relying on computer modelling to drive decision making. Entitled "fooled by lack of randomness", Dr Taylor's essay describes how people can become deluded into thinking that certain relationships between variables in a model are "real", especially when modelled by computers which can "lend an apparent objectivity to the results". Taylor provides the example of Lloyd's of London which was nearly "brought to its knees" in the 1980s. He argues that this was the result of the Lloyd's market being fooled into thinking there was little or no danger to a high excess of loss layer as a result of an overreliance on recent historical data. Taylor argues that "the variability was there, it just hadn't occurred in recent times".

This kind of problem is also relevant to government policy and regulatory rules, and in particular the implementation of Solvency II. The core principle of Solvency II is that insurers have sufficient capital to remain solvent for 199 years out of 200. In determining whether insurers meet this requirement, firms must choose a particular loss model which provides estimates of the amount of capital needed to offset assumed losses.

Taylor argues that if insurers get this wrong, as banks did under Basel II, then insurers may be undercapitalised. Alternatively, if the model chosen overestimates the amount of capital needed, insurers may become overcapitalised and thereby too expensive. Taylor argues that in order to strike the right balance, firms must understand the ways in which people can be fooled into under-or overestimating risk and to calibrate models accordingly whilst not to being over reliant upon them. Indeed, some types of events, such as those termed "black swans" are by definition beyond the realms of most modelling capabilities, despite the dramatic effects that they can have on industry and the wider economy.

Building scenarios on the future

Our expert authors identify a number of significant and interrelated technological opportunities as well as risks, which can be expected to have substantial implications for our future wellbeing and prosperity. Crucially, a number of the expert authors argue that effective action must not be deferred – what policymakers and business leaders do now will have important implications for our long-term future. In later chapters we will use this expert analysis to form the basis for some technological scenarios later in this report.

Science, innovation and the UK insurance industry[2]

David Willetts MP – Minister for Universities and Science

The UK has a world-leading insurance sector and London is the only market in which all of the world's 20 largest reinsurance groups are represented. Too often the City is regarded as shorthand for investment banking but let's be clear: the City covers far more than that and we should be proud of competitive sectors like insurance which matter a great deal for the economy.

> *"For the Government's part, we remain committed to securing the best possible outcome for the UK insurance industry under Solvency II – on the timing of implementation and on the critical detail concerning equivalence and the matching premium."*

The UK insurance sector is the third largest in the world – and the biggest in Europe, accounting for seven per cent of global premiums. Employing around 300,000 people in the UK – more than a quarter of all financial services' jobs – it contributes some £10 billion in taxes. It's also a major exporter, with about 30 per cent of its net premium income coming from overseas business. For the Government's part, we remain committed to securing the best possible outcome for the UK insurance industry under Solvency II – on the timing of implementation and on the critical detail concerning equivalence and the matching premium.

There is a wider lesson here for financial services. Insurance has faced its own travails, but it has sorted itself out, reformed its practices and emerged stronger. The controversy surrounding some Lloyd's of London underwriting syndicates was painful and I have constituents who are still living with the consequences of Equitable Life. But the City can learn from unhappy episodes like these, embrace reform and it can bounce back.

Now the UK can celebrate a strong, vigorous insurance industry. There is also, and I am the Minister responsible, a strong university and research sector in the UK – and there are connections between the two. For the rest of this essay, I want to investigate these connections – to shed light on the real nature and significance of high-tech growth, and how best to support it.

The first and most obvious function for higher and further education is to produce graduates that business can recruit – and, in the insurance industry, of course, there is a clear need for graduates with maths skills. The good news is at school level, uptake of STEM subjects – that's science, technology, engineering and maths – at GCSE and A level has been rising steadily over the past few years. We've seen a 42 per cent increase among UK-based students taking a first degree in maths over the past 10 years – and an 18 per cent increase among maths PhD entrants. In the Autumn Statement 2011, we announced that we would support a scheme to enable the kite-marking of STEM-related courses which are valued by employers. But the educational role is only one aspect of the relationship. The associations are both broader and deeper.

2 This is an abridged version of a speech given by the Minister to Willis in March 2012

Windows upon the world

The links between the UK's outstanding science and research base and what the insurance industry goes even further than education. They go right back to the open character of our society. Brokers like Willis, for example, connect the world's risks and the world's insurance capacity. Insurance has always been a global business, as shown by our merchants who sought to insure their cargoes moving across the oceans – originally in the coffee houses of the Square Mile. No doubt they do so again today, thanks to Starbucks and wifi. It's a clear case of history repeating itself, but also a classic example of Britain's reach – and not just in a purely international sense. Nowadays, UK insurers underwrite commercial activities ranging from the deep sea to earth orbit.

UK science and research is another international window on the world. Like insurance, it is bound up with Britain's history of exploration and discovery and it's what lies behind our understanding of the cultures and languages of other countries. For anywhere in the world, we're likely to have linguists, anthropologists, historians, sociologists studying it today. There are not many nations who can claim that breadth of expertise. This breadth resides not just in the humanities and social sciences. According to last year's report written by Elsevier, the UK can boast internationally-recognised research strength in more than 400 fields. That includes strengths in studying the physical and the natural world – biology, geology, geography, hydrography and all those disciplines which joined the Royal Navy and merchant fleet on their circumnavigations. British scientists still fan out across the world and study data collected from above and below it, to understand how our planet works. In February 2012, I visited British Antarctic Survey researchers on the west of the Antarctic Peninsula. The people stationed there are conducting a range of experiments including examining molluscs collected during Captain Scott's expedition with the same species collected by current researchers from the very same location to understand the effects of climate change over time. Very few countries are in a position to carry out this kind of comparative work because they don't have our history of exploration and scientific investigation.

“…scientists and insurers must gaze through the same pane of glass. Scientists' raison d'être is understanding nature and insurers also need to understand nature as the prerequisite to judging risk. Insurers and scientists, therefore, share the same need to understand our world.”

So the insurance industry has a window on the world. Scientists do too – and their activities are intrinsic to what insurers do. In fact, scientists and insurers must gaze through the same pane of glass. Scientists' raison d'être is understanding nature and insurers also need to understand nature as the prerequisite to judging risk. Insurers and scientists, therefore, share the same need to understand our world.

Earth observation exemplifies that shared mission – and for me, its true importance hit home when I visited the NASA Jet Propulsion Laboratory in Pasadena, where a large screen simultaneously shows missions monitoring the oceans, polar ice, atmospheric pollution and forest fires. It treats the world like a human patient. No one country can take responsibility for all this work, but the UK plays a leading role. In 2012 we chaired the international committee that covers space and major disasters; UK satellites provide vital data in the wake of major natural disasters. In 2012 we celebrated the tenth anniversary of the Envisat satellite – 10 years of UK-built technology providing scientists and researchers with quality data to analyse global warming and climate change.

One reason I am so keen to support the UK space sector is that I see our role as a spacefaring nation as a natural follow-on from our role as a seafaring nation. Again, it gives Britain global reach and understanding. Inmarsat, the world's leading maritime communications business is based in London, and we're doing our best to make sure that the business infrastructure is in place to grow the FTSE 100 space companies of tomorrow. That includes changing the Outer Space Act by introducing an upper limit on liability for UK operators, developing the right insurance infrastructure for space activities and investing to open up new markets.

There's another aspect of Government investment in space likely to be of particular interest to the insurance industry. In November 2011, we committed £21 million to assist in the development and launch of the UK's first Synthetic Aperture Radar satellite – better known as NovaSAR. Once NovaSAR is up and running, businesses will be able to use the data in various ways, including maritime surveillance of drug-trafficking, oil spills and piracy. With piracy, the major advantage of NovaSAR is that it has the ability to image at day or night and effectively see through clouds. NovaSAR can also cover vast areas, like the Indian Ocean, in relatively short periods of time – with sufficient resolution to detect small individual ships, their speed and direction. By marrying this information with automatic broadcast messages which identify individual ships, NovaSAR will enable law enforcement agencies to identify and target uncooperative or suspect vessels.

The Government is also investing in other branches of science to help all of us understand the world – and help insurers to underwrite it. The Met Office Hadley Centre is probably the world's leading place for combining weather and climate forecasting. In the past, the Met Office has sat with the Board of Trade and the Ministry of Defence, given its importance in protecting commercial shipping and the UK's armed forces. In 2011, it moved over to BIS and is part of the science family for which we have responsibility. We have excellent centres of meteorology such as the University of Reading. Meanwhile, the Natural Environment Research Council (NERC) is leading the £2.8million PURE programme on probability, uncertainty and risk in the Environment – improving assessment and quantification in natural hazards by developing new methods and demonstrating their applicability.

The Met Office is continuing to combine its expertise in weather and climate with the UK's researchers in environmental science. It has already brought together several institutions and agencies to form the Natural Hazards Partnership, which provides round-the-clock support to the emergency response services. Now it is extending this concept through the Environmental Science to Service Partnership, which aims to harness the nation's investment in environmental science for the benefit of society, business and government. At the same time, the UK Space Agency is opening up data for researchers and companies at the centre for Climate and Environment Monitoring from Space (CEMS). We want CEMS to become the leader in satellite data integration and information delivery.

A world in flux

Understanding the physical world is all the more necessary because of the speed at which the natural environment is altering. Natural disasters caused £100 billion of damage in 2011 and it was the costliest year in the insurance market's 323-year history. Scientists and insurers are both urgently scrutinising a world in flux.

The Iceland volcano, flash floods in Pakistan, the earthquake in Haiti, wildfires in Russia, scientists recorded 960 loss-relevant events in 2010, a world record. More than ever, insurers are reliant on Earth observation data for exposure control, damage assessment and then loss quantification. When a catastrophe happens, the insurance industry is only a few steps behind the emergency responders.

There were fewer than 400 natural catastrophes in 1980, compared to almost 1,000 in 2010 – with a significant rise in meteorological and hydrological events, and a measurable increase in climatological ones.

As the climate changes, so we expect more energy in the climate system to lead to more extreme weather events. But, of course, while we can make this general point on a probabilistic basis, individual events cannot necessarily be attributed to climate change. The past may be no guide to the future – hence the enormous value of scientific modelling to a world where there is more of value to destroy – more buildings, ships and wealth than ever before.

> *"There have been quite a few stories about financial services in recent years, some of them pretty dreadful, but they haven't focused on the London insurance market. One reason for that is its continuous engagement with the scientific community to make sure it has the best possible understanding of the world around us."*

More of these natural events are insured in the London market than anywhere else – meaning record pay-outs. But there has not been a crisis in the London market. There have been quite a few stories about financial services in recent years, some of them pretty dreadful, but they haven't focused on the London insurance market. One reason for that is its continuous engagement with the scientific community to make sure it has the best possible understanding of the world around us.

The Government's position on climate change

As a coalition government, we are informed by the available scientific evidence: evidence from temperature records in England dating back to 1659 and proxy measurements from ice cores going back thousands of years; evidence from the sophisticated models designed by NASA and the Met Office, projecting future climate under a range of emissions scenarios. The evidence is overwhelming, validated by the vast majority of scientists, and points in one direction. The earth's surface has warmed by more than 0.75 degrees centigrade since around 1900, with much of this warming occurring in the past 50 years.

