The Eight Great Technologies 10 years on

An Industrial strategy?

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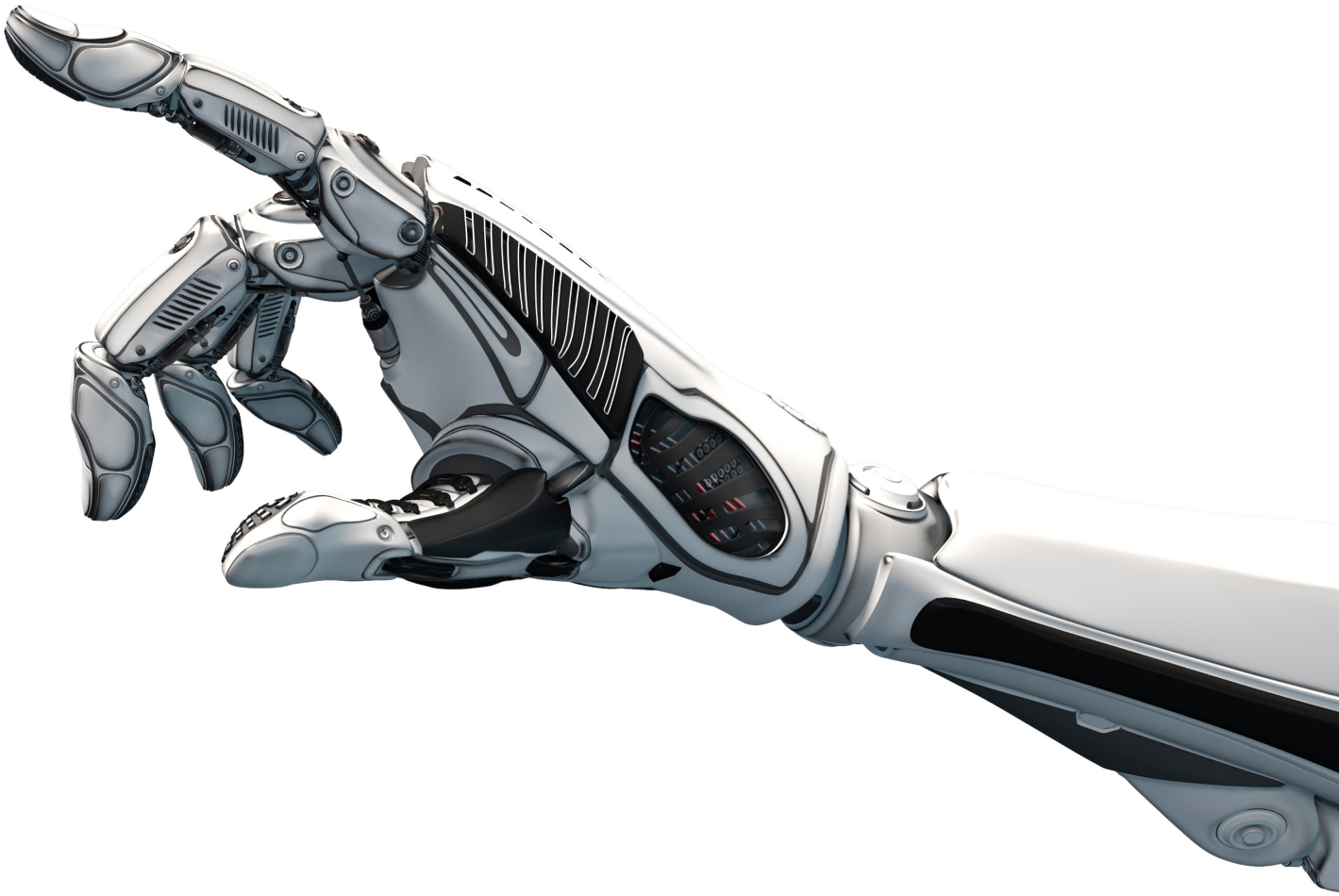

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1. Introduction

Ten years ago I launched, in a pamphlet for Policy Exchange, initiatives to invest in Eight Great Technologies[1]. Instead of vague talk about Industrial Strategy it was intended to test some very specific propositions: that Government could successfully identify key general purpose technologies and that it could back them on their way to successful commercialisation. That is why my speech ended with "a date for your diary". I invited the audience to "imagine that today we are burying a time capsule and we are going to open it up in ten years when we take stock." I specifically invited people to a Policy Exchange meeting in ten years' time on 24th January 2023 to assess my list. (It is six months since that deadline, so this pamphlet comes, in the spirit of Adrian Mole, after 10 1/2 years.)

