KEYNOTE SPEECH

CONFERENCE ON EVERYTHING

CHURCHILL COLLEGE, Sat. 5 May 2012

What a wonderful title! And what an honour it is for me to be invited to give the keynote speech.

I have to admit that I did not know about the Churchill MCR's Annual Conference on Everything. This is a splendid idea – I wish I'd thought of it myself.

I thought I would begin by reminiscing a little about our Founder. Winston Churchill died on 24 January 1965. I was in my second year, at Trinity College Oxford, the sister college of Churchill. I remember the television coverage, with the JCR bar crammed full of people, all watching intently, and all trying all too obviously not to cry. The foundation of Churchill College Cambridge was the most visible evidence of Churchill's appreciation of the value of a university education. But Churchill had already shown this throughout his life. He went to Sandhurst, rather than university. But in his years as a subaltern in the Army in India, he bombarded his mother with requests for books: he was largely self-taught. Churchill's lifelong awareness of what a university can give was shared by at least two other Prime Ministers who, like him, did not themselves go to university: the Duke of Wellington, Chancellor of Oxford University, and – from another party, and in my lifetime – Jim Callaghan.

I earn my living speaking in public, and am quite used to getting up on my hind legs and doing so. What is unusual for me is to be able to speak in a completely open-ended way. Unlike the earlier speakers today, I am not speaking to a tightly specified theme, but find myself more in the position of the speaker at a graduation ceremony. And, as it happens, the splendid title – Conference on Everything – reminds me powerfully of the last graduation ceremony I attended. My daughter Ruth graduated from Durham in Psychology in 2007, and the graduation address was given by the then Chancellor of the University of Durham, Bill Bryson, author of the famous (and excellent – highly recommended!) book *A Short History of Nearly Everything*. I loved his talk, and when Ruth found herself having her photograph taken next to him outside Durham Cathedral I went up to him and told him, quite sincerely, that I was an academic and that was the best academic address I had ever heard (he purred). He is not just a hard act, but an impossible act, to follow, so I shan't even try. I heard the Bill Bryson take on everything; the best I can do for you is give you the Nick Bingham take on everything.

One more anecdote, before I get going. Some of you will know the film Clockwise, scripted by Michael Frayn and starring John Cleese, as a batty headmaster (of a state school), due improbably to address the Headmasters' Conference (of public schools). After various misadventures, he fails to arrive on time for his speech, and so an impeccably establishment figure is drafted in at short notice to fill the gap. After a brief pause, he says, very deadpan, 'I shall talk about leadership, and charitable status'. Well, I shall talk about everything, in my own way.

I am a mathematician, and like three Fellows of this College – Peter Whittle, who came as the first Professor of Operations Research in 1970, when I had been here a year as a research student; Geoffrey Grimmett, Professor of Mathematical Statistics (the third, after my supervisor the late David Kendall and David Williams); and James Norris – I am a probabilist. Now probability and statistics go together as the two sides of the same coin, the mathematics of randomness. The greatest living statistician is Professor C. R. Rao, and I want to tell you my favourite Rao story, in honour of Churchill having been the first Cambridge college to admit women, in 1972. Rao was speaking at a conference in the University of Sheffield, twenty-odd years ago. I knew he was a great man; I hadn't realised he is a showman at heart. He began by thanking the two conference organisers, both present, and asking them to assist him in one small task. The room was packed, and divided down the middle; each organiser was asked to count hands, one on each side. Rao asked everyone present who had a brother to raise their hand. A forest of hands went up; these were carefully counted, and the totals given to Rao, who wrote them on the board and added them. He then asked everyone present who had a sister to raise their hand. Many hands went up - but it was immediately obvious, to everyone, that *far fewer* hands went up. A collective gasp of astonishment went up, and it was obvious that everyone present was flabbergasted, *except Rao.* He then proceeded to explain this. One needs to know two things. The first we all know. Academic subjects show a strong gender bias. In maths, the sex ratio may be around 50:50 at undergraduate level, but at postgrad level it's maybe 60:40, postdoc maybe 70:30, lecturer maybe 80:20, reader maybe 90:10, and at professorial level it is actually around 95:5 (one could talk about this[1], but I will confine myself here to pointing out that it's even worse in engineering, which my elder son studied – while in psychology, which my daughter studied, women predominate). The second relevant fact I didn't know (despite having fathered two children then and three now). While sperm production is to a first approximation 50:50 between male- and female-producing sperm, so 'which sperm?' is a coin-toss, at couple level things are asymmetric. Some couples are predominantly boy-producing; these are balanced by some couples being predominantly girl-producing. On being told this, I immediately realised that I had seen many examples, as I suspect you have too. The rest you can see coming. This was a distinguished mathematical audience; so, by above, a predominantly male audience. So, the parents were sampled, not from the population of all parents, but predominantly from the population of *male-producing parents*. This is an example of an insidious statistical danger known as *selection bias*.