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change in 2007 concluded that – with a probability of more than 90 per cent – most of the observed global warming since the mid-20th century is attributable to the observed increase in human-caused greenhouse gas concentrations. We are currently annually emitting more than 30 billion tonnes of CO_2 globally by burning fossil fuels. Putting all this together, average global temperatures may rise between 1.1°C and 6.4°C above 1990 levels by the end of this century.

Of course there are many uncertainties involved here – discontinuities or tipping points, for example, and the scientific community is focusing huge efforts on examining these. But as science minister, I operate purely from the available evidence.

One reason why climate change is so important is the potential burden our generation may bequeath. When Margaret Thatcher opened the Hadley Centre in May 1990, she observed that "Man's activities are already adding greenhouse gases to the Earth at an unprecedented rate, with inevitable consequences for our future climate" – and that "The problems do not lie in the future—they are here and now—and it is our children and grandchildren, who are already growing up, who will be affected." This relates to the central theme of my book, The Pinch – fairness between generations.

According to a DEFRA climate change risk assessment published in January 2012, for example, annual damage to properties in England and Wales from river and sea flooding is projected to rise to between £2 billion and £12 billion annually by the 2080s – against a current cost of around £1.3 billion. While premature deaths due to cold winters are projected to decrease significantly, premature deaths due to hotter summers are likely to increase – by up to around 4,000 by the 2050s. From a scientific perspective, uncertainties around tipping points, and the potentially incalculable costs that these could impose on our descendants, are rather big bets to place on the future when there are sound arguments – and good business opportunities – for moving towards a low carbon economy now.

The modelled world

Thus far, this essay has illustrated the significance of the links between the work of scientists studying climate change and the natural world, and the work of the insurance industry. But that is not the end of the story, for there is another connection besides. It's not only what we research that matters, but how we do it. The sheer volume of data is currently one of the biggest challenges facing science. Analysing all that data for scientific discovery is one of our great challenges.

One of the classic ways in which we handle these large volumes of data is through algorithms. And this year, in June, we marked the centenary of the birth of the great British scientist who, more than anyone else, linked the maths of algorithms to modern computing: Alan Turing. Handling large datasets is a key skill in financial services, in advanced manufacturing, and in scientific research too. That is why the Government is investing £165 million in e-infrastructure. And in March 2012 I co-chaired, with Professor Dominic Tildesley, the first meeting of the e-infrastructure leadership council that is going to ensure the UK maintains its global lead in this discipline.

Computational modelling, as I've already suggested, is well developed for predicting the natural world, but there is huge potential in combining high performance computing and analytics to improve existing models: the better the model, the better the business decision. The UK has great strengths in modelling and simulation software, but we also need the mathematics knowhow to exploit future architectures, combine methodologies in solving complex problems and handle the associated storage and data analysis issues.

A recent international review rated the UK as excellent in the mathematical sciences, with world-leading researchers in every subfield. I know that some of our mathematicians are worried that the importance of maths research is being overlooked. I take their concern very seriously – and so does the Engineering and Physical Sciences Research Council. In response to the review's recommendations, the EPSRC published an action plan in November 2011. In fact, the EPSRC tell me that they will be increasing the total amount of resources going into maths through their wider work on societal challenges over the period covered by the spending review.

So far as the City is concerned, the Government have pledged support for a doctoral training centre in financial computing at University College, London. The £20 million centre – for £7.5 million from the Research Councils leveraged the remaining investment – has a particular interest in algorithmic risk simulation.

> *"...through a market match algorithm, insurance brokers can harness new technology to deliver a modern version of the classic broker function. The customer wins thanks to better information about the market, which drives competition. Business wins thanks to better access to more customers. The UK wins by insurers being at the forefront of innovation and also based in the UK."*

This is where insurance fits in – presumably hoping clients will place their business with them. For example, through a market match algorithm, insurance brokers can harness new technology to deliver a modern version of the classic broker function. The customer wins thanks to better information about the market, which drives competition. Business wins thanks to better access to more customers. The UK wins by insurers being at the forefront of innovation and also based in the UK.

In fact, a range of major UK firms and sectors are essentially in the algorithm business. Autonomy is one, of course, but they are not alone. WPP may be thought of as a services company, and its R&D budget is officially small, but sophisticated sentiment analysis is crucial to its business. And what about Tesco, who rely on club cards and algorithms to achieve smart customer segmentation and targeting? Algorithms seek out and discover new relationships and business opportunities that would otherwise be invisible and unexploited.

> *“Our comparative advantage is different. It is the skill to programme those computers to maximise their capabilities, and employ those capabilities to great effect in business. It is also to develop new market opportunities in, for example, low energy use computing.”*

I am not saying that the UK will have the world’s biggest or fastest computers, though we do need to be there or thereabouts. Our comparative advantage is different. It is the skill to programme those computers to maximise their capabilities, and employ those capabilities to great effect in business. It is also to develop new market opportunities in, for example, low energy use computing. In 2012 I opened the world’s most energy efficient high performance computer in Edinburgh. BlueGene/Q can carry something like 800 million million calculations a second, yet requires only the electricity needed to run a light bulb.

So we have seen several connections between what insurers do and the UK’s scientific activities. UK insurance and UK science share a need to understand the world around us and to understand how it is changing. We’ve seen how both rely on sophisticated maths-based models. Let me finally take a step back and connect all this to the wider argument about the Government’s growth strategy.

Defining and supporting high-tech industry

Earlier in 2012 I set out the Coalition’s commitment to high-tech growth – not just as a nice idea but as something we should actively pursue through the right mix of policies backing science, research and innovation. One challenge to my speech was that high tech may sound sexy but it just isn’t big enough to matter today; in the future, perhaps, but not now.

It is true that official statistics record high-tech businesses as a small part of our GDP. The OECD definition of a high-tech industry is one with a R&D-to-output ratio of more than 4 per cent. By this measure, high tech does indeed look small in the UK. Indeed, measured in this way, high tech invariably comprises a small part of any advanced economy. But we need to look behind that definition, because it’s a bad guide to policy. It completely fails to account for the way in which scientific knowledge flows into industries. Many low-tech activities, such as timber products or warehousing, have important scientific inputs. Therefore, general purpose technologies permeate the economy – with an impact extending way beyond so-called high-tech sectors.

By the OECD definition, insurance is not officially a high-tech industry. Even though it's classed as "knowledge intensive" – with more than one third of its workforce qualified to degree level – insurance is considered to do little by way of R&D. I very much doubt that any insurance company spends anything like four per cent of its turnover on R&D.

But, as I have argued in this essay, insurers actually depend to a considerable degree on high-tech science and research. Insurers' excellent global performance depends in part on access to world-class science which does not show up in figures measuring insurance activity.

So high tech matters far more than official figures suggest, and that challenge to my January speech – that high tech remains relatively unimportant – is misguided. Even apparently low-tech industries may depend on high-tech investment and research. Currently, the UK has high-tech industries flying under the radar and – once we recognise them – it becomes clear how crucially important high-tech capability really is. That's why the UK's high-tech strategy is so central – why investment in general purpose technologies like high-performance computing and our commitment to scientific research are so necessary to rebalancing the UK economy.

Risks and opportunities: adoption and non-adoption of key technologies for the UK

James Woudhuysen, Professor of Forecasting and Innovation, De Montfort University, Leicester

adoption and non-adoption of key technologies for the UK

Introduction

Will rates of development in technology increase at the same pace over the next decades as they have over past ones? How can we effectively manage evolutions in technology to ensure the safety and security of users? These are interesting questions, but each contains its own unstated premises.

In historical terms, the recent pace of development of new technologies, across a broad front, may not have been especially rapid.[3] While new applications on hand-held devices receive a lot of attention, they are far from the whole story. On the whole, technological development may actually be slowing down, not speeding up. Big American IT companies prefer to hoard hundreds of billions of dollars rather than invest that money in innovation.[4] In America and Europe, business and government research and development (R&D) as proportions of GDP have long been stagnating.[5]

The idea that the impetuous evolution of (information) technology threatens everyone's safety and security is also rather banal. As early as 1964, the 'muckraking' US journalist Vance Packard wrote, in his book The Naked Society, about the increase in surveillance ('since the beginning of World War II'), and 'the tremendous amount of electronic eavesdropping that now occurs'.[6] The unprecedented sensation of a mass loss of privacy today is one thing. But just how much should we really fear that loss, or blame it on omnipotent IT systems?

> *"What's new, rather, is that technology is regarded as fundamentally problematic, if not a little dangerous. Being complex and in some sense counter-posed to the workings of nature, technology today is perceived to be more a risk to be insured against than a down-payment on a better future."*

In discussions of growth, technology takes a back seat to endless debates on taxation and state expenditure. Indeed, technology has caught some of today's broader distrust of growth.[7]

In Britain, as in other parts of the West, the risks of failing to invest in technological innovation are rarely talked about. Yet we know from history that new technologies can lay the basis for whole new industries, and so create millions of jobs. Even in the Depression of the 1930s, Britain saw innovation and employment grow in fields such as radio, appliances and vehicles.

What follows is an overview of five technological domains that have great potential, but which enjoy less-than-great economic and political support. These domains are not the only ones of merit, nor are each of them guaranteed a great future. But they already form the object of international interest.

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3 Tyler Cowen, The Great Stagnation: *How America Ate All the Low-Hanging Fruit of Modern History, Got Sick, and Will (Eventually) Feel Better*; Dutton, 2011; James Woudhuysen, ed, Big Potatoes: the London Manifesto for Innovation, Thinking Apart, 2010

4 Jim Pyke, 'Large Tech Giants Hoarding Cash? Why Apple Is Unique', Seeking Alpha, 22 August 2011, on http://seekingalpha.com/article/288780-large-tech-giants-hoarding-cash-why-apple-is-unique

5 See Organisation for Economic Co-operation and Development (OECD), *Main Science and Technology Indicators (MSTI): 2011/1 edition*, Key Figures, charts for business and government expenditure as percentages of GDP, p21, on http://www.oecd.org/dataoecd/27/52/47406944.pdf

6 Vance Packard, The Naked Society [1964], Penguin Books, 1966, p20

7 See the discussion of the categories 'addiction' to energy and 'technological fix' in James Woudhuysen and Joe Kaplinsky, *Energise! A future for energy innovation*, Beautiful Books, 2009, pp84–85, 88–89. For a broader critique of what he calls 'growth scepticism', see Daniel Ben-Ami, Ferraris for All: In Defence of Economic Progress, Policy Press, 2010

1. Nanomaterials: the example of food packaging

In October 2011 the European Commission defined a nanomaterial as a natural, incidental or manufactured material containing particles, of which 50 per cent or more are in the size range 1 nm–100 nm [between one and 100 billionths of a metre].[8] 'Nanotechnologies' therefore refer to a wide variety of techniques, covering a wide variety of industries.