Could Governments reasonably identify key technologies that were worth investing in? Many of the sceptics at the time believed we could not. As well as identifying key technologies based on an assessment of their comparative advantage, could we successfully promote them and deliver real economic benefits for Britain? Those were challenges to any Industrial Strategy and I saw the 8GT as a test case to assess whether the sceptics were right. So now Policy Exchange have invited me back to see how that exercise looks ten years on, judged against what I said ten years ago. One Soviet bloc dictatorship made keeping old newspaper cuttings a criminal offence so as to avoid such risky scrutiny. That is not the spirit of Policy Exchange.

The exercise is surprisingly topical as there is a renewed interest in backing key technologies with the recent announcement of five priority technologies. The intervening decade has seen a host of different initiatives to promote innovation, some of them proclaimed as part of an Industrial Strategy. It can look like random policy churn with little consistency and even less to show for them[2]. Ambitious initiatives are launched but then binned by new ministers who proudly announce they have got rid of these examples of the failed industrial strategies of the past. Indeed the very terms industrial policy or even more ambitiously industrial strategy have such negative connotations that their use has itself become a source of instability. At least the sheer range of initiatives, many of which have had some appraisal of their economic impact, enables us to identify if any of them actually worked. Stephen Roper at Warwick Business School for example analysed the effects of public funding for corporate R&D from the Engineering and Physical Sciences Research Council (EPSRC) and Innovate UK on British business and found they increased their turnover and employment 6% faster in 3 years and 28% faster 6 years after, compared with similar firms which did not receive support. He found particularly strong effects for small firms and those with lower starting performance.

1. David Willetts *Eight Great Technologies* Policy Exchange 2013.
2. Diane Coyle and Adam Muhtar *Industrial Policy: Learning from the Past*. Benet Institute, Productivity Insights Paper 002. October 2021

2. Industrial Strategy: Horizontal or Vertical?

There is understandably deep scepticism about Industrial Strategy going back to the failures of ambitious plans such as Concorde and civil nuclear power and culminating in the disaster of the British car industry. They were key evidence for the Thatcher critique that these programmes just wasted money and often propped up failing industries. David Henderson, who went on to become chief economist at the OECD, produced an influential paper in 1977 on the failure of AGR reactors and Concorde[3]. His 1985 Reith lectures were an eloquent case for the free market, demolishing popular misconceptions about the particular value of certain economic activities over others. It was a powerful critique of industrial strategy. I was working in the No 10 Policy Unit at the time and got his book based on those lectures into Margaret Thatcher's box - for light holiday reading[4].

There are some parts of the economy that just want to be left alone to get on with their business within a stable and favourable environment. But innovation happens in the messy space between curiosity-driven research and the market-place. It is here that the dilemmas of Industrial Strategy are most acute. The classic market liberal view would be that if research academics have got a great idea companies ought to be able to spot it and invest in it. Government should restrict itself to policies that support research and innovation in general. That means good funding of curiosity driven research based on merit not status and protected from political interference by the Haldane principle; attracting smart researchers to the UK; an effective IP regime; tax credits for company spend on R&D; and not much else. After that we should expect business and venture capitalists (VCs) to take over. Public policy can promote venture capital with soft funding for new funds so that their profitability is enhanced and hence more commercial funding is attracted but without any attempt to promote investment in particular technologies. That is the Treasury view and its adherents can be found across Whitehall.

It is "horizontal" policy which is supposed to apply neutrally across all sectors and technologies. The fear is that if Government actually takes a view and promotes specific places or technologies or sectors it will end up wasting money. The lesson is supposed to be that we can't pick winners: instead losers pick the pockets of tax-payers. It is therefore the job of a truly reforming pro-market Government to roll back any such ill-conceived interventions. That view is still to be found in Whitehall and Westminster where fear of repeating the mistakes of the 1960s and

3. David Henderson *Two British Errors: their Probable Size and some Possible Lessons* Oxford Economic Papers 1977.
4. David Henderson *Innocence and Design: The Influence of Economic Ideas on Policy* Blackwell 1986.

