

UK Strategy for Nanotechnology

Subject:

Synthesis of interviews with scientific Thought Leaders in academia on elements for a UK Strategy for nanotechnology

Authors:

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Abstract:

Leading research scientists in the UK were canvassed for their opinion on future opportunities and challenges linked to nanotechnology research in the UK. No such review has taken place in the past on an independent basis by any of the stake-holders, which in itself is surprising based on the multi-billion dollar investments taking place in countries such as US, Germany, France and Japan.

Recommendations are presented to decision makers in terms of education and industrial opportunities, for the benefit of the United Kingdom. The key conclusions are based on interviews with forty six leading researchers in nanotechnology on an independent and confidential manner, and call for urgent action to streamline and overhaul the current methodology for developing areas of national importance such as nanotechnology, which can form the basis for a circa \$1Trillion manufacturing industry base in 5 years as forecasted by the National Science Foundation (NSF). The dire repercussions of not tapping the huge resource base present in the UK is unimaginable and will make the investment made to date highly ineffective and boost other nations which tap into the knowledge gained via UK research investment in this area.

Keywords:

Nanotechnology strategy UK United Kingdom education research Industry University spin-out legal

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Introduction

The authors of this report are both independent individuals linked to nanotechnology and working closely with academics. High ranking British academics were asked their thoughts on positioning Britain in terms of excellence in research / engineering nanotechnology. In order to have a degree of focus three generic questions were presented; note care was taken not to guide their answers:

- How can the UK attract train and retain scientists of the highest calibre to Nanotechnology?
- What are the crucial opportunities which research should target, which could be leverage into new product for the greater good of the UK?
- What positive messaging and safety legislation should there be to ensure that these novel ideas are taken and not shut down by lobbyists?

We originally intended to include attributable quotes, however a number of those approached initially stated they couldn't put their name to such a report as they were concerned that it could be seen as being political and even jeopardize their chances of getting funding or support from their institutions. The report is now a consensual document including their unmodified viewpoint. Those who have agreed to the content are listed in Appendix I

Annex 2 is the summary of the recommendations made by those we canvassed, and we also strongly recommend reading in the excellent Roberts Report¹ much of which is still highly relevant today.

A number of additional opinions were raised during the process of putting this report together, which is reflected in the report proper.

Motivation

Russia, Germany, China and the US are visibly pump-priming the nano-sciences as they see the \$1T global market by 2015 as an economic pull for jobs and industry. This comes at a time when the current government in the UK is looking for an ROI on the significant investment under the MNT programme over the last decade and cut-backs look inevitable in all public spending.

Tom Warwick, in his global dealings with nanotechnologists since 1993 was struck by the strength of feeling in the UK that *the scientists* view was not necessarily getting through to those making decision on policy or funding as there is no truly independent channel. In discussion with Thierry Bontoux, who at that time was in a Business Development role at The London Centre of Nanotechnology, they jointly decided to put forward a neutral report. The motivation for such a report was to give an understanding of "feelings" extracted directly from the researchers involved with nanotechnology at a high level. The only interest of the Authors is to contribute positively to the general economy and position of Britain in the world. It is interesting to note that while

¹ HM Treasury, *SET for success: The supply of people with science, technology, engineering and mathematical skills*. (Report of Sir Gareth Roberts' Review), April 2002

disagreement was not expressed against the content of this document some contributors still did not feel able to endorse it publically.

Nature of Nanotechnology

Nanomaterials have been around for centuries, carbon black can be traced back to the ancient Chinese, while colour changes exhibited by nano-sized silver particles were used in stained glass windows in the Middle Ages.

A new field of applied science, nanotechnology, has emerged taking advantage of such differences as the massively different ratio of surface area to volume, amongst others, which results in property changes of materials, e.g. Metals can become harder and ceramics can become softer at the nanoscale.

The usual examples of successful nanoproducts include stronger lighter materials for sports equipment, or colourless titanium oxide as used in sun screen. However nanotechnology is a truly interdisciplinary science and there is huge promise for commercial development in nanomedicine; nanosensors for the early detection of disease, energy; more efficient fuel cells, photovoltaic and retro-insulation for older buildings, self cleaning windows and stronger, lighter composites and as we move away from micro electronics there will be new directions such as nano electronics combining nanobio and electronics.