There is a tail-piece to this. For years, I simply accepted the second fact, but had the wit to ask a doctor friend over a drink once what the reason was. He laughed, and said, 'It's sex, Nick'. We are both fathers (our wives, who are best friends, met in the maternity hospital), so I told him that I was aware that we mammals reproduced sexually, and asked for the mechanism. I should have known: I was aware that vaginal ph varied during the menstrual cycle, and that one of acid or alkali favoured one of boys or girls. In the tone of someone explaining the facts of life to a grown man, he went on to explain that a woman's libido also varied during the cycle, but in different ways for different women .... Obvious enough, really – but only with hindsight – like so many things in science.

The professor of mathematical finance here in Cambridge is Chris Rogers (a very brilliant man, whose PhD I examined back in 1978). His first chair was at Queen Mary College in London, and I went to his inaugural. During this, Chris produced a coup de théatre in the Rao class. He talked about the famous spire at Salisbury Cathedral. Of course, one can go to the point in the centre of the square formed by the main pillars, and look up. One knows what one will see: a perspective effect, as the four pillars appear to get closer together the higher one looks. But, as Chris pointed out, one sees more: all is as expected up to the level of the roof of the nave; above that, one can see the pillars visibly bending inwards. This is actually quite frightening: one

[1] I won't here, as it would take me too far from my main theme

feels very vulnerable, standing beneath several thousand tons of masonry, visibly out of kilter. As Chris continued: the men who designed and built Salisbury Cathedral *didn't know what a force is.*

As I am interested in architecture, I cannot resist at going off on a digression here on the history of architecture. Cambridge is full of beautiful old buildings. These too were designed and built by men who didn't know what a force is. So too were the buildings of ancient Rome (my favourite example being the Pont du Gard near Arles, below which I learned to swim in 1958). The Romans were great pragmatists, and their buildings stand because they were over-engineered: they were built as political statements (about the glory of Rome), and (slave) labour and materials were cheap. Nowadays, whenever there is a high wind, one sees structural damage on the evening news - typically, the roofs of garage forecourts being blown off. And whenever there is a large earthquake, one sees fearful damage – even in advanced countries such as Japan, which have and enforce building regulations. Of course, nowadays, we have structural engineers, who *do* know what a force is, and building regs, and over-engineering just isn't done, because it would be *too expensive* ....

One can split the world into two categories in all sorts of ways, but the way that this is leading up to is between those who know calculus and those who don't. No one can accuse me of being prejudiced against people who don't know calculus: I am married to one, and am the father of two. (My wife is a fellow-academic, but on the social science side; our daughter used me as her secret weapon for her statistics, but this didn't go that far; our younger son is doing Eng Lit. He has inherited his father's literary side, and his Granny's: my mother taught English, and my father taught French - but knew calculus!) I have been teaching maths at university level for 43 years now, and have taught every kind of calculus course. But (until I was asked to do so at City University last year) I had never taught calculus *from scratch.* I knew that I would love the experience (and did). What I didn't realise was that it would make me *a better mathematician.* I can't quite put my finger on how it did (after all, I really do know basic calculus!) - but I know it did. As my first Head of Department (James Taylor) said to me when I was a rookie, there are only two ways to understand anything in mathematics properly – to do research in it, or to teach it. Spot on.

I cannot resist telling two stories from my childhood, both about calculus, and/or, my father. The first is a differential calculus story. When I was perhaps four, my father was driving me perhaps two miles from the farming village where I grew up (Wighill, near Tadcaster, in what was then the West Riding of Yorkshire). I noticed the flickering needle on the dashboard instruments, and asked my father what it was. He replied that it was the speedometer, telling us how fast we were going – which was 30 miles an hour. I replied, "But Dad – we haven't been driving for an hour". He was delighted with this: it showed so clearly that the idea of a derivative/rate of change/velocity is not innate, but acquired.

The second is an integral calculus story. We were driving through Tadcaster, which is famous for its breweries (John Smith's Magnet Ales, Sam Smith's Taddy Ales, etc.) John's had an octagonal stone-faced chimney (which would have fallen on the playground at Tadcaster Grammar School, had it collapsed during my first few years at TGS, on the Leeds Road site); Sam's has an even taller tower, circular and made of brick. At the age of seven or eight, I asked my father how one could make round chimneys out of straight bricks. Again, he was delighted with this: he knew calculus, and saw the point.