1970s casts a long shadow. Much of the policy churn is driven by brief periods when such a sceptical view is in the ascendant after which the slow process of rebuilding practical initiatives starts again. Indeed just as innovation happening in the messy area where pure research is applied so successful policy is found in that similarly messy area between laissez faire Olympian detachment and getting lost in the weeds of trying to promote and steer particular firms.

The sceptical view is reinforced by an unusual and particularly English doctrine of the unknowability of technological advance. The development of new technology is apparently so random and unpredictable that there is no point trying to support it. It is true that we do not have perfect foresight, however I came to believe that quite a lot can be forecast pretty well, especially after the initial advances in fundamental science. Science and technology is difficult but it is not fundamentally more difficult than many areas with which public policy engages. Many educated British politicians and advisers who are happy to hazard a view on reform of pensions or the causes of unemployment or the path of the war in Ukraine are filled with deep anxiety when asked to consider compound semi-conductors or genomics. Other advanced countries do not have this problem or at least not so acutely. It is the result of the peculiar English education system which means that many people regarded as well-educated will not have done any Maths or Science since the age of sixteen. The Prime Minister is right to focus particularly on the problem of so many young people not doing Maths after the age of sixteen when it is fundamental to so much of the modern world. C P Snow's *Two Cultures* is not about a fundamental gap between the Arts and the Sciences; it is a well-observed critique of the consequences of the English education system:

"this cultural divide is not just an English phenomenon: it exists all over the western world. But it probably seems at its sharpest in England, for two reasons. One is our fanatical belief in educational specialisation, which is much more deeply ingrained in us that in any country in the world, west or east."[5] Early specialisation is one reason we are bad at commercialising our scientific discoveries because it is a barrier to moving science into the mainstream and enabling private funders or company executives to invest with confidence. Many of them are anxious about anything scientific or technological – investing in shopping centres seems so much less scary. It is also a significant barrier to good public policy where a great way to disguise ignorance is to assert that these things are fundamentally unknowable. Instead civil service expertise becomes process not substance –sometimes empowering outside consultants to advise on the substance instead. Peter Thiel's Zero To One is a powerful critique of the crippling effects of thinking we can't know anything about scientific and technological advance:

"You can expect the future to take a definite form or you can treat it as hazily uncertain. If you treat the future as something definite, it makes sense to understand it in advance and work to shape it. But if you expect an indefinite future ruled by randomness, you'll give up trying to master

5. C P Snow *The Two Cultures* Cambridge University Press 1998 p17

it….Indefinite attitudes to the future explain what's most dysfunctional in our world today. Process trumps substance: when people lack concrete plans to carry out they use formal rules to assemble a portfolio of various options."[6]

I myself am a lay person with an education leaving me shockingly ignorant of much of science and technology. But I have had the good fortune of many real experts patiently explaining stuff to me. Indeed I now chair the UK Space Agency. It really is rocket science and even that is susceptible to engagement by lay people. So I used to be one of those people with classic Treasury scepticism together with deep ignorance of science and technology. Two prominent politicians – Michael Heseltine in the 1990s and Peter Mandelson in the 2000s led the rediscovery of Industrial Strategy. I had already started to see the inadequacy of the Treasury view as an account of what Government could or should do. I can still remember my first flicker of doubt about it. Health policy was one of the areas I worked on in the No 10 Policy Unit in the 1980s. We laboured long and hard on a new policy to tackle breast cancer with Britain's first mammography screening programme. At no point did anyone at any meeting ask whether we had any industrial capacity actually to make the innovative new mammography equipment that would be needed to deliver our policy or if we might use our new policy and the forthcoming procurement of kit to promote it. After we announced the new policy someone from the industry asked me why we hadn't tipped them off about our plans so they could have started designing the right kit for our objectives. That small example was an early lesson in how uninterested Whitehall could be in the real supply side. Decades later I was talking to a Treasury minister who was proud of the economic sophistication of the contract for difference model for promoting renewable energy, notably offshore wind. I said it was indeed a great model and had led to the creation of a successful global offshore wind industry but because of the lack of UK Government interest in the supply side the main company to benefit was Denmark's Orsted, now the world's largest offshore wind company. The minister paused and said "that is a new angle which hasn't been put to me". The same lesson still needs to be learned.