Nano-scale work has improved the surfaces of cars, the dressings applied to wounds, and the flame retardancy of plastics. In Germany, the Inno-CNT scientific alliance groups 90 partners together to work with carbon nanotubes in the fields of energy and the environment, mobility, lightweight construction, electronics, and health and safety.[9] In Britain, the Government's Technology Strategy Board lists more than 20 microtechnology and nanotechnology centres. There are specialists in fabrication (10), medicine (4), metrology (2), health and safety (1), and in materials (6).[10]

> *Typically enough, fears about the risks posed by nanomaterials have preceded real breakthroughs in the genre.*

Typically enough, fears about the risks posed by nanomaterials have preceded real breakthroughs in the genre. In 1986 the American technologist K Eric Drexler said that 'grey goo', or masses of uncontrolled, nanotechnology-scale, replicating molecular machines, posed 'an obvious threat to otters, people, cacti and ferns – to the rich fabric of the biosphere and all that we prize'.[11] In 1992 the writer Michael Crichton pursued a similar theme in his thriller, *Prey*. In 2004, Prince Charles warned that regulation on nanotechnology had 'to develop at the same rate as the technology itself', and that a precautionary approach should be applied.[12]

In fact the next 100 years will show that nanomaterials have so far developed too slowly, not too fast. They show particular promise in the packaging of food, a vital part of the British economy.[13] In America, potential applications have been found in paper that demonstrates antibacterial activity against E. coli, and in transparent coatings to make plastic bottles both stronger, and more capable of keeping their contents fizzy.[14]

> *The decision facing manufacturers and retailers serving food to UK markets will be whether to capitalise on public acquiescence to nanopackaging, or rather to allow scaremongers and regulators to keep the initiative.*

Right now, qualitative research by Britain's Food Standards Agency suggests that consumers take a relatively charitable view of food packaging applications using nanomaterials to extend shelf-life or to detect when food begins to spoil.[15] The decision facing manufacturers and retailers serving food to UK markets will be whether to capitalise on public acquiescence to nanopackaging, or rather to allow scaremongers and regulators to keep the initiative.

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8 'Commission Recommendation' of 18 October 2011 on the definition of nanomaterial, Official Journal of the European Union, 20 October 2011, p40, on http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:275:0038:0040:EN:PDF Note: microtechnology relates to distances of around a millionth of a metre

9 'Inno.CNT: Nanomaterials of the next generation', on http://www.inno-cnt.de/en/uebercnt.php

10 'Micro and Nano Technology Centres', on http://www.innovateuk.org/deliveringinnovation/micronanotechnologycentres.ashx

11 Eric Drexler, *Engines of Creation: the Coming Era of Nanotechnology* (1986), Anchor, 1987, p172

12 Article for *The Independent on Sunday*, 10 July 2004, on http://www.princeofwales.gov.uk/speechesandarticles/an_article_by_hrh_the_prince_of_wales_on_nanotechnology_the__59.html

13 Many of those working in Britain's enormous food industry work with different forms of food packaging in their jobs. In Q1 of 2011, the food chain in Great Britain, excluding agriculture, employed 3.05 million people. Department for Environment, Food and Rural Affairs/Office for National Statistics, Food Statistics Pocketbook 2011, 2011, p17, on http://www.defra.gov.uk/statistics/files/defra-stats-foodfarm-food-pocketbook-2011.pdf

14 See Ronen Gottesman and others, 'Sonochemical Coating of Paper by Microbiocidal Silver Nanoparticles', *Langmuir*, 2011, Vol 27 No 2, pp720–6, and "Nano-bricks" may help build better packaging to keep foods fresher longer', ScienceDaily, 27 March 2011, on http://www.sciencedaily.com/releases/2011/03/110327191031.htm

15 Food Standards Agency, *FSA Citizens Forums: Nanotechnology and Food*, April 2011, pp15–17, on http://www.food.gov.uk/multimedia/pdfs/publication/fsacfnanotechnologyfood.pdf

2. Electronic components

In 2002 and again in 2006, years before Japan's recent ordeal by earthquake, tsunami and nuclear blast, responsible authorities on both sides of the Atlantic gave some mention to the use of IT around disasters and healthcare. Announcing a convergence between nanotechnologies, biotechnologies, IT and cognitive science, American experts asked about the field use of mobile IT in responding to disasters, and eulogised 'comfortable, wearable' sensors that would 'enhance every person's awareness of his or her health condition, environment, chemical pollutants, potential hazards...'.[16] In Paris, economists wrote about the remote sensing of disasters, and considered how best to transmit and display warnings about them.[17]

> *"The potential prize is a big one: over the next decades, the use of sensors and displays in disasters and health could dramatically lower the world's risks."*

However, in both disasters and personal health, the 21st century's evidence so far suggests that progress in the use of IT needs to speed up. The potential prize is a big one: over the next decades, the use of sensors and displays in disasters and health could dramatically lower the world's risks.

Sensors and displays will become more capable. Printing layers of electronic ink on to long rolls of flexible material held at ambient temperatures, firms specialising in semiconductors such as Intel (US) and ARM Holdings (UK) will continue to bring down the scale and costs of electronic components.[18] The result will be chips, sensors, displays and other electronic systems that, compared with today's versions, are light, use little energy and process detailed images quickly.

Britain has strengths in sensors, displays and the broader domain of printing in electronic inks, whether plastic or otherwise organic in composition. At Imperial College, London, the Plastic Electronics Doctoral Training Centre has a team looking at non-invasive sensors that can detect diabetes from people's breath.[19] Plastic Logic, co-founded by Cambridge University Professor Sir Richard Friend and backed by Herman Hauser, a top technology financier, offers Russian students a 475g, 27.2cm e-book reader that, at $400, boasts a shatterproof, glare-free display and, nearly, a once-a-week charging regime.[20] At Sedgefield, County Durham, the Printable Electronics Technology Centre uses organic inks to design, develop and prototype not just thin film transistors for displays, but also solid-state lighting and photovoltaics.[21]

These efforts are commendable, but are they enough? In the US, the Defense Advanced Research Projects Agency uses the new, more miniaturised chips and sensors to build Unmanned Aerial Vehicles (UAVs) the size of birds or insects ('microdrones'),[22] as well as sense-and-communicate electronic systems mounted on and powered by insects.[23]

Economically, militarily and in many other ways, there is a lot riding on the new generation of electronic components.

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16 Mihail C Roco and William Sims Bainbridge, eds, *Converging Technologies for Improving Human Performance: Nanotechnology, Biotechnology, Information Technology and Cognitive Science* (2002), sponsored by the US National Science Foundation and Department of Commerce, Kluwer Academic Publishers (currently Springer), 2003, pp 5, 127, on http://www.wtec.org/ConvergingTechnologies/Report/NBIC_report.pdf

17 OECD, *Information Technology Outlook*, 2006. pp259–262, 272, on http://www.keepeek.com/Digital-Asset-Management/oecd/science-and-technology/oecd-information-technology-outlook-2006_it_outlook-2006-en The OECD's ideas on convergence and wearable sensors derive in no small measure from Mihail C Roco and William Sims Bainbridge, eds, *Converging Technologies*, op cit

18 Today the half-pitch in an electronic array, defined as half the distance between identical features in it, is 22 nanometres, or billionths of a metre

19 'Non-Invasive Sensors for the Detection of Diabetes via Breath Samples', on http://www3.imperial.ac.uk/plasticelectronicsdtc/research/cwmbproj

20 'Plastic Logic Introduces the Plastic Logic 100, Brings Innovation to the Future of Education in Russia', 12 September 2011, on http://www.plasticlogic.com/news/pr_education_announce_sep122011.php

21 'About PETEC', on http://www.uk-cpi.com/3_pages/focus/petec/about/index.html

22 See for example Elisabeth Bumiller and Thom Shanker, 'War Evolves With Drones, Some Tiny as Bugs', New York Times, 19 June 2011, on http://www.nytimes.com/2011/06/20/world/20drones.html?pagewanted=all

23 'Tiny cyborg beetles could recharge just by flying', InnovationNewsDaily, 29 November 2011, on http://www.msnbc.msn.com/id/45483410/ns/technology_and_science-innovation/#.TvjLVJibB9k At the University of Michigan, Khalil Najafi and Erkan Aktakka have used the movement of an insect's wings to power a tiny piezoelectric generator. For an overview of power supply systems for electronics, with a favourable appraisal of piezoelectric devices, see K A Cook-Chennault, N Thambi and A M Sastry, 'Powering MEMS portable devices – a review of non-regenerative and regenerative power supply systems with special emphasis on piezoelectric energy harvesting systems', *Smart Materials and Structures*, Volume 17 Number 4, August 2008, on http://deepblue.lib.umich.edu/bitstream/2027.42/64168/1/sms8_4_043001.pdf

3. Automotive systems

For the next decade or so, the most significant changes in automotive components will be in basic assemblies and in IT.

In Durham, Comesys (Control and Measurement Systems) Europe has shown how assemblies will change. On its accelerator pedals, Comesys doesn't fit complicated sliding sensors, but non-contact rotary ones that greatly simplify the mechanics. Result: a more accurate pedal, fewer carbon emissions and low wear – a lifespan claimed to be more than 10 million cycles.[24]

With Comesys pedals, Digital Signal Processing is also important, underlining the modern car's growing dependence on electronics. Already Japan and Germany have begun to build radar-based collision avoidance systems into cars – to warn the driver to use evasive tactics and to prepare the vehicle when a collision is inevitable. There will also be more incident avoidance systems, in which telemetry monitors key components in lorries to ensure that they break down less frequently.

> “*Even before mass automotive IT has matured, however, we can be certain there will be concerns about which kind of insurer to call if systems bring about a motorway pile-up.*”

The future will see collision avoidance used to allow vehicles to move together in close-up convoys – especially if Britain continues to build no new main roads. **Even before mass automotive IT has matured, however, we can be certain there will be concerns about which kind of insurer to call if systems bring about a motorway pile-up.**

What about replacements for, or at least additions to, the internal combustion engine? Well: an all-electric car is a wonderful thing, but it won't be around as a serious proportion of the world's fleet for decades. Still, Britain can already claim advance in electric motors. Torque-to-mass ratios on two Yokeless And Segmented Armature (YASA) motors made by Oxford YASA Motors are high enough to be able to accelerate a vehicle to 60mph in less than five seconds.[25]

Beyond electric power-trains, fuel cells powered by hydrogen are an option. From its global HQ in Loughborough, Intelligent Energy already uses a hydrogen fuel cell with a proton exchange membrane to build, with PSA Peugeot Citroën, a medium-range, light urban delivery vehicle – and, with The Suzuki Motor Corporation, a motorbike.[26]

Perhaps the most encouraging development in hydrogen cars is one that almost turns the fuel itself into a component. At the Rutherford Appleton Laboratory, Harwell, Oxfordshire, Cella Energy stores hydrogen as hydrides encapsulated in polyimide-based microfibres.[27] Cella's hope is to make the microfibres into pellets that can be brought by tanker from oil refineries (which is where most of the world's hydrogen is to be found), and then pumped, as a fluid, to cars at petrol stations equipped simply with modified pumps. No need to insure against mishaps with the 700 atmospheres of pressure usually needed to store hydrogen. No need to persuade petrol station franchisees of the need to build a whole new hydrogen infrastructure.