As you will know, the ancient Greeks knew the area of a circle (and the volume and surface area of a sphere, etc.) – so they knew calculus, but not by that name, and only *integral* calculus. Every one of us here learned *differential* calculus *first* – and this stems from Newton (of this University – *Principia*, 1687) and Leibniz – from whom we get all our calculus notation, except for the 'dot for velocity, double dot for acceleration', which is Newton. The *Principia* is the most important book in the history of mathematics (and, arguably, science), because it gave us *both* calculus *and* Newton's Laws of Motion. To know what a force is, one has to know what an acceleration is; so one needs to be able to differentiate, *twice*. The ancient Greeks were superb mathematicians. If they had had the derivative, they would have gone on to the second derivative. Armed with that, they might well have discovered Newton's Laws of Motion - *in antiquity*. These triggered the Scientific Revolution. If the Scientific Revolution had happened in antiquity, the world would have been spared the Dark Ages, and technologically we would be two millennia further advanced. In other ways too the ancient Greeks came tantalisingly close. For example, we think of the passage from a geocentric to a heliocentric view as stemming from Copernicus in 1543, but there are clear hints of this in antiquity, in the work of Herakleides and Aristarchus.

One of the lovely things about the history of mathematics, and of science, is that it picks up on our own experience, of learning when young. Our first mathematical experience is learning to count. I can remember learning about tens, hundreds, thousands, millions, billions, trillions etc. , and wondering where this ended. So I asked my mother what the biggest number was. She smiled, and said there wasn't one. For some reason, I not only didn't believe this, I thought it was the kind of thing grown-ups fobbed children off with (why I don't know: when I asked my parents where babies came from, they told me - everyone does nowadays, but they didn't then). I got very cross, and demanded to be told what the biggest number is. My mother smiled again, and said that there wasn't one – there couldn't be, as if there were one could always add one on and get something even bigger. I felt (I am not religious, by the way) as if the Heavens had opened up and God Himself had spoken to me. This was my first experience of mathematical proof. I am a professional mathematician, and have proved a theorem or two in my time, but that remains my most vivid single mathematical experience.

Back to the ancient Greeks. We learn in primary school about primes, and how to factorise a natural number (positive integer) into a product of prime factors. Primes are still fascinating: I had the great pleasure last term of resurrecting the Analytic Number Theory course at Imperial College London, which culminates in the Prime Number Theorem (PNT). The Greeks loved primes too; Euclid proved that there are infinitely many of them. The assertion that one can factor into a product of primes (uniquely to within order) is familiar to us from primary school. The result – the Fundamental Theorem of Arithmetic (FTA) – was first stated and proved by Gauss, the greatest mathematician who ever lived, in his thesis *Disquisitiones arithmeticae* of 1801. It would seem clear that the Greeks "knew this really", even though, being men of their time, they didn't say it. But, Salomon Bochner (1899-1982), a fine mathematician who knew Greek and wrote on the history of mathematics, said firmly that not only did the Greeks not know FTA, they did not have a mathematical notation adequate even to express it! Not knowing Greek, I have to take his word for this.

Back to the primes. If one lists them (or the first so many), one is struck by how higgledy-piggledy they are. They are (in one sense) obviously not random: one can't get much more God-given, or canonical, than the natural numbers in general and the primes in particular. But, PNT (1896) says that the number of primes up to n looks like $n/\log n$ and Landau's extension to this (1900) says that the number of integers up to n with $k+1$ prime factors (with or without multiplicity) looks like $n(\log\log n)^k/(k!\log n)$. If we divide by n (to turn counts into proportions), let k vary and put $\lambda := \log\log n$, this gives us the Poisson distribution with parameter λ. This is the 'signature of randomness', in a discrete setting such as here (the normal or Gaussian distribution with the same mean $\log\log n$, to which it approximates for large n, is the 'signature of randomness' in a continuous setting). This led the late, great Mark Kac (1914-84 – I had lunch with Mark Kac and his wife Kitty, with David Kendall, here in Churchill in 1969) to say that *primes play a game of chance* (Kac's Dictum). The result is the Erdös-Kac central limit theorem of 1939, the "official birth" of the subject of probabilistic number theory. Paul Erdös (1913-96) was famously prolific and had lots of collaborators (he had Erdös number 0; they had Erdös number 1; their collaborators had Erdös number 2, etc.; I have my Erdös number 2 through Gérald Tenenbaum); DPMMS here has several generations of distinguished Erdös descendants. My old friend and contemporary R. C. Vaughan (Bob Vaughan, David Wallace and I are all 1945 vintage) has his own form of Kac's Dictum: *It's obvious that the primes are randomly distributed – we just don't know what that means yet* (Vaughan's dictum). My wife's instant response ((Cecilie) Bingham's Dictum): *Primes play a game of chance – we just don't know the rules yet.*

Continuing with randomness: when this unfolds in time, one speaks of a stochastic process. Just as the normal law is the prototype in static settings, *Brownian motion* is the prototype in dynamic settings. This takes its name from the Scottish botanist Robert Brown (1773-1858), who when studying pollen particles suspended in water observed (1828) that they danced about perpetually. One can observe the same phenomenon in the gaseous rather than the liquid phase, when one sees dust particles dancing in sunbeams (again, I asked my mother why they did this, and she replied 'currents in the air' – not bad). But again, the millennium is wrong. When I spoke recently at the LSE, my friend Andreas Kyprianou was in the audience, and reminded me that this same phenomenon was recorded by Lucretius in *De rerum naturae* (c. 50 BC). We played with the idea of starting a campaign to have this called Lucretian motion, but realised this was a lost cause. After all, it is Oxford, not Cambridge, that is the home of lost causes.