Stimulus packages, preferentially investing in nano, are being put together in the G8 countries. Interestingly China is now the 3rd most productive in terms of scientific papers citing nano, through massive investment and relatively lax legislation, it aims to dominate this field. The US view nanotechnology as providing jobs for the future while Russia sees it as a successor to the oil and gas industries.

Is nano hype or reality?

The American NSF predicted that Nanotechnology will be a \$1T market globally by 2015, is it any wonder that this field is generating so much interest. But why not in the UK?

Nano has been around since the dawn of time and is very much reality. However, much classical research has been re-branded as nano in order to jump on the bandwagon. Colloid and particle science are relatively strong in the UK and have sought new funding by being seen to be nano. Tissue engineers, catalysis scientists and plastics electronics specialists, who are solutions driven, have all shied away from the nano label as they don't see it bringing added value.

There have been a whole raft of reports on the potential of nanotechnology, some sponsored by the government, but so many reports concern themselves with safety, toxicity and legislation and are reluctant to predict where future business will be generated. Joined up thinking is required as we would be better advised to invest in areas which the UK is more likely to become a major player. How funding is distributed needs to be looked at, the idea that geographical distribution is fairer overlooks the fact that this field of science requires heavy investment in capital equipment. There are many advantages of a few key sites.

Part of the issue with nanotechnology is that it has not yet emerged into a true branch of science in the way that biochemistry branched away from biological sciences and physical chemistry. It is a platform of technologies looking for commercial applications, a tool kit we can dip into. Many scientists still see nanotechnology as being a sub-set of their discipline, yet now a physicist will be just as likely to be looking for help with “the chemistry” as the biologist who required the physicist to develop the instrumentation a decade ago. There are still plenty of things to be discovered at molecular and atomic scale, Nanotechnology is today about enhancing the functionality by nature of its quantum effects, salvation, thermal, magnetic and electronic properties, amongst others.

Through the MNT programme, the Government has been significantly investing in nanotechnology over the past decade and is now looking for evidence of return on its investment. This is a major difficulty associated with nanotechnology. Some of the scientists involved in nano are looking to understand Nature, while the remainder behaves as engineers developing technologies. Canny scientists looking for a better chance of funding rebranded some of their research as nanotech in order to benefit from this easier path to grants.

It is very important for UK’s economical future to understand that Nanotechnology is as much fundamental research as it is the development of engineering solutions and while it is convenient to label some of these as being “nano” it is not necessarily helpful to do so as a solution may be macro, micro or nano.

Environment

The funding landscape available to nanotechnologists has a greater range of options open to it, if the project can be described as being Life Sciences oriented. Researchers need to choose their funding body based on their assessment of which is most likely to fund. Specifically, the unprepared researcher who sends in a cross disciplinary bid into a particular Research Council without prior discussion is likely to suffer a rejection; EPSRC for example may reject a proposal on the basis that there is a strong biological element. It is understood by the authors that the relevant research councils are trying to be very pro-active in encouraging people to form multi-disciplinary teams, not only in “nano” but across many other topics too, however this was not the perception of those on the ground making the applications. This is a counter-intuitive since nanotechnology is interdisciplinary. It also seems that the outputs of research in nanotechnology can actually be limited, due to the original orientation given to their grants. This idea does not seem to be new, but those who have lobbied research councils said that they had been strongly advised against it by those in control, and many expressed fears of being penalised if they did so.

Research Institutions

Under the MNT 23 laboratories were set up in the UK specifically funded for research in nanotechnology. At the time Regional Development Agencies fought their corners and it was determined to spread funding geographically. However this kind of research requires huge capital investments and often smaller academic groups are not as cost effective as bigger laboratories.

Today's bright fledgling academic is likely to be able to secure some start-up funding at his new institution but must apply for funds for a specific project. He will build up his group and forge links with other academics nationally or internationally largely through networking; themed conferences, and contacts made while working for his former supervisor etc. However he will be wary of sharing too much information with anyone who may be in competition with him i.e. likely to beat him to a publication. Much of his early years are spent securing grants to buy capital equipment and build his group. There are some exceptions notably fellowships from EPSRC, Royal Society and the Newton Fellowships² which do attract top-level. These schemes should be expanded giving the UK the capability to retain the foreign student it has trained.