That's the thing with innovation. **Although no unconventional technology is likely to overtake conventional automotive engines and fossil fuels for decades, a really ingenious innovation just might make significant inroads at an unexpected rate. The risk here lies not with the innovation, but rather with Britain's vehicle manufacturing sector. A major employer and a surprisingly resilient feature of UK plc, it must be ready for the major changes in mass transportation that the 21st century may bring.**

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24 ‘Technology’, on http://comesys.co.kr/europe/technology.htm

25 ‘The YASA™ Motor’, on http://yasamotors.com/technology

26 ‘Intelligent Energy at Unprecedented Showcase of Fuel Cell Electric Mobility Technology in France’ 11 October 2011, on http://www.intelligent-energy.com/news_events_and_press/news/94/

27 The fibres are given a nano-scale porosity through the use of a technique Cella calls coaxial electrospinning or electrospraying. Cella Energy, ‘Our technology’, on http://www.cellaenergy.com/index.php?page=technology

4. Airport passenger flow and security

For the period 2010–2030, Boeing forecasts an annual rise of 4.2 per cent in the number of passengers using aeroplanes. In Britain, the Department for Transport projects that the number of passengers using Britain's airports will grow from 372 million in 2008 to 540 million in 2050.[28]

With this kind of expansion, machines that automate security checks on airport passengers will be much in demand. Yet Britain's record with iris recognition at airports has not been an entirely happy one – and international business travellers may mark the country down as a consequence.[29]

Perhaps the biometric technologies pioneered by Human Recognition Systems, Liverpool, and AOptix Technologies, California, point a way forward. Installed at Gatwick Airport, HRS's MFlow Track system quickly, and without much intrusion, captures irises and faces at a distance of about a metre, going on to match them to other forms of identification – typically, boarding passes. It speeds passage through airport security checkpoints, even if it doesn't claim to be a substitute for passport control. Another system at Gatwick, MFlow Journey, employs passive face recognition to track people flow at identified areas, and displays queue times so that passengers can choose the fastest-moving lane.[30]

Systems for allowing secure movement through buildings could well find outlets beyond airports. But if they were to grow too ubiquitous, the risk is that they become something of a signal of society's fears. Security is good; but an atmosphere permeated by security systems won't necessarily make people feel safer.[31]

5. Machines that work under the sea

After the 2010 *Deepwater Horizon* disaster in the Gulf of Mexico, the world woke up to the use of undersea robots to track and staunch the escape of oil. In fact, submarine robotics has a future more noble still.

The Earth's surface is mostly covered by water, but the planet's seabeds have yet fully to be exploited. In 110km off Rio de Janeiro, Brazil, FMC Technologies, Houston, will provide the oil company Petrobras with a 'subsea separation module' that will segregate heavy oil, gas, sand and water… at a depth of up to 900m. Petrobras says that it hopes to have marine oil extraction done without oil platforms by 2020, using undersea machines and robots, some automatic, some controlled from the surface.[32]

Britain's experience in pumping CO_2 in North Sea oil and gas operations may come in handy if keeping the gas undersea becomes a fruitful part of carbon capture and storage (CCS) around coal-fired power stations. But oil, gas and CO_2 storage by no means exhaust the potential of the seabed. There, metal sulphides – copper, zinc, silver, gold – have already attracted the interest of China, Russia, India and South Korea. And on top of that, the range of species now being found on the seabed is enormous. Already, pharmaceutical companies have begun experimenting with sea cucumbers, in pursuit of drugs for treating cancer.[33]

Britain has capabilities around the seabed mining. Headquartered near Newcastle, SMD began design and manufacture of seabed ploughs in the 1970s. SMD's Quantum is the company's latest remote operated vehicle for construction and survey work. With a total hydraulic power of more than 170kW, it can dig trenches in strong currents, to a depth of 3000 metres of seawater.[34]

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28 Boeing, 'Current Market Outlook 2011-2030', on http://www.boeing.com/commercial/cmo/; David Millward, 'Local airports "to double their capacity in next 40 years"', *The Daily Telegraph*, 26 November 2011, p14

29 Helen Warrell and Rose Jacobs, 'Airport iris-scanning system is scaled back', *Financial Times*, 15 November 2011

30 HRS, 'World first as Gatwick invests in pioneering biometric technology', 19 October 2011, on http://www.hrsid.com/press-releases/mflow/70-World-first-as-Gatwick-invests-in-pioneering-biometric-technology

31 On the general phenomenon of giving in to the terrorist agenda, see Frank Furedi, *Invitation to Terror: the Expanding Empire of the Unknown*, Continuum International Publishing Group, 2007

32 'Marlim Oil Field, Brazil', offshore-technology.com, on http://www.offshore-technology.com/projects/marlimpetro/; Robin Yapp, 'Brazil to replace oil rigs with "underwater cities"', *Daily Telegraph*, 29 December 2010, on http://www.telegraph.co.uk/finance/newsbysector/energy/oilandgas/8228548/Brazil-to-replace-oil-rigs-with-underwater-cities.html

33 'Suddenly, a wider world below the waterline', *The Economist*, 14 May 2009, on http://www.economist.com/node/13649265

34 Quantum specification, on http://www.smd.co.uk/download.php?file=/page/123_119_10.pdf

Environmental organisations, however, will no doubt protest man's further exploitation of the seabed, because of the danger of pollution, and also because of perceived or real threats to biodiversity. On the other hand, claims on the seabed by competing countries are multiplying. There is no need to talk up the prospect of 'resource wars'. **But the chances are that, as undersea technologies for exploration, mining and harvesting grow more sophisticated, so too will the controversy, diplomacy, litigation and insurance that surround them.**

6. Conclusion

As we have said, the five technological domains considered above do not exhaust all those that will prove important in years to come. One could take, for example, 3D printing, even if some of the claims made for its future may turn out a little extravagant.[35] Nevertheless, nanomaterials for food packaging, miniaturised electronics and clever automotive systems each have a vibrant future. So, too, do the smoothing and securing of large-scale flows of people around airports and elsewhere, and the excavation of the seabed.

On the whole, Britain's commercial and state interest in the technologies of the future is not all that it could be. The Government's commitment to put £50m behind research into industrial applications of graphene – two-dimensional lattices of carbon – is creditable enough; yet if we compare this sum, or those fielded by private investors in R&D, with those routinely spent in banking or insurance, the sense of a real commitment to technology is missing.

> *"...as we suggested in our discussion of sensors and displays in relation to disasters and to personal health, technology itself can often be developed to mitigate risk."*

With every new technology, beginning with fire, there are risks attached. However, as we suggested in our discussion of sensors and displays in relation to disasters and to personal health, technology itself can often be developed to mitigate risk. The use of fire, after all, also let to the fire extinguisher, the fire engine, the fire blanket and the fire escape.

Were Britain not to get more serious about the domains we have described, a huge risk might well be encountered. Food, electronics and travel are already vital to the economy, and the seas around this island form a key asset. Not to fund technological advance in these domains could reduce the UK to competitive insignificance.

35 For an enthusiastic appraisal of 3D printing, see Peter Marsh, 'Production processes: A lightbulb moment', *Financial Times*, 28 December 2011, on http://www.ft.com/cms/s/0/b59678b4-313b-11e1-a62a-00144feabdc0.html#axzz1i1lqRUYA

Failures in Ultra Large Scale Complex Systems

Professor Dave Cliff, University of Bristol, Director, UK Large-Scale Complex IT Systems Research & Training Initiative

Summary

Advances in information and communications technology (ITC) in the past two decades have radically altered the nature and scale of risks associated with failures in technological systems. Previously independent engineered systems are increasingly being connected together to form super-systems known as systems-of-systems. Unanticipated interactions between components in complex networked systems can cause domino-effect chain reactions to ripple out causing "cascade failure" or "contagious collapse". Such events are typically very rare, but very serious when they do occur. In current and future networked systems-of-systems, the scale of the networks can be truly vast, the failures can propagate faster than humans are comfortably able to deal with, and the magnitude of the risks (the potential scale of losses that such cascade failures can cause) can be huge. The reality of this situation is illustrated here with a specific example: the unprecedented gyrations in the US financial markets on the afternoon of May 6th, 2010, a series of events that came dangerously close to causing a global meltdown of the world's financial markets. If appropriate action is not taken by governments, societies, and industry practitioners, national-scale and international-scale contagious collapses of key large-scale complex technological systems could in future pose a significant risk. Systems-of-systems are increasingly critical to maintaining the socioeconomic wellbeing of extremely large numbers of people. The implications of cascade failure in socioeconomically critical systems are bleak.

Introduction

As the CII celebrates its centenary, looking back over the past 100 years it is clear that a major change has occurred in the past decade or so in almost all functions of advanced economies: information management, transaction-processing, accounting, and record-keeping systems that were previously paper-based are now increasingly migrating to wholly electronic systems where data is digitised at the point of generation, and thereafter all information is stored and transmitted in electronic form. The explosive growth of the internet and the world-wide web around the turn of the millennium, and the current shift toward remotely-accessed "cloud computing" systems, means that any computer can talk to any other, and the physical position of a data store is now often of little or no relevance: the data is "in the cloud", accessible from anywhere with a decent internet connection.

> *"Increasingly, automated processing of data, and automatic selection and execution of appropriate actions, is being trusted to computers; and the human workers who previously performed those roles are expected to find work elsewhere."*

failures in ultra large-scale complex Systems

Furthermore, the ongoing exponential falls in the real costs of computing and communications hardware mean that the computers that store and move data around can increasingly be called upon to analyse the data and act upon the results of the analysis. Computer systems are capable of analysing vastly more data than a human head can hold, and can do so on split-second timescales. Increasingly, automated processing of data, and automatic selection and execution of appropriate actions, is being trusted to computers; and the human workers who previously performed those roles are expected to find work elsewhere. Moreover, just as a human worker could improve over time as her experience grew, so current computer systems are increasingly able to adapt and learn from their experience.

> *"Ultra large scale systems represent major challenges to the engineers responsible for the construction and ongoing maintenance of the constituent systems, and they also present major challenges to anyone concerned with the measurement and control of risk."*

These technology developments mean that networks connecting adaptive computer systems, each performing jobs that were previously done by skilled humans, will become ever more prominent in 21st Century life. Increasingly, systems will be composed of networks where the nodes, the components in the network, are themselves each stand-alone systems that were designed and constructed with little or no foreknowledge of the other systems that they would subsequently be connected to. Networked systems composed of interacting but otherwise independent systems are known technically as systems-of-systems (SoS). Typically, each of the constituent systems in a SoS consists not only of technology components but also of the people, and groups or teams or firms composed of people, that interact with the technology – for this reason, the systems that are linked in a SoS are referred to as socio-technical systems, as then is the SoS itself. Geographically distributed socio-technical systems-of-systems where the nodes in the network of systems are themselves heavily dependent on computer technology are known as large-scale software-intensive socio-technical systems-of-systems. Because this is quite a long phrase, and its acronym LSSISTSoS isn't particularly elegant either, as an alternative many practitioners now refer to such systems simply as ultra large scale or ULS systems. ULS systems represent major challenges to the engineers responsible for the construction and ongoing maintenance of the constituent systems, and they also present major challenges to anyone concerned with the measurement and control of risk in the SoS as a whole (i.e., systemic risk).