One can enjoy oneself as a lecturer by asking a class why Brown's suspension of pollen in water did not do what Brown expected it to do - settle down in time, through frictional drag, so that he could focus on individual grains properly. There must be an energy source to keep things going: what is it? It can take a fair amount of probing to get the relevant four-letter word out of the audience: *heat* (the ambient temperature in the surrounding laboratory environment).

The mention of heat leads me on to a conversation I had with my elder son

James, when he was an undergrad at Birmingham doing Chemical Engineering. I asked him how much of his time went on chem and how much on eng (about 10% chem to 90% eng). He added that most of ChemEng consists of taking procedures that one can do in the lab easily enough, and scaling them up to industrial scale, and that most of the nitty-gritty of this boils down to heat transfer. This leads on to the marvellous subjects of Thermodynamics and Statistical Mechanics. When the first place I worked – Westfield College, University of London, then in Hampstead – closed, like the other small colleges of the University of London, in the first round of Thatcherite cuts in 1983-4, much of its library was sold off to interested staff. I bought for maybe 50p a book I still have and treasure (Flügge, *Handbuch der Physik* III.2), the first article of which ends with the most famous two-sentence passage in the history of science. This is Rudolf Clausius (1822-1888) in 1865:

Die Energie der Welt ist konstant.

Die Entropie der Welt strebt einem Maximum zu.

(The energy of the world (meaning here, the universe) is constant.

The entropy of the world/the universe strives towards a maximum.) The first is the Law of Conservation of Energy (First Law of Thermodynamics), the second is the Second Law of Thermodynamics.

I have excellent academic links with the University of Ulm, and Ulm was the birthplace of Albert Einstein (1879-1955). I was there in 2005, when they celebrated Einstein Year, the centenary of his annus mirabilis: his three papers on the special theory of relativity, the photoelectric effect (birth of the photon) – and Brownian motion. Observing Brownian motion is perhaps the simplest common illustration of a phenomenon on three scales of magnitude: macroscopic (us), microscopic (the water molecules, or atoms in the air), and mesoscopic (pollen or dust particles). Einstein was able to show that the variance of the displacement of a Brownian particle should grow linearly with time, and that the constant of proportionality – *diffusion coefficient* – was informative about *Avogadro's number*. This work was taken further by Marian von Smoluchowski (1872-1917, from 1906-16). I have held chairs in a number of places, but only had to give an inaugural lecture once, at Birkbeck College, London in 1997. I chose as my title Fluctuations; as I had to say something substantial but to a general audience, I pitched the talk at James, then 15. The contents were based on two papers I wrote, the first – Estimating diffusion coefficients from count data: Einstein-Smoluchowski theory revisited – with my former pupil Bruce Dunham in 1997, the sequel with Dr Susan Pitts of Cambridge in 1998.

One of the things I love about science, and about teaching it, is that one can see it all around one. In one's early teens, one studies optics, and learns how light rays are reflected at a mirror: angle of incidence = angle of reflection (and Snell's law for refraction – explaining why a stick looks bent if half of it is under water). And of course, direct light is stronger than reflected light: one expects some frictional loss, as it were. I have mentioned Kac already; his name is forever linked, in the Feynman-Kac formula, with that of Richard Feynman (1918-88). Feynman was a wonderful author, and one of his best books is *QED*, or *Quantum electrodynamics* (Q.E.D. meant 'quod erat demonstrandum' at the end of a proof, but that was long ago, when one learned Latin at school - indeed, one had to have Latin to try for Oxbridge). Feynman takes as the theme of his book one phenomenon: *partial reflection of light at a mirror*. His hero in the physics of his lifetime was Dirac, of this University; his hero in the physics of previous centuries was Newton, also of this University, the author of Opticks (spelled with a 'ck'), 1704. What impressed Feynman about Newton's work on partial reflection of light at a mirror was not that Newton solved it (he couldn't: it is a quantum phenomenon, and Newton worked two centuries before the quantum age), but that he recognised that there is a deep mystery here.

Newton advocated the *corpuscular theory of light* (mentioned already, in Einstein's work of 1905 on the photoelectric effect). The *wave theory of light* was advocated by Christiaan Huygens (1629-1695) in 1678. The two were seen as incompatible, and there was a scientific dispute between them (bitter at times, as tended to be the case with Newton). The wave theory was confirmed by later interference results by Thomas Young in 1801. But it was not until the quantum age that the two theories were recognised as two different aspects of the same thing – wave-particle duality: everything - matter and radiation - is *both* waves *and* particles. This sad case of a scientific dispute that need not have been is instructive: always bear in mind that two theories may both be subsumed into a third, that we don't have yet. Meanwhile, look for consensus rather than a straight fight. Blessed are the peacemakers, as it were.