A number of the interviewees were pragmatic, suggesting that where the bright young researcher were able to join an established centre of excellence, which was well resourced with equipment, not only would there be a reduced need for a capital grant as they could buy access to existing equipment, rather than building their own arsenal of expensive instrumentation over time, there would also be a significant benefit in being part of an existing community. Further benefits would be; intellectual support as well as the benefit of mixing scientists with engineers who complement each other with their different psychologies, attitudes to team-work and problem solving, the former discovering problems, while the latter like to solve them. This kind of solution has already been successfully put into practice in France and Germany and is a model we could do well to consider.

Education

Science is often serendipitous; we can't always predict where the breakthroughs will come from, although as Pasteur is famous for saying "chance favours the prepared mind" nor what the future challenges will be, it is therefore vital that we continue to invest in fundamental as well as applied science. A significant number of drugs have been discovered by accidental discovery, Penicillin is one of the more famous ones, but the list is long and worth noting as it could have been considered that drug discovery is largely through repetitive drudgery and targeted research³. This is also what attracts both people to study and invest in science and underpins the UK's international science reputation.

A very strong positive aspect is the high ranking of UK universities in world league tables with four out of the top ten universities in the world being British⁴. Furthermore between 2002/3 and 2006/7, there was an 11 per cent increase in the number of students taking first degrees in the STEM subjects, and a 35 per cent increase in students getting masters degrees⁵. It is pleasing to note that the UK trains well, many respondents using the term "the UK punches well above its weight in terms of academic scientific excellence". However, there is a fear of investment cuts and that the next generation of Global Top Scientists could be trained in China, India or the USA. Not only that, but if

² <http://www.newtonfellowships.org/>

³ *Journal of Receptor and Signal Transduction Research* 19 (1-4):15-39 (1999) CHANCE FAVORS THE PREPARED MIND – FROM SERENDIPITY TO RATIONAL DRUG DESIGN

⁴ <http://www.timeshighereducation.co.uk/hybrid.asp?typeCode=438>

⁵ Speech of Lord Drayson on February the 4th, 2009 at the Royal Society

the UK is training the next generation of Top Scientists there is a need to ensure that they have a right to stay and work if they attain a certain standard here. It was commented that ten years ago Stanford had a very high proportion of foreign students in the sciences, and the system allowed them to stay on creating wealth in the US. Silicon Valley is a success story which directly came from Stanford's attitude to tech transfer; the dean of engineering Frederick Terman during the '40's and '50s aggressively encouraged his faculty and graduates to start their own companies. The successful companies including HP and Varian, amongst others, are a pull on talent from the university, who in turn as is common in the US invest back in their *alma mater*.

The Government's attempts to improve the UK's productivity and competitiveness could be undermined if the incoming students can't see future opportunities in nanotechnology leading to rewarding careers if there is no visible strategy with joined up thinking as there is in the US, China and other G8 countries. There are also mismatches between the skills of graduates and postgraduates and the skills required by employers (many have difficulty in applying their technical knowledge in a practical environment and are seen to lack strong transferable skills). It is estimated that one in six engineering employers had 'hard to fill' vacancies, particularly at the higher end of the skills spectrum.

A root cause of this situation is found in secondary schools and further education colleges, where science teachers are often required to teach areas of science that they did not study at degree level (nor, in many cases, at A-level). We still need larger cohorts of young people studying maths, physics, chemistry and biology post-16 at A-level, before going on to both pure and applied degrees⁶. And we know that the best preparation for this involves boosting the numbers of pupils taking triple science at GCSE. Unfortunately these syllabuses are turning off our young students with their highly repetitive nature and lack of opportunity to apply creative thought.

While the good news is that postdoctoral researchers can now receive pay that is comparable with initial earnings in Industry, a definite improvement since 2002, however they are faced with an uncertain future since post-doctoral scholarships are typically only guaranteed for two years. There should be a longer, not shorter research commitment to postdoctoral researchers if we want to keep the best in the UK. Any shortening of the research contracts from the current 2 years average would have devastating consequences.