That ULS systems pose major challenges, and that traditional engineering practice is not at all well developed to meet those challenges, was first recognised in defence and aerospace circles, but it is now clear that as computer systems in all aspects of modern life are connected together via global telecommunications networks, so ULS issues and problems are starting to be felt in other domains such as international financial markets, national-scale health and social care systems, and national- and international-scale provisioning of vital utilities such as electrical power, water and sewage, and transport infrastructure.

A primary concern in ULS is the occurrence of mathematically nonlinear interactions between the constituent entities: the constituents may have nonlinearities in their responses, or in their interactions with one another, that compound across the entire system in such a way that it is difficult or even impossible to accurately predict the system-level behaviour even if you have perfect knowledge of all the nonlinearities in the constituents and their interactions: this is a long-winded way of saying that the ULS system may be a complex system, exhibiting emergent behaviour.

One of the most worrying types of emergent behaviour (i.e., of system-level dynamics that are difficult or impossible to predict from reductive analysis of the individual constituents) is cascade failure. It may be that the system is stable if component A fails, and is also stable if component B fails, but if components A and B fail at the same time then the combined effects of the simultaneous failure cause components C and D and E to fail, which in turn cause failures in components F and G and H and I and J, and so on, until a large proportion of the entire system, possibly all of it, collapses into failure. In such circumstances, the failure has cascaded over the entire system; the manifest similarity between this and the spread of contagious disease in populations of organisms means that such sequences of events are also known as contagious collapse.

> *"Probably the best-known examples of cascade failures are those that have occurred in the electrical power transmission networks of various countries. 2003 was a vintage year for such problems, with cascades causing major power blackouts across Ontario, Canada and a number of north eastern states of the USA on one afternoon in August; in large areas of south London and surrounding counties one evening a couple of weeks later; and then in most of Italy and part of Switzerland one night in September. The biggest such blackout so far (measured by number of people affected) left around 100 million people in Java and Bali without power for six and a half hours in August 2005."*

Thus far, major cascade failures in socioeconomically critical ULS systems have been avoided. Nevertheless, there is one notable event in the recent past where a contagious collapse in a worldwide ULS systems was avoided by sheer lucky timing: on the afternoon of May 6th, 2010, the world's financial markets came dangerously close to global meltdown, in a sequence of events that is now widely known as the "Flash Crash". This is an event described and discussed at length by Cliff & Northrop:[36]

"On that day, in a period lasting roughly 30 minutes from approximately 2:30pm to 3:00pm EST, the US equity markets underwent an extraordinary upheaval: a sudden catastrophic collapse followed by an equally unprecedented meteoric rise. In the space of only a few minutes, the Dow Jones Industrial Average dropped by over 600 points, its biggest ever intra-day loss of points, representing the disappearance of more than 850 billion dollars of market value. In the course of this sudden downturn, the share-prices of several blue-chip multinational companies went haywire, with shares in companies that had previously been trading at a few tens of dollars plummeting to $0.01 in some instances, and rocketing to values of $100,000 in others."

"Then as suddenly as this downturn occurred, it reversed, and over the course of another few minutes most of the 600-point loss in the Dow was recovered, and share prices returned to levels within a few percentage points of the values they had held before the crash. That recovery, which took less than twenty minutes, was the largest one-day gain in the Dow's history." (Cliff & Northrop, 2011)

36 D. Cliff & L. Northrop (2011) "The Global Financial Markets: An Ultra Large Scale Systems Perspective", Briefing paper for UK Government Office for Science Foresight project on The Future of Computer Trading in the Financial Markets. http://tinyurl.com/3vwkh6a

While many human traders operate in the current financial markets, it is also the case that very many trades are made by autonomous adaptive computer systems, known as algorithmic trading systems or less formally as robot traders. Various analyses of the market events on May 6th, 2010 implicated robot trading systems as being at least partly responsible for the great speed at which the swings in prices occurred. That afternoon's events prompted the US Commodities and Futures Trading Commission (CFTC) and the US Securities and Exchange Commission (SEC) to work together on a joint inquiry into what had happened. The inquiry's final report was released on September 30th, 2010.[37] Cliff & Northrop go on to explain why the Flash Crash is such a concern:

"...[T]he Flash Crash could have occurred any time that day. Certainly the specific time-period during which the Flash Crash occurred, roughly 2:30pm to 3:00pm, was not cited as a causal factor in the official CFTC/SEC report on the events of May 6th, nor in the much more detailed analysis performed by Nanex Corp. ... we think that in fact the much, much bigger worry is... what would have happened if it had occurred a couple of hours or so later that day. Specifically, we think that the true nightmare scenario would have been if the crash's 600-point down-spike, the trillion-dollar write-off, had occurred immediately before market close: that is, if the markets had closed just after the steep drop, before the equally fast recovery had a chance to start. Faced with New York showing its biggest ever one-day drop in the final 15 minutes before close of business on May 6th, and in the absence of any plausible public-domain reason for that happening, combined with the growing nervousness that the Greek government would default on its sovereign debt and throw the entire Euro-zone economic union into chaos, traders in Tokyo would have had only one rational reaction: sell. The likelihood is that Tokyo would have seen one of its biggest ever one-day losses. Following this, as the mainland European bourses and the London markets opened on the morning of May 7th, seeing the unprecedented sell-offs that had afflicted first New York and then Tokyo, European markets would have followed into precipitous freefall. None of this would have been particularly useful in strengthening confidence in the Greek debt crisis or the future of the Euro, either. And, as far as we can tell, the only reason that this sequence of events was not triggered was down to mere lucky timing. Put simply, on the afternoon of May 6th, 2010, the world's financial system dodged a bullet." (Cliff & Northrop, 2011).

Although the Flash Crash was a particularly extreme event, similar negative events have been witnessed in other major markets in the period since May, 2010. Examples include: a sharp down-spike and immediate recovery in the price of gold on May 2nd, 2011; a dramatic crash in the price of silver in after-hours trading on May 3rd, 2011; and a bizarre oscillatory pattern steadily growing in amplitude, followed by a crash, in the price of US natural gas on June 8th, 2011. There is widespread speculation that, in each case, the root cause was either robot traders that had been incorrectly programmed, or unexpected interactions between otherwise benign robot traders – that is, undesirable emergent behaviours in the market.

> *" In essence, normalisation of deviance is a "groupthink" failure of process where potentially disastrous deviant events are ever more tolerated on the implicit assumption that, because they have not yet actually caused a disaster, so their future likelihood of causing a disaster is perceived to be diminished. "*

37 CFTC & SEC (2010) *Findings Regarding the Market Events of May 6th*, 2010. Report of the staffs of the CFTC and SEC to the Joint Advisory Committee on Emerging Regulatory Issues. September 30th, 2010. http://www.sec.gov/news/studies/2010/marketevents-report.pdf

These negative events are now sufficiently frequent that they are starting to fit worryingly well with the notion of normalisation of deviance that the sociologist Diane Vaughan introduced in her groundbreaking analysis of the events leading up to the catastrophic loss of the NASA space shuttle Challenger.[38] Vaughan argued that staff at NASA, and at Morton Thiokol, the company that supplied NASA with the shuttle's solid rocket boosters (SRB), had unthinkingly allowed deviant events (i.e., negative events, such as component failures, that had previously been argued to be avoided at all costs because they could seriously compromise the safety of the shuttle system) to become normalised (i.e., to be seen as routine occurrences).

In essence, normalisation of deviance is a "groupthink" failure of process where potentially disastrous deviant events are ever more tolerated on the implicit assumption that, because they have not yet actually caused a disaster, so their future likelihood of causing a disaster is perceived to be diminished. Failures in the SRB seals had been witnessed many times before the loss of Challenger, and had come to be thought of as an issue for future revision, rather than an immediate threat to the lives of the astronauts. After the subsequent loss of the shuttle Columbia, Vaughan was invited onto the official accident investigation board and shockingly found that once again normalisation of deviance had allowed a serious deviant event (lumps of insulating foam breaking off from the shuttle's SRBs and external fuel tank and striking the heat-insulating tiles on the shuttle's underside, damaging them) to be seen as a normalised, routine maintenance issue.

There is nothing in Vaughan's analysis of the events at NASA that is specific to the shuttle program or the aerospace industry in general: normalisation of deviance is a malign process that can, in principle, occur in any organisation or group of organisations.

And so a question that seems to be particularly pertinent for the next few years, and indeed for the next few decades, is this: to what extent is normalisation of deviance occurring in the management and maintenance of socio-economically critical ULS systems? Events in the financial markets on the day of the Flash Crash, and other strange movements since then, seem obviously to be deviant and yet the more they occur without triggering a catastrophic cascade failure or contagious collapse, the more such events are tolerated, and so these deviant events become normalised.

And, as was made clear above, the financial markets are not the only large-scale complex software-intensive socio-technical systems-of-systems that modern economies have grown to be critically dependent upon: we've concentrated on financial markets here simply because the Flash Crash and the other deviant events that have occurred in the markets since then serve as a forceful illustration of a more general point.

> *"While a noninterventionist argument has certain appeals, it seems less plausible when applied to national or international ULS systems – failures in ultra large scale systems can easily have ultra large scale consequences, possibly constituting existential threats to entire nations."*

38 D. Vaughan (1997) The Challenger Launch Decision: Risky Technology, Culture, and Deviance at NASA. University of Chicago Press

What can be done? Some argue for a laissez-faire approach that borders on the Darwinian: failures will always occur, in general there will be many small failures and the occasional very big one, and this acts as a selection pressure in the survival-of-the fittest world that is modern commerce. Put bluntly, the argument is that stuff happens and we just need to learn to deal with it, to live with it, when it does. While such a noninterventionist argument has certain appeals, it seems less plausible when applied to national or international ULS systems – failures in ultra large scale systems can easily have ultra large scale consequences, possibly constituting existential threats to entire nations. Taking a "stuff happens" approach to the collapse of national health and social care systems, or to international financial markets, seems recklessly incautious.

Instead, perhaps lessons can be learned from long-established industries and professions where the consequences of failure are so high that the avoidance and mitigation of failures is deeply woven into the practice. Studies of what are known technically as high-reliability organisations (HROs) such as surgical teams, firefighter crews, and aircraft-carrier flight-deck management, have revealed a core set of common values and approaches that mark out successful HROs.[39] These include a no-blame approach to dealing with deviant events, and conducting post-event analyses of all operations or procedures, including the large number of routinely successful ones, to identify what might have gone wrong, and whether things could be improved, even though nothing went wrong.

Valuable lessons might also be learnt from practices in nuclear power engineering, where practitioners have had to develop advanced methods for quantifying and analysing risks in complex engineered systems, as an act of self-preservation in the face of what very often threatens to be potentially overwhelming popular and political opposition to nuclear projects. In particular, nuclear engineers have developed a sophisticated set of tools known as probabilistic risk assessment (PRA) initially based on traditional frequentist statistics and more recently extended to employ modern Bayesian approaches.[40] Applying PRA to modern ULS systems would probably require extension of the state-of-the-art techniques, but such an investment of effort should pay significant rewards in the longer term.