Just as interesting, but different, are the life sciences. In 2009, there was an exhibition in the Natural History Museum, just round the corner from Imperial College where I work, in honour of the sesquicentenary of Darwin's *Origin of the Species* of 1859. I was very flattered that my daughter Ruth, who is a primary teacher, set great store by seeing it with her father. When I read the *Origin of the Species* some years before, I couldn't put it down, found it not just utterly convincing but undeniable, and wished I had read it when young (who knows – I might have become a biologist). I find it deeply worrying that the book's message is denied by millions of people in the advanced world (I refer, with regret, to fundamentalist opinion in the USA - Christian, protestant). I have no religious affiliation (culturally, I'm an "Anglican atheist"), but I wish to state that I was impressed by the then Pope's reaction to the book. He appointed a committee of scholars from the (Jesuit) Gregorian University in Rome to read it and advise him. They advised him, quite correctly, that no one could read the book with an open mind and not accept its thrust. Accordingly, he changed the Church's position, from a literal interpretation of the Book of Genesis towards its present position - that the domain of science is the material world and that of the Church is the spiritual world.

Meanwhile, the Church of England had its troubles. The Rev. Dr William Buckland (1784-1856) expended much intellectual energy attempting to reconcile then-new geological discoveries with Genesis — to the detriment of his mental health. In the 1860 Oxford debate between Thomas Henry Huxley (1825-95 – "Darwin's Bulldog", whose bust is in the hall of the Huxley Building, home to the Imperial College Maths Dept.) and the Bishop of Oxford, Samuel Wilberforce ("Soapy Sam"), Wilberforce was coached by Richard Owen (1804-1892), later Director of the Natural History Museum. Owen opposed Darwin, and his reputation has not worn well (his statue used to be on the ground-floor stairs in the Natural History Museum, but I noticed when last there that it has gone).

Genetics stems from the work of the monk Gregor Mendel (1822-84) in 1865. This was neglected at the time, but rediscovered in 1900. In the early 1900s, Mendelian genetics and Darwinian evolution were thought to be incompatible (as were the wave and particle theories of light!), but a synthesis between them emerged, largely through the works of R. A. (Sir Ronald) Fisher (1890-1962), Sewall Wright (1889-1988) and J. B. S. Haldane (1892-1964), and led to the field of population genetics. Remarkably enough, Fisher was also the greatest statistician who ever lived. He was Arthur Balfour Professor of Genetics at Cambridge from 1943-59. He was based at Whittinghame Lodge, long before this became part of Churchill, and conducted experiments on mice there. I lived in Whittinghame Lodge during my first year in Churchill (1966-7), and unkind jokes were made at that time to the effect that Fisher's mice could still be smelled on Whittinghame Lodge residents.

Modern genetics has had spectacular success with such things as the Human Genome Project. And the public's awareness of genetics was much increased as a result of Richard Dawkins's 1976 book The Selfish Gene. Dawkins was the first professor of the public understanding of science in Oxford, the chair now held by the mathematician Marcus du Sautoy. I am delighted that Cambridge has a chair in the public understanding of risk, held since 2007 by David Spiegelhalter.

Risk is meat and drink to a probabilist such as myself. Of course, one important area here is medical statistics, as in David Spiegelhalter's work. But the last conference I attended on risk focussed not on science, but on the Dismal Science itself: Economics, and in particular on finance. Here things become much more murky. This is inescapable. Of course, mathematical finance is an important, flourishing and very interesting area; I have worked in it (as most probabilists have these days); I have written a book about it; I have already mentioned Chris Rogers' work. Of course, we should use mathematics to study anything important and to which it can be applied – and mathematical finance is both of these. But, having just recommended Dawkins' popular book, I am now going to recommend another: *23 Things They Don't Tell You About Capitalism*, by Ha-Joon Chang, Reader here in Cambridge. Thing 1: There is no such thing as a free market (our masters/mistresses in Westminster/Whitehall please note!) One cannot separate economics (of which finance is part) from politics. And, as Bismarck so famously said, politics is not an exact science. So there are limits to which mathematics can be usefully applied to our present economic problems.

In addition to my main base at Imperial, I am a Visiting Professor at the LSE. Walking there, I pass the New Academic Building. When The Queen opened the NAB on 5.11.2008, she famously turned to her host, and asked firmly - of our economic troubles since 2008 – "Why weren't we warned?" This wonderfully obvious question received no clear answer at the time, but I am very glad to say that the British Academy (within whose domain such matters lie, unlike the exact sciences so central to Churchill's mission and David Wallace's academic background, which are the domain of the Royal Society) took up the challenge. A working party of FBAs was set up, and eventually reported its findings, in the form of a letter to HMQ.