Strategy for Research

This situation has more implications for scientists in nanotechnology as they are now expected to extrapolate expected outcomes of their research providing project Gantt charts with their EPSRC grant applications. Since most of the great developments we have seen from UK scientists over the years have emerged and evolved fortuitously from research, this form of funding is generally seen to be overly constraining and restrictive. The US, France and Germany have all chosen to segregate fundamental research from engineering development which removes the schizophrenic situation researchers have to be in order to get funding in UK. They have to demonstrate fundamental

⁶ Speech of Lord Drayson on February the 4th, 2009 at the Royal Society

research (creation of knowledge) and engineering development (application of present knowledge). This situation finds its equivalence in the debate amongst scientist pro or con Blue-Sky research.

The argument for Blue-Sky research is clear, there is no obvious evidence that directed research is any more effective than responsive mode to achieve near term socio-economic benefit. The opposing perspective is the call for more control over public funds arguing that academics should not be given “Carte Blanche” as they owe a debt to society to do some useful applied research and to turn science into applications for future wealth generation. However, with wealth creation in mind there are examples, where short-termism has led to additional cost in the long-term. Fundamental research in nuclear physics was abandoned in the eighties on the basis that there was no long-term ROI and thirty years later UK has to buy its nuclear technology from France. Research in Nanotechnology is today making huge progress throughout the world and is heavily financed in the entire developed and developing world. In the US and many European countries it is also used as a recession buster. UK must do the same if it doesn't want to jeopardise its future technological position.

Broadly speaking, the conclusion is that we need to retain our Nanotechnologists once they have been trained. The career path issues and many more aspects were examined in the excellent Roberts Report and the recommendations are as relevant today as they were in 2002. Young scientists go where things are exciting. They may also go where they think they are supporting their ideals. We would do well to look at the level of expertise already obtained in Medical Research which tends to secure the top brains in the country. One advantage in picking a career in the medical sciences is that not only is there a higher level of funding, but more competition in terms of where the funding can be secured. Physical Scientists in general can apply to EPSRC, medics have BBSRC, Wellcome Trust, the MRC, Cancer Research and a whole range of charities linked to specific diseases and medical disorders. A similar approach should be considered for the rest of Nanotechnology.

Industrial Strategy

Although there were no direct questions covering industrial strategy for the UK with respect to Nanotechnology there were a lot of comments made on that topic and we felt it was important to report them.

Academics showed a general concern that universities remit was not to carry out Industrial research and development on behalf of industry on top of their normal work, or to understand the industrial outcomes of the research they performed. Academics are by nature not entrepreneurial and are often simply afraid of the idea of dealing with industry; otherwise they would be working inside industry enjoying share-options and higher salaries! However, Open Innovation is quite another matter, where firms would be encouraged to incorporate external ideas, from universities, as well as internal ones.

Some interviewed wondered why regions like those around Cambridge in the UK or Stanford in the USA were successful with Open Innovation spawning so many successful start-ups, where as others grasped that it was a combination of the universities encouraging spin-outs combined with a pool of employees ready to jump from one high(er) risk employer to another should their original company

fold. The remit of the KTNs (Knowledge Transfer Networks) could be biased more strongly to help SMEs and start-ups leverage Open Innovation, taking advantage of technology and IP generated within Universities as the process rarely works organically at the moment.

We think Nanotechnology is an opportunity for the UK to regain its former dominant industrial position if funds are invested now for the creation of industrial start-ups. Indeed Britain has clear competitive advantages in some areas likely to be closely linked to nanotech, such as biomedical and healthcare and energy where we stand a reasonable chance of being the No 1 or No 2 player globally. However, care must be taken not to mimic the VC model looking for a 10:1 ROI in early stages of funding a spin-out as the authors are aware of a number of potential opportunities simply not presented for commercialization due to the overly onerous investment conditions. It is recommended that if the City is involved in such a way that it does not try to impose old trading models to new technologies but rather that it contributes in a positive way by better understanding the scope of possibilities.

It was also recommended to consider an alternative to the classic Spin-out namely a Leak-out whereby either an internal or external entrepreneur could use the universities facilities and funding for the purpose of generating a marketable technology. It was felt that more academics and start ups would be prepared to take the risk if it was shared, along with the potential wins on shared IP and revenues. In the case where this approach failed the IP would still reside with Universities and they would be free to sell it on or try to develop and market it with someone else. Whichever system is considered, financial incentives such as tax credits are needed to push the entrepreneur to take risks. Examples were discussed of researchers who had set up in North America or Switzerland instead of UK.