Back in the 1980s even Margaret Thatcher herself was involved in one of the most conspicuously successful industrial policies. After the dismal decline of the British motor car industry she set about attracting Japanese car companies to set up here, linking it to another successful initiative of hers – the European Single Market. She flew to Japan and directly pitched for their investments with strong financial incentives.

That is not a solitary example. Vodafone grew to be a major global mobile phone company on the back of an extremely effective British official campaign during the 1980s to shape mobile phone standards in Europe and then globally around its operating system[7]. Influencing the setting of international standards is key especially if they can be linked to intellectual property which has already been patented. Dan Breznitz puts the point very well:

6. Peter Thiel *Zero To One*. Crown Business 2014 pp61-62
7. Stephen Temple was the key official in DTI who drove this. His book *Inside the Mobile Revolution: A Political History of GSM* 2010 is an excellent real-world account of what industrial policy looks like now in a global economy.

"Technology standards are the platforms on which current markets evolve and further innovation is developed. They determine the winners and losers of technological battles….firms (and their regions) that manage to insert their patents as standard… secure to themselves and their communities a reliable source of income and jobs as well as increase opportunities to shape the global trajectories of technologies and industries"[8]

One further complication for the UK is that our regulators such as Ofcom are often the British representative on the key international bodies but their remit is to promote competition not to promote the UK's business opportunities. Their statutory duties can be a key part of the problem, restricting their role and not enabling them to promote investment or innovation. Stephen Temple would have found it much harder to work as he did to promote Vodafone in today's environment where much of the work he did has been farmed out to a regulator operating at arms-length from Government.

The Treasury is the great sceptic of any role for Government. It is a typical mix of intellectual rigour and institutional self-interest as such a policy requires a powerful department of the real economy to deliver it and the Treasury has always tried to subvert any such department. The failure of Wilson's Department for Economic Affairs, partly because of Treasury hostility, was a key element in the wider loss of confidence in Industrial Strategy. But the Treasury is also the Department responsible for financial services and if a sector is its own responsibility, not under the purview of a rival department, the Treasury has proved surprisingly willing to practise industrial strategy. Indeed it has been rather good at it. Big Bang in 1986, cited by the Chancellor in his 2022 Autumn Statement, was a deliberate attempt to change the City's operating model, so it promoted big global integrated banks operating out of London. Extending the Jubilee line to Canary Wharf was key to ensure there was enough space with good transport links to service this growing sector. Would such a project have been delivered for a new manufacturing centre? More recently the Treasury has taken a real interest in FinTech and, working with the Bank of England, charged the FCA to drive it forward with for example a Sandbox environment in which innovations could be safely trialled. The Deputy Governor the Bank of England gave an excellent review of the issues[9]. The regulatory sand-box is a great way of promoting innovation and should be used elsewhere. Imagine responsible regulators and ministers publicly assessing and promoting other new technologies in the same way – the serious opportunities and also risks of on-line learning in education or the role of agri-tech in boosting the performance of UK farming.

Behind the Thatcherite rhetoric and even at her instigation we have therefore actually been doing industrial strategy after all, usually aimed at promoting innovation. Even the Treasury is at it. But there are still many sceptics who believe that there is something really bad called "picking winners" which has been tried and failed. It has become an all-purpose term of abuse and has led to deep wariness about the capacity of Government

8. Dan Breznitz *Innovation in Real Places* OUP 2021 p154
9. *Reflections on DeFi, Digital Currencies and Regulation* – speech by Jon Cunliffe 21November 2022

to do anything useful to promote growth apart from just getting out of the way. (Nicholas Ridley was such a Thatcherite Secretary of State for Trade and Industry. He was also a heavy smoker. He was a wonderful man for whom I worked but his view of his role in the Department was pithily summarised as "no in tray, no out tray, only an ash tray".) Ministers and officials come to think that you can't actually have a view or a strategy to do anything in particular. Real decisions on key technologies or how to promote entire sectors are of course very different from backing individual companies. There can however be tricky cases in some advanced technologies where there is only one company with a particular capability and nowadays security angles here are increasingly important – so for example Sheffield Forgemasters is the only British company making advanced steel components for nuclear powered submarines and other key sectors: it was eventually taken over by the MoD in 2021.