> *"The worry is that, in the absence of a major failure that scares the public and politicians into action, nothing will be done. If that is the case, normalization of deviance seems likely to deliver us a catastrophe eventually; we need only wait."*

Efforts such as the encouragement of adoption of HRO approaches, and/or the development of PRA methods applicable to ULS systems, are only likely to be of any value if they can be done in an appropriate political and regulatory climate. Public concerns at losses of spaceships or aircraft and worries about nuclear accidents quickly found political support and so appropriate regulations and requirements were set in place to govern risky engineering endeavours such as new aerospace or nuclear projects. Similarly, it will probably be necessary for sizeable amounts of political capital to be expended on the introduction of regulations for ULS systems engineering. The worry is that, in the absence of a major failure that scares the public and politicians into action, nothing will be done. If that is the case, normalisation of deviance seems likely to deliver us a catastrophe eventually; we need only wait.

39 See, e.g. K. Weick & K. Sutcliffe (2007) Managing the Unexpected, 2nd edition, Jossey Bass

40 See, e.g. M. Stamatelatos et al. (2002a) *Probabilistic Risk Assessment Procedures Guide for NASA Managers and Practitioners*. www.hq.nasa.gov/office/codeq/doctree/praguide.pdf; H. Dezfuli, et al. (2009) Bayesian Inference for NASA Probabilistic Risk and Reliability Analysis. NASA SP-2009-569: http://www.hq.nasa.gov/office/codeq/doctree/SP2009569.pdf; & D. Hubbard (2009) *The Failure of Risk Management. Why It's Broken and How to Fix It.* John Wiley

Fooled by lack of randomness

Dr Peter Taylor – Research Fellow at Oxford University and risk specialist

This contribution reflects on how well we deal with uncertainty. The principal argument is that our drive for simplification can mask underlying uncertainty and mislead us into thinking we know something when we don't – we become "fooled by lack of randomness". We will explore how this can come about, and reflect on implications for policymakers in general, and on the capital adequacy of insurance companies as a particular illustration.

The Uncertain Century

We have long sought to understand the world by breaking it down into incontrovertible facts and then building it back up again in order to understand and make things. We have sent men to the moon, built cars that park themselves, even engineered our own DNA. But as we moved into the 21st Century, it became clear that a "reductionist" approach didn't adequately explain the complexities of the world. Old certainties have morphed into new uncertainties. John Kay puts it starkly:

> *"It is hard to overstate the damage done in the recent past by people who thought they knew more about the world than they really did.[41]"*

Kay is but one of a wave of authors since the turn of the century who has taken our hubris to task. In *Useless Arithmetic*, Orin and Linda Pilkey[42] examine models which were used to support the interests of businessmen and politicians rather than adequately represent reality, with disastrous consequences in areas such as fishing and mining; in *The Future of Everything*, David Orrell[43] challenges whether we can in general make meaningful predictions about real-life systems, notably climate and genetics; Denis Noble's *The Music of Life*[44] disputes the central dogma of biology that what we are is solely a consequence of our genetic make-up, and in *Complex Systems and the Origin of Wealth*, Eric Beinhocker[45] debunks the certainties of classical economics in favour of an evolutionary model.

One author who has tapped into this zeitgeist of the new century is Nicholas Nassim Taleb. In *The Black Swan*[46], Taleb challenges our view that the world is a game of chance with known outcomes like roulette and argues instead that we should learn to expect the unexpected. In his earlier book *Fooled by Randomness*[47] he argued that selection ("survivor") bias can falsely associate success with certain attributes – for example, that a particular investment strategy was the reason that someone became a millionaire when in reality they benefitted from a boom and some lucky breaks.

The best-seller lists show we prefer narratives which offer lists of qualities as the keys to success rather than pure luck, yet businesses built on these principles and lauded in one era fail rapidly in another.[48] How we deal with uncertainties is where "fooled by *lack* of randomness" comes into play – if our models suppress randomness in favour of finding a simple explanation. The regularity, precision and seeming accuracy of the outputs from models – especially when produced by computers which lend an apparent objectivity to the results – can lead to false beliefs which can, in turn, justify inappropriate actions and policies. One recent example is where computer models for rating and correlating financial instruments based on subprime mortgages promoted a massive bubble of debt. Another example is using average damage factors to estimate the loss to properties in the event of a windstorm such as a repeat of Hurricane Andrew. And after Hurricane Andrew in 1992, many underwriters indeed set their

41 Kay J (2010) *Obliquity*, Profile Books
42 Pilkey O and Pilkey-Jones L (2006) *Useless Arithmetic*, Columbia University Press
43 Orrell D (2008) *The Future of Everything: The Science of Prediction*, Basic Books
44 Noble D (2008) *The Music of Life: Biology Beyond Genes*, OUP
45 Beinhocker E D (2005) *Complex Systems and The Origin of Wealth,* rh business books
46 Taleb N N (2007) *The Black Swan*, Random House
47 Taleb N N (2006) *Fooled by Randomness*, Penguin
48 See for example, Ormerod P (2006) *Why Most Things Fail: And How to Fix It*, Faber and Faber

excesses to the average in just such a way so that their models showed low exposure to hurricane loss. In the real world, of course, some properties are damaged more and some less than the average, so underwriters can actually experience very large losses. Statistics, too, can mislead when calamities are infrequent. In the LMX (London Market eXcess of loss) spiral of the 1980s that brought Lloyd's to its knees, it was possible to quote excellent historical claims statistics to argue there was little or no risk to a high excess of loss layer whereas in reality, the variability was there, it just hadn't occurred in recent history. The perception of an apparently risk-free premium meant, as with the mortgage debt bubbles in the 1990s and again in the 2000s, more trades were created which amplified the degree of systemic risk.

Representing Randomness

By "randomness" we mean one of two types of uncertainty – the first (*aleatory*) due to intrinsic chance of an outcome that hasn't happened, such as the chance of heads before a coin is tossed, and the second (*epistemic*) due to lack of knowledge, such as the chance of heads after the coin has been tossed but the outcome is not yet known.

Also problematic in the real world, as opposed to the simplicity of games of chance, is *Knightian* uncertainty about outcomes that we don't know. Keynes described it as follows:

> *"By "uncertain" knowledge, let me explain, I do not mean merely to distinguish what is known for certain from what is only probable. The game of roulette is not subject, in this sense, to uncertainty: nor is the prospect of a victory bond being drawn. ...Even the weather is only moderately uncertain. The sense in which I am using the term is that in which the prospect of a European war is uncertain, or the price of copper and the rate of interest twenty years hence, or the obsolescence of a new invention, or the position of private wealth-owners in the social system in 1970. About these matters there is no scientific basis on which to form any calculable probability whatever. We simply do not know.*[49]"

All three types of uncertainty can be illustrated by imagining placing 80 red balls and 20 white balls into a bag, and shaking the bag. The (aleatory) chance of a red ball before we pick is 80%, the (epistemic) chance of a red ball when we have picked one out but not yet looked at it is still 80%. The further (Knightian) uncertainty would come in if, for example, the ball when revealed turned out to be coloured blue! Had we known that the red colour on the balls was due to a litmus dye, and that the bag had been used to store lime, then it would not have surprised us that the ball went in red and came out blue. That this was the case, though, was not known, nor was the prospect of a blue ball appearing at all. Once such outcomes and scenarios can be conceived, they can be built into the model. Yet this is but one of many scenarios that could have been conjectured for one of many potential different outcomes.

How do we deal with this unforeseeable type of uncertainty – the "unknown unknowns" or "black swans"? Perhaps one could construct a family of models and give each model its own credence and in this way "fuse" them to create a super-model? But where does one draw the line? We are chasing an impossible dream and have at some point to "take a view" (or "view of views" or ...). When this is done it still comes down to a set of outcomes and numeric chances of each outcome which add up to 100%. To cope with any residual Knightian uncertainty one can then add a "catchall" outcome. Thus we can establish a way of dealing with uncertainty that comes down to probabilities and statistics.

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49 Keynes JM (1937) *The General Theory of Employment* Quarterly Journal of Economics, vol. 51 pp. 212–14

Ways we can be Fooled by Lack of Randomness

Let's now try to characterise the cant, diagnose the duff, and flush out the false gods that understate uncertainty. Not that long ago we had but rules of thumb with which to estimate risks and assess the consequences of policy decisions. Computers, with their ever more extensive data and powerful programmes, now provide a virtual world where we can explore from the comfort of our own desktops a wide range of scenarios and assumptions. Whether designing a new bridge, assessing the state of the environment, predicting the return on financial instruments, or determining characteristics from our genetic make-up, we have better information and tools than ever. What could possibly upset our Panglossian confidence? Tad Montross of GenRe answered it bluntly for us when denouncing "model madness" in financial markets:

> *"Understanding the models, particularly their limitations and sensitivity to assumptions, is the new task we face. Many of the banking and financial institution problems and failures of the past decade can be directly tied to model failure or overly optimistic judgments in the setting of assumptions or the parameterisation of a model.[50]"*

Commentaries on the 2008 financial crisis in Gillian Tett's *Fool's Gold*[51] and Michael Lewis's *The Big Short*[52] show how the investment banking industry was able to delude and collude in a massive Ponzi scheme. Whilst such occurrences are hardly new, as recounted in *This Time is Different* by Reinhart and Rogoff[53], modern computers and telecommunications have amplified rather than moderated our recklessness. If there's money to be made while passing round an ever-hotter potato ever faster, then people will use whatever arguments they can find to justify continuing with the game, and computer models are their ideal cohorts.

Reflecting on recent events, here are four characterisations of flawed thinking that led us to be "fooled by lack of randomness":

1. **Fooled by Averages** akin to the advice to someone wanting to wade through a river that its average depth is 4 feet when in practice the middle is 10 feet deep. As mentioned above, averages were instrumental in escalating the subprime fiasco[54], where Rating Agencies used the average not the distribution of good and bad underlying risks to rate securities. A few quality underlying loans were able to make the rest seem acceptable through the average when in reality the bulk of the loans were very poor risks. Averages are seductive to those wishing for a single number as an answer, but an average does not express the chance of extreme behaviour and can thereby mislead us as to the chance and severity of the downside.

2. **Fooled by Correlation.** Many things typically happen at once in the real world. In understanding all of these moving parts, isn't it the "Occam's razor" view to assume they are all independent? Unfortunately, that's usually the worst assumption that can be made as it means one thing going bad won't affect another, or a common cause might not affect both together. Yet again this is what happened in the financial crisis of 2008 as the (now obviously) erroneous assumption was made that defaults on mortgage payments were independent by region. The error was compounded by banks estimating their portfolio diversification (that is reduction of risk from independent randomness) using a simple correlation tool called the "Gaussian Copula"[55] to price Collateralised Debt Obligations, and compounded further when the Rating Agencies adopted the same tool. Double oops.