Opportunities

The UK needs a strong science and engineering base for its future economic growth and nanotechnologies are the new frontier that industry needs to conquer. Therefore it is the ideal opportunity given to Britain to regain its industrial position it once had. At the same time being multidisciplinary it will strength the position of the UK Bio Industry and could give Britain the chance to recover its former position in other fields of industry such as micro electronics and telecommunications, albeit in the new nano, rather than the previous micro format. To stimulate everyone's efforts there needs to be some kind of ambitious challenge similar to getting a man on the moon by the end of the decade as dictated in America in the sixties. A target for the UK could be to lead the way in having >20% of its energy coming from renewables by 2020.

Energy

Energy is a vast theme where nanotechnology will bring huge improvement. There are applications in nearly every subject from renewable energy to insulation of older buildings, energy storage, and Photovoltaic cells.

Bio

Healthcare, nano-biology, diagnostics and drug delivery are fields of research where it is very difficult to separate science and development. A small improvement in drug efficacy can often result in dramatic improvements in healthcare the principle being where fewer drugs need to be used there are fewer side effects. The pharmacology industry is significant and well represented in the UK but hasn't fully bought into 'nano' yet, mainly because they are not interested in nano *per se* as they have not yet been presented with the benefits.

Information processing, quantum information processing, spintronics

Moore's law, relating to density of semiconductor devices using photolithography and silicon based technology, shows limitations accumulating beyond 2012. Pure scientists in the UK and elsewhere are working on solutions to advance beyond these limits by developing new paradigms for micro-chips including research into molecular, spintronic and quantum computing. The fact that Britain has no local semiconductor industry is not a problem since this new technology will not be ready for at least another ten years. However, in the meantime there are areas where nanotechnology will be able to help the UK and launch the country in a competitive direction. These include classical reversible information processing (no heat dissipation) enabling electronics to work faster with less energy. This is a field where the technology barriers are lower and thus constitutes an opportunity for Britain to come out with commercialisable results and technology in a short term. Here again ambitious challenges have to be led and financed by the government.

Software is the final opportunity to be mentioned here. It is something the UK is good at, and will result in very short term ROI. The current CMOS speed restrictions are significant, so in the short term the only way to improve the processing power of our computers is to improve the software performance. In a 2008 article in InfoWorld, Randall C. Kennedy, formerly of Intel, introduced the term bloat. He described using successive versions of Microsoft Office between the year 2000 and 2007 as his premise. Despite the gains in computational performance during this time period according to Moore's law, Office 2007 took longer to perform the same task compared to Office 2000 on a computer of its prototypical year.

Legislation

The people interviewed were in favour of responsible development and being expert in their field they fully understood the needs and challenges to work within current legislation both in the UK and Europe.

Scientists and authorities need to handle nanotechnology carefully by public dialogue and ensure they have their facts right, however most felt that the reporting in the popular press seems accurate so far. There are a few people around in the UK who like to raise issues just to create a bit of fame and notice for themselves. Above all nanotech is yet to be proven to be quantitatively different from other branches of science so the main recommendations were:

1. Don't over-legislate

2. Use existing legislation as far as possible but nanoparticles need to be treated in the same way as new chemicals are introduced to the market)
3. Don't legislate for what you cannot measure or detect
4. Use case studies to help people to understand and be sensible, not huge legislation books that no-one reads (and those who read them don't understand)

There is scepticism over industry sponsored research particularly relating to safety testing. "The facts aren't slaves to the paymaster"

About the authors

Dr Thierry Bontoux

Thierry is the founder and director of TBx Consulting Ltd (www.tbx-consulting.com). Thierry earned an M.Sc at University Paris VI (France) and a Ph.D in engineering at the University of Osaka (Japan), and was deputy director of the London Centre for Nanotechnology (UK) in charge of business development following an extensive experience in the aerospace and military industry at C-level. His company, TBx Consulting Ltd provides assistance in fields of Strategy, programme management and Interim Management.