One of the wonderful things about science is that one knows when one is wrong. In the humanities - literary criticism, for example - there is no right and wrong. The social sciences, and in particular Economics, have aspects of both (I am conscious of this tension in the contrasting names of my two academic bases - the Imperial College of Science, Technology and Medicine and the London School of Economics and Political Science). Relevant here is the life's work of the late Professor Milton Friedman (1912-2006). Friedman was a statistician of some distinction, but turned towards economics, and became the intellectual driving force behind the Chicago School of Economics (the "Chicago Boys" advised Pinochet following the overthrow of the Allende Government in Chile in 1973), and of the neo-conservative political movements exemplified by the governments of Thatcher (1979-90) in the UK and Reagan (1980-88) in the US. I have often heard it said that the Chicago Boys have captured the academic profession in Economics. By contrast, the post-War consensus, of which I am proud to be a child, was more influenced by the work of J. M. Keynes (1883-1946), of King's College Cambridge. Keynes' influence diminished during the 70s and later, but has increased since the roof fell in on the economies of the US in 2007, UK in 2008, etc. The policy questions facing us today cannot be separated from those arising when comparing the economic ideas of Keynes and Friedman. One of the things I find depressing here is how much of public discussion of these vitally important matters proceeds with no mention of Keynes, despite his influence on world economic recovery from the Great Depression of the inter-war years, and later after WWII. The phrase "re-invent the wheel" tends to go through my mind when listening to the news nowadays.

My general views here are known: see my website, or my (invited) paper in the Royal Statistical Society journal Significance, The Crash of 2008: a mathematician's view (5.4 (2008), 173-5). One anecdote here: knowing my involvement in mathematical finance, my wife gave me for Christmas 2008 *The Age of Turbulence*, the autobiography of Alan Greenspan (1926-), chairman of the Fed from 1987-2006, for long "the world's favourite central banker", a highly intelligent man, much influenced by Friedman. Most of the text of the book - which is well-written, entertaining and informative – was written in a spirit of Panglossian optimism: "All is for the best in this best of all possible worlds; markets know best; we have free markets, and these are self-correcting; therefore, nothing much will go wrong because nothing much can go wrong". There are occasional hints that there might be more to it than that, but these are conspicuous by their rarity. The book was published in the US in 2007; shortly afterwards, the roof fell in in the US (sub-prime mortgages, collapse of Lehman Brothers, ...). There was of course great public interest; the book sold out, so needed re-issuing, and there was an opportunity to add to it. The 2008 edition included an epilogue, in which

Mr Greenspan revised his overall views somewhat. Then the roof fell in in the UK in 2008 (Northern Rock, ...). Eventually Mr Greenspan admitted that "the whole intellectual edifice [of risk management] collapsed in the summer of last year" (evidence to the US House Committee on Oversight and Government Reform, 23 October 2008).

I have no wish to cast stones at Mr Greenspan; I don't doubt that he, and most of the other principals in these matters, acted in good faith. The point to make here is that, whereas in science we know when we are wrong, and science progresses by the endless search for better theories, and in the arts it is not a question of right or wrong but of opinion, taste and judgement, in the social sciences in general and in economics in particular, we fall between these two stools and in some sense, it seems to me, get the worst of both worlds. We are in a recession, which dominates our public life, and blights the lives of many. Questions abound; I will confine myself here to two. The first concerns quantitative easing. QE was an emergency measure, credited with stopping the rot at the time. The idea was to restore the availability of credit, and so stimulate the economy, by in effect presenting bank with large amounts of new money. My assessment so far is that this money has largely vanished from sight and into the capital reserves of the banks (if I make more than passing reference to bankers' bonuses I shall lower the tone by swearing in public), and I think this was predictable. History will no doubt give its verdict on QE; what I would like to see now is better informed public debate on it. The second question concerns the eurozone. While I was writing my book on mathematical finance with my friend and then Birkbeck colleague Rüdiger Kiesel (1st ed. 1998, 2nd ed. 2004), the euro had been agreed and was moving towards implementation. We would relax at the end of a day's hard writing over a drink, and had several long discussions on the euro project. I said that it wouldn't work, because the European economies were too dissimilar to be stable over time when constrained within one currency zone, without the flexibility of being able to change exchange rates, let alone interest rates. Rüdiger was pro-euro. I wondered at the time how much of this was my being a man of the left and him a man of the right. I wonder now, in view of the current and ongoing crises (Greek debt, youth unemployment in Spain at 50%, etc.) both how long the status quo is sustainable, and how on earth we are going to cope with the convulsions to come. Greenspan's title *The Age of Turbulence* was very apt - but I fear we ain't seen nothing yet.