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50 Montross F (2010) *Model Madness*, GenRe

51 Tett G (2009) Fool's Gold: *How Unrestrained Greed Corrupted a Dream, Shattered Global Markets and Unleashed a Catastrophe*, Little Brown

52 Lewis M (2010) *The Big Short*, Allen Lane

53 Reinhart & Rogoff (2009) *This Time Is Different: Eight Centuries of Financial Folly*, Princeton University Press

54 See Lewis (2010)

55 See Salmon F (2009) Recipe for Disaster: *The Formula That Killed Wall Street*, Wired Magazine 17.03 (23rd February 2009)

3. **Fooled by History.** This is when we under/overestimate risk as a result of relying on limited historical evidence. A narrow view of history, for example, might lull us into a false sense of security by showing little evidence of correlation between the moving parts, or no occurrence of significant losses or large failures. We saw this, for example, in the LMX Spiral example mentioned previously and also with the 2011 Tohoku earthquake where:

> *Thus, the short seismological record (the seismometer was invented in the 1880s) misled seismologists into assuming that the largest earthquakes known on a particular subduction zone were the largest that would happen.*[56]

4. **Fooled by Convenience** in choice of probability distributions – the issue here is the "technical" matter of using simple functions for computational ease and tractability, rather than those justified by or appropriate to the problem in hand. A common error is to use a simple function such as the "bell curve" Gaussian probability distribution, with its symmetric single peak and rapid tail-off, rather than the less convenient skewed, fat-tailed, multi-peaked distribution. These technical quibbles can make all the difference to the calculated numbers, as they did with the "Gaussian Copula" mentioned previously, and it is the extremes that cause businesses, governments and societies to collapse.

Turning now to some of the implications of a fuller treatment of uncertainty, let us look at how it affects the general issue of policymaking and, as a particular illustration, the capital requirements of insurance companies.

Policymakers prefer simple explanations and are generally uncomfortable with uncertainty. What is the point of all this science, after all, if not to provide precision? What, though, if it is in the nature of things that facts and predictions are unavoidably fuzzy? How can you ever make policy? Which politician can afford to take even a small chance of a well-publicised bad outcome? And it turns out that in many cases the evidence is equivocal, the knowledge uncertain, and the predictions dubious. If the uncertainty can't be removed, then it's futile to rail against the lack of precision. 'Twas ever so' – we have to make decisions with imperfect information. The rational answer is to ensure the uncertainties are brought out and not disguised by wish-fulfilment or vested interests.

In line with the concern over capital adequacy in banks, new "Solvency II" regulations are being implemented in the insurance industry in the EU in 2014. The core principle in Solvency II is that insurers must have sufficient funds to remain solvent for 199 years out of 200 (or to have a 99.5% chance of being solvent in any one year). This is called a "1 in 200 Annual Value at Risk" criterion. To determine that the liabilities of an insurer fall within this criterion has meant the adoption of probabilistic models – catastrophe loss models and Monte Carlo "Dynamic Financial Analysis" models. All good so far? Well, not quite, because the key issue is choice of model and, in particular, whether other assumptions or other models would give commensurate estimates of capital required. The issue is model risk (the risk that the model incorrectly describes reality), yet regulators still fight shy of requiring estimates of the model risk. If they get it wrong, as the regulators did under Basel II for the Banks by allowing fundamentally flawed models, then insurers will be undercapitalised. Conversely, the models might err the other way, too, and the criterion become uncommercial and insurance too capital intensive and thereby too expensive as a business. It's a difficult wire to walk, but at the most basic level, key to traversing it successfully will be to avoid being "fooled by lack of randomness".

Acknowledgements

A big thank you to Annie Milan, and especially Ian Nicol, for their incisive comments and suggestions.

56 Stein S and Okal E (2011) *The size of the 2011 Tohoku earthquake need not have been a surprise*, Eos, Vol. 92, No. 27, 5 July 2011

The three scenarios

In the previous section, a number of pre-eminent authors identified significant and interrelated technological risks and opportunities, which could have severe implications for long-term wellbeing and prosperity. By pulling together some of their key conclusions, it is possible to outline a few simple, technological futures facing the world.

Before setting out these narratives a few words of caution are necessary. There are a number of assumptions that underpin the following scenarios which, if changed, would dramatically affect the outcomes of our imagined worlds. One core assumption is that technological development is, broadly speaking, a "good thing" because it helps boost economic growth, increase human wellbeing and extend lives.

Those who lived through the First and Second World Wars may not agree with this statement. Technological progress made possible the development of weapons capable of destroying entire towns and cities. The bombings of Hiroshima and Nagasaki would not have been possible without extraordinary scientific progress made by pioneers like Einstein and Oppenheimer. In this context, scientific and technological progress (if that is the appropriate term) directly led to the deaths of thousands of innocent civilians. It is possible then, that in the future, technological advance creates the conditions for ever more cost effective ways of destroying each other rather than improving and extending lives.

All three scenarios also assume that unfettered technological progress is, in some cases at least, potentially dangerous – risks associated with new technologies must be managed appropriately, we argue, which in some instances, means regulation and/or government oversight. Again, this assumption may not hold in practice – a laissez faire approach may, ultimately, be the most suitable for ensuring a better world. For example, if safety regulations and government oversight was removed from the development of new technologies and from the products and services that spawn from them, the markets in which they operate may naturally weed out the good from the bad. Technological progress may, therefore, be characterised by some failures, but in the long run, we may be better off and progress may be faster than it would otherwise have been.

And finally, it should be noted that the causation implied by our scenarios may also be inaccurate. The number of variables involved and the complex relationships between them are so complex that, for simplicities sake, it is necessary to exclude many possible permutations and interaction effects that could lead to futures completely different to the ones envisaged here. Therefore, rather than being used as concrete forecasts for future planning, these scenarios should instead help guide decision makers into considering how they might react as different possible futures unfold.

Scenario 1

Upside – technological renaissance

In our best case scenario, there is prolonged investment in new technology by government and industry providing a long-term sustainable boost to the global economy. This investment helps to underpin the comparative advantage of countries which, like the UK, have particular capability in high tech industries. Countries with relatively "low-tech" industries also benefit from technological developments – farming, for example, is made increasingly profitable through the use of biotechnology, which helps to grow crops in arid areas.

Whilst reliance on technology increases, and particularly in the area of ICT, this is tempered by an improved understanding of what technology can and cannot do. With respect to large scale IT systems-of-systems, organisations take the risk of "cascade failure" seriously and adopt the zero tolerance to failure approach taken by "high reliability organisations". Governments and regulators also understand the risks posed by reliance on large scale systems and carefully regulate them to ensure that such systems are implemented and maintained with appropriate skill and expertise.

Firms utilise the latest computational modelling software and techniques to estimate the risks facing them and adapt their business models with this in mind. However, risk managers understand the limitations of such modelling and undertake careful, qualitative, horizon scanning to seek out possible "black swan" events. Quantitative modelling, therefore, remains crucial to successful risk assessment but this is complemented by a more wide-ranging approach to understanding risk – supported by firms' executive teams. There is, therefore, a renewed focus on the behavioural and cultural elements so important in underpinning good decision making in firms.[57]

Implications for the insurance industry

Insurers are able to help encourage investment in new technology. By underwriting new technology and the equipment and resources necessary to build and sustain such technology, the industry is able to provide protection in case of failure – an important condition for innovation and the dissemination of technology. And through appropriate pricing strategies, insurers are able to incentivise the right kinds of technology. Much like the industry played a key role in bringing about seat belts in cars and shaping fire safety regulations in buildings, the industry is able to identify the key risks associated with new technologies and provide economic incentives for users to limit their exposure to the downside risks associated with them. This is in part, made possible, by insurers building links with universities and other research centres including through direct investment and sponsorship of research.

57 See Ashby (2011) Back to basics: Rethinking Risk Management and Regulation in a Post-Crisis World, CII Thinkpiece Series, No. 61. In explaining the financial crisis, Ashby notes that risk managers place a significant amount of emphasis on the types of behaviours and social norms which govern decision making in organisations

Insurers remain aware of the possibility of "cascade failure" in large scale IT systems-of-systems and take precautions to raise awareness about their possibility and to protect policyholders in the event of such failures taking place. Working closely with government and the relevant regulatory bodies, insurers become well placed to understand some of the risks associated with large scale systems and impart their wisdom about how to prevent a systemic failure from occurring.

In this context, insurers are also smart users of ICT. They embrace new computational modelling technology to improve core business functions like marketing and underwriting but they are careful not to place too much reliance on the outputs of such modelling processes. Indeed, they make considerable effort to combine this quantitative approach with a consideration of some of the risks and business practices that are more difficult to measure. Insurers, therefore, remain well suited to identifying "black swan" type events, or at least preparing their businesses in such a way that they become better able to survive in extreme circumstances. The industry is, therefore, able to continually strike the right balance between being well capitalised yet cost effective.

Scenario 2

Central – the status quo

In the central scenario, there is some investment in new technology and innovation by government and industry stimulating global economic growth but investment is not as extensive as in our upside scenario. Indeed whilst the UK is still able to demonstrate a comparative advantage in high-tech industry and innovation, there is room for improvement. Similarly, low-tech industries like farming are unable to fully utilise the benefits of new developments like biotechnology to increase reliability and productivity.

As in the upside scenario, reliance on technology will increase, and particularly in ICT but this is not set against significant improvements in levels of understanding and care in the use of that technology. Regarding large scale IT systems, organisations make some provisions to assess the likelihood of systemic failure but do not apply the principles of high reliability organisations. So called “normalisation of deviance” remains a worrying characteristic of this scenario, and this leads to a number of large scale systems failures. Episodes like the Flash Crash lead to sudden falls in confidence, and will, for short periods of time, disrupt the normal functioning of the economy. The situation is compounded by governments failing to put in place proper regulation and oversight in this area.

Firms place increasing reliance on computational modelling to assess risks facing their businesses and adapt their business models accordingly. There are parallels with the decade leading up to the financial crisis, as firms continue to rely too rigidly on inadequate models to determine capital allocation and regulators remain too concerned with compliance rather than understanding the changing nature of risk. In the absence of appropriate horizon scanning and a proper appreciation of the human and social factors influencing business decision making, firms do not manage risk appropriately and the financial system is characterised by occasional crises affecting particular institutions and sometimes threatening the system as a whole.

Implications for the insurance industry

In this scenario, insurers are able to help stimulate some investment in new technology through the underwriting of research and development processes and providing cover for those using new technology. However, with firms and governments less willing to invest in innovation in the first place, insurance can only go so far in stimulating technological progress. Indeed, insurers develop some links to universities and research centres but they rarely directly invest, or sponsor new research.

As in the upside scenario, through appropriate pricing, the industry is able to incentivise improved technology by highlighting particularly risky areas, though because insurers have less stringent links to the latest research and development, their assessment of the risks posed by new technology, products and services is less reliable. Insurers, therefore, sometimes get the pricing of products wrong leading to underwriting losses.

With technology being used less reliably, insurers face increased claims costs. For example, with respect to large scale IT systems, occasional failures cause losses for individuals and businesses affected – and some of these losses will be covered by insurers. Unfortunately, in this central scenario, insurers are less prepared for the “cascade failure” of such systems. Insurers understand some of the risks, but do not take sufficient effort to gain in-depth knowledge of this risk, raise awareness amongst policyholders or press for greater government oversight. Occasional losses emanating from systems failures, therefore, eat into insurers’ capital to a greater extent than in the first scenario.

Insurers are also less smart users of ICT. Whilst they utilise more sophisticated computational modelling techniques, they place too much emphasis on the outputs of such an approach. They, therefore, become less able to identify potential black swan events – such as large scale systems failures – because they become overly dependent on quantifying risk. The industry is, therefore, characterised by being relatively undercapitalised in the “good times” and overcapitalised in the “bad”. Firms, therefore, fail to strike the appropriate balance set out in the first scenario – occasional institutional failure will result.