Tom Warwick

In the early nineties Tom took his commercial experience to a Cambridge UK manufacturer of Ultra High Vacuum Scanning Tunneling microscopes. Doubling the turnover twice caused a cash-flow crisis resulting in the sale of the business to Oxford Instruments where he stayed on for two further years selling world-wide. Tom was headhunted by Digital Instruments, which subsequently merged with Veeco Inc, to set up their UK operations. At Veeco Tom progressed to become GM of European Operations and VP Global sales for their instrumentation metrology business. Tom is currently a GM for NanoInk a Chicago based manufacturer of benchtop nanolithography systems.

Annexe 1 : List of Scientific researchers interviewed

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Annexe 2: Brief summary of the recommendation to decision makers

What value can be extracted?

The UK has a very strong reputation for science internationally, we punch well above our weight by any metric; there was early investment into nano and the UK has a good track record in filing IP, seeding spin-outs and start ups. The expectation is that there will be strong growth opportunities in this field over the next 10-20 years.

How to train and retain

While academics do have a debt to society and should do some applied research, the panel generally felt that the best inventions have come from Blue-Sky research, through responsive mode grant applications as opposed to directed ones and frequently were not on the original plan of work. The discovery of fullerenes was given as an example by a couple of respondents.

Academe is populated by two camps, fundamental research from which all science is based and applied research to solve problems of commercial and societal need.

Most agreed that secondary education and careers advice does not portray science to be an exciting option nor is it obvious what potential careers a SET degree can lead into. It is more typical than not for both fresh graduates and PhDs to leave science altogether in favour of more commercial roles with higher salaries.

Recommendations:

- Make science more interesting and relevant at secondary school level,
- Reduce the 23 nanotech centres in the UK to 3-6 Centres of Excellence, where there is a critical mass of equipment and know-how.
- Allow nanotech centres to mix engineering and fundamental research on equal grounds to retain graduates with engineering state of minds.
- Brightest scientists ability to be funded for an extended period (up to 10) years and attach them to a centre of excellence to remove the funding application pressures, and burden of setting up their own group.
- Take medical funding as a model, where there are more sources to go to for grants, Physical scientists can only go to EPSRC where as in Medicine there are MRC, Wellcome, Cancer Research and other charities etc .
- Remove perceived barriers for progressing an invention through the supply chain, incentives through tax credits can't remain only at the start-up phase to develop tomorrow's Google's and HP's on this side of the Atlantic.
- Consider having UK researchers looking at US funding models, particularly VC in life sciences, diagnostics on west coast.

Crucial Opportunities to target

By their nature, a number of those polled could only comment on their field, or were very defensive about directed research however three main areas were cited repeatedly.

1. Healthcare, nanobio, diagnostics/drug delivery, nanomedicine and telemedicine more likely to be enabled by nano and thought to have more realistic potential for ROI than genomics.
2. Information processing, quantum information processing, spintronics, cross-over between nanobio and micro electronics
3. Energy, obvious nano contributions to solar, thermoelectric and whole coatings area.

Some thought there should be a broad target like the Apollo Mission e.g. UK to lead the way in having >20% of its energy coming from renewable sources by 2020.

Positive messaging and safety legislation

Many felt that safety issues are no different from regular research unless there was a specific particulate issue. It is important not to cripple science with over-legislation, everyone warned against holding back on research in case it could be shut down by lobbyists. All felt that we could do a better job of positive messaging. There is no such thing as a risk free society, the general public are aware of the risks of driving and side-effects of drugs, but in those cases the benefits outweigh the risks.

Leveraging an ROI on the investment in science

British industry doesn't see the role of universities as doing their research and development on a contract basis, great inventions have come out of non-directed research.

There are however instances where industry can partner with universities and go for example after EU Framework money. Nanotech would be a good test case; SMEs could be provided with grant writing help to go after EU FP7 funds. The full economic costing requirements for universities should be relaxed when partnering with business as this makes us less competitive than our European partners. Furthermore guidance should be available throughout the whole supply chain.

Our universities are good at fundamental science, and need to be encouraged still to be more realistic over the value attached to IP, making commercialisation more attractive.

Germany's linked approach should also be considered per their recent strategy for nanotechnology, which matches a proportion of directed research funds to industries already strong in Germany which include pharmaceutical, chemical and automotive. This ties in particularly well with the Max Planck and Fraunhofer technical education model.

We would encourage the growth of start-ups and fledgling companies so that the UK can benefit from the employment and wealth generation which results from successful companies. The Stanford model is one we recommend following.