As Bismarck said, politics is not an exact science. So those of us who love the exact sciences should perhaps seek to avoid it. Indeed, I hanker for what is to me the Golden Age of vanished innocence – the years of the post-war consensus (1945-79), when most things were not political (of course, there were lots of arguments, but these seem pretty small beer in hindsight). The trouble is that *everything important enough becomes political*, a dictum I learned from the late M. Maurice Couve de Murville (1907-99; Foreign Minister 1958-68, Premier 1968-69). Take education, for example: fitting enough, as we are here in an academic institution. Education is overwhelmingly important (one recalls the use of 'Education, education, education' as a political slogan some time ago). But, most of us who work in education, at whatever level, have come to regard the political dimension to our lives with fear and dread. Most people in education would agree that there is too much political interference nowadays (this is not a party political comment - it applies irrespective of party). But of course, a degree of political control is inevitable, as education is, broadly, in the public domain rather than the private domain. So we have to be publicly accountable, and subject to political control, which (thank goodness) is democratic. There is much to criticise, and criticise I do – but let me quote our Founder on this subject. Democracy, as Winston Churchill so famously said, is the worst system of government ever invented – except for all the others.

Public accountability - the price we pay for use of public money - is accompanied by the need for management, a subject on which I will permit myself a digression. I fondly recall the time when things worked well (or well enough), and management was not much in evidence. Certainly most universities did not teach the subject, for instance. Now, things work less well (at least, to my perhaps jaundiced eye), and management is all around us (and taught in most universities, to large numbers of the aspiring young). Once upon a time, things were done in house, within the institution, by people who had experience specific to that institution and that subject. Nowadays, a great deal is outsourced (e.g., in the Civil Service), and done by temporarily hired outsiders (which always reminds me, with my interest in military history, of the use of mercenaries and soldiers of fortune in the late Middle Ages). Management consultancy firms abound, the brand leaders being McKinseys. The McKinsey motto is simple: Everything gets measured, and what gets measured gets managed. Here we have, in a nutshell, much of what is wrong with the way we do things. There is nothing wrong with measuring things. But this motto betrays a mindset that has thrown the baby out with the bathwater.

One aspect of this rampant managerialism which I have encountered many times is an obsessive and inappropriate preoccupation with size. Society nowadays, rightly, opposes racism and sexism. Yet, many university managers are blatant sizeists. I can understand this (to a degree) in the laboratory sciences, which are fearfully expensive; economies of scale are possible, and cutting-edge lab science needs horribly expensive equipment. Forty years ago, every university had departments of Physics and Chemistry. A little homework on university websites will reveal that this is far from true now. The rot set in in the early 80s (when the smaller London colleges closed, as I mentioned). The various research assessment exercises, which were meant to give proper accountability for use of public money, and by introducing openness and transparency to drive up standards, exacerbated this: it was the view of some of the leaders of the UK Physics community, for example, that small Physics departments were bad and should close (David Wallace will recall this period). Many of them did. So too did many Chemistry departments (I recall the heroic defence of the Sussex Chemistry Department by Harry Kroto, a Nobel prizewinner as well as an FRS, but even Harry eventually left and went to the US). I deplore all this, but I can understand it because Physics and Chemistry are expensive. What sticks in my gullet is when the same thing happens to Mathematics. Mathematics is cheap. No one would dream of sending their child to a secondary school with didn't teach Maths (they couldn't, thank goodness – Maths is compulsory at schools before the Sixth Form). My view is simple. If you haven't got a decent Maths Department, you're not a decent university. If you haven't got a Maths Department, you're not a university at all[2].

I view much of this as a result of the inappropriate introduction, into the public sector in general and education and universities in particular, of thinking found in the private sector. But it is often inappropriate even there. I will tell one anecdote here. During the post-war building boom, there was lots of pre-fabrication, and around that time windows started to be made of metal (e.g. aluminium) rather than wood. The leading firm of this time was called Crittall Windows. It fell in 1968 to a hostile takeover, by the financier Jim Slater (1929-); with the Tory politician the late Peter Walker (1932-2010), he founded the firm Slater Walker, noted for its corporate raids. The firm got into difficulties during the 70s, but during the 60s it took over Crittall

[2]The 1992 universities are special cases here, but I will not go into this here through lack of space

Windows. During the hostile take-over, Slater maintained that, because he was offering a premium over the current share price, it was he, not the Crittall management, who had the real interests of the shareholders - who own the company - at heart; as he clearly neither knew nor cared about windows, the Crittall managing director didn't agree; they agreed to differ on this. On taking over the company, Slater convened a meeting, in which he announced "The commodity we will be making in this company is not windows – it is money". After the meeting, in despair, the Crittall manager asked Slater why he had targeted this particular company. Slater said "Because it is the right size". The Crittall manager commented that this is like choosing a wife for her vital statistics.