The classic liberal view rests on a clear distinction between "horizontal" policies, applying across all sectors equally to promote a stronger supply side, and "vertical" ones for particular places or sectors or technologies. The distinction looks clear but in the real world of policy the horizontal often tilts unexpectedly and ministers and their advisers find themselves sliding, rather baffled and disoriented, into a position which is surprisingly vertical. Here are some examples.

The purest classical liberal will agree on the importance of public investment in infrastructure but where do you actually put it? How do you decide? Perhaps it looks safe just to do the cost benefit analysis on the current distribution of people and activity. But what if that is changing? Could you work instead on the basis of a future plan?

Government needs to procure goods and services but from whom and on what criteria? Should they have a track-record but in that case could you ever buy from an innovative start-up? (New procurement legislation tries to tackle some of this.) Procurement by the NHS is potentially a powerful tool for promoting life sciences but why has it proved so hard to do in practice? One big VC fund would not invest in any British life sciences start-up which had selling to the NHS as part of its business model because of the difficulty of getting it to adopt any innovation. What could Government do about that?

The UK has its own trade policy post Brexit. That boils down to negotiation on the terms of access to particular markets – what are our priorities in any negotiation?

A new technology is emerging – should new regulations be drafted for autonomous cars or genetic modification? (Two examples of excellent recent initiatives.) Should they reflect our own capabilities? Should we try to influence international standards?

Education and training is another horizontal policy but in what form? What if specific industries are growing but held back by shortages of particular skills? The Home Office identifies shortage occupations - should their list shape domestic skills policy?

The idea of Industrial Strategy has become so burdened with past

associations that it has ceased to be a useful term. But really it is just an attempt to answer those sorts of questions. It means thinking strategically about how to grow your economy. Inward investors say they can have conversations on these real issues with individual American states or Federal agencies which often have quite ambitious industrial policies but find it much harder with anyone in England. It is not socialism. It just recognises that a key role of Government is to bear risk. Indeed Government is the biggest bearer of risk we have got – that is why we have a welfare state as well. There are limits to how much risk commercial enterprises will accept. These risks are particularly high with innovation-driven by science and technology. If Government takes on some of the risk it can promote business investment alongside it. Think of those illustrations of thermometers on the side of Church steeples showing how an appeal to raise £1m to restore it is going. Cautious official advice can often be that if they succeed in raising £900k from others then Government can put in the last £100k. (Though then you are caught in a Catch 22 as by that point the Treasury can argue that public money isn't needed.) But often Government has most impact if it puts in the first £100k, signalling that this is a serious project worth backing, and promoting more private funding. And there is now rigorous economic evidence that this pays off with more growth. Public support need not displace or distort private investment it can increase it and nudge it into key innovative new technologies.

The danger with such interventions is not picking losers: it is playing safe and pushing extra resource to the big incumbents. Requirements for private co-funding early on can mean that only big companies have the capacity to join the programme. The British managers of global businesses make persuasive points that there is an international competition going on about where to locate a new activity and British funding and engagement can persuade their global HQ to invest in the UK. I was involved in persuading IBM to locate some of its research in cognitive computing at our new Hartree Centre for digital innovation at Daresbury in Cheshire by committing public expenditure to the programme. On another occasion Vince Cable flew to the US successfully to persuade GM to invest in Ellesmere Port. But there is more beyond the big players. There are also lots of programmes for start-ups. The gap is sustained support for rapidly growing scale-ups. One way to reduce the risk of capture by the big players is to focus is on new technologies and industries. Then one is less likely to be backing incumbents and more likely to reach the fresh scale-ups. New technologies are inherently disruptive. As Schumpeter observed: "In general it is not the owner of stagecoaches who builds railways."[10] The barriers have been public procurement processes that look for a long track record and do not fund innovation. Moreover policy churn with the endless launch of new schemes gives advantages to big companies with public affairs departments tracking all the new initiatives. One reason I relaunched the excellent SMART programme of innovation grants for small business which the late David Young had first set out in the 1980s was that the brand name was still well-recognised so we had a better

10. J A Schumpeter *The Theory of Economic Development* 1934 Transaction Publishers p66

chance of reaching smaller companies.