Scenario 3

Downside – the great reversal

In our worst case scenario, investment in new technology is limited. Few governments or industries are prepared to take the risk and invest in research and development so innovation is restricted. The consequences of this are depressed long-run rates of global economic growth and countries such as the UK are unable to develop their comparative advantage in high-tech industries.

Reliance on existing technology increases – particularly with regards to ICT and this is not tempered by a careful consideration of the limitations of this outdated technology. With respect to large scale IT systems, organisations fail to take the risk of cascade failure seriously – indeed there is significant complacency across those operating such systems as well as amongst those likely to be affected by their failure. Governments do not, therefore, take measures to ensure that large scale systems are carefully regulated and controlled and households and businesses do not think about how to protect themselves in case a cascade failure occurs.

Normalisation of deviance is commonplace, leading to multiple systems failures. Episodes like the Flash Crash will be followed by systems failures in other realms like power stations and airliners. The result is not just a global economic downturn but such events will act to undermine overall confidence in technology related to the damaged industries. There will be calls to abandon certain technologies – like nuclear power for example – where systems failures are likely to cause the most extreme types of catastrophes. A significant slow-down in technological development will lead to global problems with resource allocation which may, in turn, spark geopolitical tension.

In this downside scenario, firms increasingly rely on computational modelling as the basis for making business decisions despite the fact that the software and assumptions driving those models are out of date. Unfortunately, without undertaking sufficient horizon scanning for emerging risks that are largely immeasurable, firms are unable to prepare for "black swan" type events or even see some of the inadequacies of their normal day-to-day business operations.

Implications for the insurance industry

In this scenario, insurers are unable to stimulate increased investment in technology. Given little effort by government or industry (including insurance) in the area of supporting research and development, insurers have few risks related to new technologies to underwrite, which, assuming all else remains equal, results in a fall in premium income. Depressed global economic growth rates stemming from low levels of investment in innovation and technology also affects premium growth across other business lines.

The real problem in the downside scenario though, is not so much the fall in premium income, but a rise in claims stemming from the failures of large scale systems, and the industry being ill equipped to deal with such failures. Insurers are unprepared, failing to fully understand the risks to which they are exposed through their policyholders. Insurers, therefore, fail to build-in this risk when writing products and do not hold enough capital in the event of large losses stemming from systemic failures. Large scale systems failures, therefore, act to undermine the solvency of insurance institutions.

One reason why insurers fail to spot "black swans" like those associated with large scale systems, is because of an overreliance on outdated computational models. By focusing only on what outcomes the model delivers, rather than the assumptions underpinning it, and engaging in wider qualitative horizon scanning, insurers are blind to big potential risks to their capital. In short, a world rigidly relying on outdated technology, without a proper understanding of the limitations of that technology, risks the stability of the insurance industry itself with dire consequences for the rest of society.

Scenarios at a glance

The following table summarises the key features underpinning each scenario.

Upside – technological renaissance		Central – status quo		Downside – the great reversal	
Investment in new technology		**Investment in new technology**		**Investment in new technology**	
Surge in investment led by government and industry.	✔	Surge in investment led by government and industry [yes but not as extensive].	✔	Surge in investment led by government and industry.	✖
Increased use of new technologies to improve business practices.	✔	Increased use of new technologies to improve business practices.	✔	Increased use of new technologies to improve business practices.	✖
Improved understanding of technological risks.	✔	Improved understanding of technological risks. [yes but only up to a point]	✔	Improved understanding of technological risks.	✖
Large Scale IT Systems		**Large Scale IT Systems**		**Large Scale IT Systems**	
Systems are managed with a zero tolerance to failure approach	✔	Systems are managed with a zero tolerance to failure approach.	✖	Systems are managed with a zero tolerance to failure approach.	✖
Enhanced regulation and oversight.	✔	Enhanced regulation and oversight.	✖	Enhanced regulation and oversight.	✖
Risk management		**Risk management**		**Risk management**	
Firms adopt the latest computational models to model risk.	✔	Firms adopt the latest computational models to model risk.	✔	Firms adopt the latest computational models to model risk.	✖
Firms understand the limitations of models.	✔	Firms understand the limitations of models.	✖	Firms understand the limitations of models.	✖
Undertake qualitative, horizon scanning for emerging risks.	✔	Undertake qualitative, horizon scanning for emerging risks.	✖	Undertake qualitative, horizon scanning for emerging risks.	✖
Rigorous approach to risk management supported by senior management team.	✔	Rigorous approach to risk management supported by senior management team.	✖	Rigorous approach to risk management supported by senior management team.	✖
The role of insurers		**The role of insurers**		**The role of insurers**	
A leading player in assessing and advising third parties on their technological risks.	✔	A leading player in assessing and advising third parties on their technological risks.	✔	A leading player in assessing and advising third parties on their technological risks.	✖
Build links with scientific research centres	✔	Build links with scientific research centres. [yes but not as extensive]	✔	Build links with scientific research centres	✖
Embrace new technology to improve underwriting, claims, marketing...	✔	Embrace new technology to improve underwriting, claims, marketing...	✔	Embrace new technology to improve underwriting, claims, marketing...	✖
Deliver appropriate pricing of technological risks.	✔	Deliver appropriate pricing of technological risks.	✖	Deliver appropriate pricing of technological risks.	✖
Work closely with government and relevant regulatory bodies to identify big technological risks.	✔	Work closely with government and relevant regulatory bodies to identify big technological risks.	✖	Work closely with government and relevant regulatory bodies to identify big technological risks.	✖
Take a wide ranging approach to risk management.	✔	Take a wide ranging approach to risk management.	✖	Take a wide ranging approach to risk management.	✖

Conclusion

Our technological future will be a careful balancing act. On the one hand, this report has argued that continuing developments in technology will help spur economic activity, improve wellbeing and underpin longer lives. On the other hand, there are likely to be risks associated with new technology, which will need careful assessment and management. In many ways, continuing innovation will ensure that technology evolves into ever more safe and user-friendly versions of itself. But, complacency can be dangerous, especially if we base core household and business decisions upon technology we do not fully understand. If we get this drastically wrong, failures could lead to a dangerous slow down in innovation and research and development, as mistrust in technology grows. This is the result of our worst case scenario.

How we balance the opportunities and risks afforded by technological change will shape our future and the insurance industry can play a key part in getting this balance right. The industry has a multifaceted role to play. Embracing technology will be important for the industry to improve the way it underwrites risks, processes claims, markets products to consumers and identifies risks to its own solvency. And by acquiring expertise in new technologies as well as research and development processes, the industry will also be well placed to raise awareness amongst the wider general public, whether this is through the appropriate pricing of risk or through collaborative efforts with other industries, sectors and government bodies.

But, growth in technology and expertise in the use of that technology will not be enough to prepare us for some of the “black swans” which could lurk ahead. As Dr Peter Taylor has argued in this report, modelling the future based on data taken from the past will always be fraught with potential pitfalls. Even something relatively simple to model like longevity, has proven challenging in recent times with the International Monetary Fund arguing in early 2012 that most models have consistently underestimated the extent to which populations are growing older.[58] In short, where the risks are difficult to quantify, a deep, qualitative understanding of the world around us, informed by reliable empirical evidence and taking into account competing viewpoints on the same problem is likely to be critical to success. In this respect, technology can only take us so far.

This should not, however, downplay the extent to which technology can make a difference to our lives. Indeed, technology has truly transformed the way in which we live. For a large proportion of the world’s population, how we work, eat, sleep and interact is vastly different today from what it was when the CII was granted its Royal Charter a hundred years ago. But we should not forget that access to technology is far from equally distributed – for some, particularly those living in parts of the developing world, access to a phone line or a television set is rare. And even across the developed world there are some who cannot afford a personal computer with access the internet. Thankfully, progress on this front is gaining momentum. Smart phones, for example, are threatening to level the playing field by providing an affordable way for people to access the internet in locations without phone lines and basic infrastructure, but the fact remains that there are still many who are at an immediate disadvantage because they lack access to technology that others take for granted.

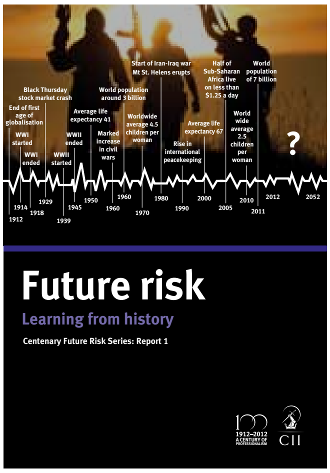
All this underlines the central argument of this report: governments, industries and the societies which they serve must continue to espouse the benefits of innovation and encourage the dissemination of new technology which has the potential to improve lives. But this must not be done without understanding the many risks and limitations of technology and an active approach to ensuring that the benefits are reaped by everyone.

58 IMF (April 2012) “The Financial Impact of Longevity Risk” estimates that on average people live three years longer than expected

Next report in the series

In our next report within the centenary series, we will look at possible demographic futures. Similar to this report, experts will set out diverse and compelling narratives on what the future might hold, and we will seek to build a number of simple scenarios to set out some implications for the insurance and financial services industry.

Previous reports within the Future Risk series

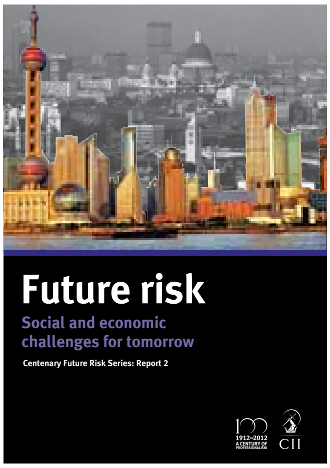


Future risk: learning from history

The first report within our centenary series reflects on past trends and their potential implications for future risk as well as discussing some initial findings from a global survey into the risk perceptions of members of the public from across the globe. It sets out the methodology for the entire series and identifies themes for further investigation.

Report accessible via:

http://www.cii100.com/wp-content/uploads/2012/Future%20risk.pdf



Future risk: social and economic challenges for tomorrow

The second report in the centenary series focuses on some of the big socioeconomic risks identified by the first report. Utilising expert analysis from George Magnus of UBS Bank and David Smith of The Sunday Times amongst others, we outlined three possible socioeconomic scenarios and their potential implications for the insurance industry. We then discussed how the industry can play a key role in determining a better future.

Report accessible via:

http://www.cii.co.uk/knowledge/policy-and-public-affairs/articles/future-risk-social-and-economic/17413

Future risk: Climate change and energy security

The third report in the centenary series focuses on climate change and energy security. World leading experts including the Government's Chief Scientific Adviser, Professor Sir John Beddington, and the International Energy Agency's Chief Economist, Dr Fatih Birol outline what the future might hold. Again we use the expert analysis as the basis for the construction of three scenarios and their implications for the insurance sector.

Report accessible via:

http://www.cii.co.uk/knowledge/policy-and-public-affairs/articles/future-risk-climate-change-and-energy-security-global-challenges-and-implications/19188

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