Now I yield to no one in my appreciation of the female form. Traditionally, I prefer the fuller figure, but one's personal preferences are just that, personal, and not the point here. Anyone who thinks that a woman's vital statistics are the most important thing about a woman has missed the point. No one would deny that. The point here is the devastating damage that this sort of crass, brutal reductionism has cost us all, applied on the wider scale. The Crittall-Slater exchange – windows v. money – serves to me as a beautiful example in miniature of the systematic distortion of the British economy from a balanced one based on industry and services to an unbalanced post-industrial one based on services in general and financial services in particular. This has left the UK economy, which successive governments prided themselves was pre-eminent in financial services, flat-footed and worse off than our competitors now that the roof has fallen in on financial services. And I find disturbing echoes of Slater's focus on money (not that it did him much good - his firm went bust, and he described himself as a "minus millionaire") in the relentless focus on money in the thinking, rhetoric and actions of many of those who run British universities today. Of course, universities are expensive; universities need money; universities need to be managed, and managed well. But universities are not about money - and to think, talk and behave as if they do, all of which I encounter every day, is to throw the baby out with the bathwater.

I spoke earlier about the Scientific Revolution. This led on to the Agricultural Revolution, and to the Industrial Revolution (in all of which, I note in passing and with pride, Britain played a leading role). It also led on to the Enlightenment, and to the modern world. I spoke earlier about proof. Proof is the essence of mathematics. Mathematics is the common core of all science. Science is the difference between the modern world and the Middle Ages. Without mathematics, there is no science; without science, we're back in the Middle Ages, burning witches. That, in brief, is the case for mathematics. And how wonderful it is that Mathematics is not vulnerable to take-over by an ideologically motivated faction, such as the Chicago Boys in Economics.

You are all young, and most of you are scientists. So it would be sensible to give you some advice, and as it happens there is a good book on this, *Advice to a Young Scientist* (1979), by Sir Peter Medawar (1915-1987). *Work on problems to which people want to know the answers.* As Medawar points out, almost anything becomes interesting if studied in sufficient depth. Keep collecting stamps, beer-cans or whatever for your spare time, and spend your working life working on something that matters. If in doubt, apply the Medawar Test: does it matter to anyone but you? You may also find it useful to bear in mind Robert May's view of some of the main problem areas of contemporary science: the very big (cosmology, etc.), the very small (particle physics, etc.), and the very complex (biology). He pointed out that the simplest life form is more complex than a star. I remembered my former Chemistry teacher's story of his professor, who would say to students "A turnip's a better chemist than you'll ever be, lad".

My Cambridge years were spent as a research student in the Statistical Laboratory (the Stats Lab is part of DPMMS, in CMS just over the road). Peter Whittle wrote a fine account of the Stats Lab history, *A Realised Path*, in 1993, to which I contributed. The following passage is taken from my website:

"On a daily basis, I found the Stats Lab a wonderfully congenial mathematical home – friendly, stimulating, fun. Where I felt it showed its personality as an institution most clearly was in the Friday seminars. I found the sheer quality of the talks I attended over a three-year period, and the tremendous range of subjects covered, a revelation. One heard many splendid talks, and some great ones. Rényi, for instance, was a great man, and it showed in every talk of his I attended. David Williams' first talk was unforgettable. On a much humbler level, I made my own professional debut as a speaker in the Stats Lab.

"But perhaps even more vividly than the talks, I remember the teas afterwards. There was no stuffy inhibition about asking questions: the conversation flowed, starting with the talk, and going off enthusiastically in any or every direction. One was left with an overwhelming sense that everything was interesting – and so, that one should be interested in everything. No one quite lives up to this, of course, but as a general guiding principle in professional life it has served me as well as anything has. I owe it to the Stats Lab tea-room, where I drank it in as the mathematical equivalent of my mother's milk."

As I mentioned, I was at Tadcaster Grammar School (1955-63), where my headmaster was Mr W. N. Bicknell, a remarkable man to whom I owe a great deal. I remember on one Speech Day hearing him giving, in effect, his personal philosophy, as a man and as a teacher. The theme he kept returning to was wonder - how interesting, and wonderful, everything is. I was struck by this at the time, but wondered whether perhaps he had over-stated it. I recalled this when writing my Stats Lab piece above, and realised he hadn't. The world is so full of fascinating things that we will never, in our brief lifespans, run out of interesting things to do. I noticed when a young academic that the more I learned, the more I became aware of how much I ought to know but didn't. So I felt as if I were running hard, but drifting slowly backwards. At first, I found this disconcerting, but eventually the penny dropped, and I realised that this is the touchstone of academic health. Who better to close with here in Cambridge than Newton, and the title of one of the standard biographies of Newton, *Never at Rest*. From the front material of Westfall's book of 1980:
"A Vulgar Mechanick can practice what he has been taught or seen done, but if he is in an error he knows not how to find it out and correct it, and if you put him out of his road, he is at a stand; Whereas he that is able to reason nimbly and judiciously about figure, force and motion, is never at rest till he gets over every rub".
Isaac Newton to Nathaniel Hawes, 25 May 1694.

Thank you. NHB, 5.5.2012