New technologies and enterprises are on a long and tricky journey to the market. Easing some of the risk burdens on business as they innovate is one of the best ways Government can promote growth. It is a serious mistake for Government to withdraw its support too soon and then expect commercial investors to take it on. It may hide its mistake by complaining that business leaders are risk averse but actually it is expecting them to take more risk than in many other countries. This lesson is harder to learn because by the time there is an IPO and another unicorn floats on the stock exchange the original support from an Innovate UK programme may well have disappeared from view. Innovative companies usually only identify previous equity investments when they float. Non-dilutive funding such as Innovate UK grants are not part of the capital table so will not be visible, even to experienced investors coming in at that stage. This promotes the illusion that all this "just happens" because of savvy City investors with no public policy behind it. Bold self-confident tech entrepreneurs and VC investors perform an invaluable role but they can understate the role of public agencies in getting these companies going in the first place.

3. Lessons from America

This account of the role of Government promoting key technologies is what Republicans do in America. Behind America's rhetoric of a Jeffersonian state of sturdy individualists there is the reality of a Hamiltonian state spending and regulating to promote national greatness through science and technology. Indeed Alexander Hamilton's *Report on the Subject of Manufactures* of 1791 remains very pertinent - and he did end up as America's first Treasury Secretary and the star of his own musical. He argues for an economic policy aimed at "rendering the total mass of useful and productive labor in a community *greater than it would other be*" He also deploys the national security argument that "it will tend to render the United States, independent of foreign nations for military and other essential supplies.".[11]

In America it is widely understood that it is one of the roles of Government to lower the risks facing innovators. I have met US technology entrepreneurs who would never get public financial support in the UK but when you ask how their new gismo is funded will say they have already sold the first 10,000 to the Department of Defence even though they have not yet got a working prototype. (This incidentally is impossible in the UK because the Treasury Green Book rules out any prior payment for delivery of any good or service. So one of the powerful American tools for promoting innovation is not available in the UK.) The US DoD was even a partner in the human genome project. The US has an industrial strategy which is hidden behind a security strategy. They have a security strategy that they should aim to be the global leader across all key technologies. It began after the Second World War reinforced by the fright they had when the Soviets launched Sputnik. That finally crystallised their security and technology doctrine which is quite simply – no surprises. Nobody anywhere in the world should be developing a key new technology of which the US is unaware and which they can't match.

That doctrine means they provide systematic help to business especially in high tech on a scale which is not understood by British policy-makers who take American free market rhetoric at face value. What America actually does makes British anxieties about "picking winners" look absurdly querulous. We think somehow our business leaders are risk averse when they aren't worse than anywhere else. The problem is we expect them to bear more risk than in the US because there is a shortage of smart Government procurement and support for innovation. America helps its high-tech start-ups much further on the long journey to market than here. Elon Musk would not have got where he is without very substantial federal

11. These quotations come from Dani Rodrik's paper *An Industrial Policy for Good Jobs* published by The Hamilton Project, September 2022

and state funds – about $7b according to one estimate[12]. In Britain he would be denounced as a subsidy junkie. During my time as minister I noticed how the US Government became increasingly interested in extending the life of the International Space Station, having at first opposed the idea. The explanation was that it would mean that they could provide bigger long-term contracts to Elon Musk to supply it – a good example of smart industrial policy which the UK would find hard to grasp. America also has significant state funds which are often not included in comparative analyses of national industrial policies. (Elon Musk got over $1b from the state of Nevada to locate Tesla there and build a giga factory.) America has fewer constraints on these programmes than the rules of the European Single Market which are far more market liberal - as the European rules were heavily influenced by Margaret Thatcher's Britain in the heyday of free market thinking.

Here is a statement from a programme director in DARPA describing how he promoted new semi-conductor technologies.

"Take the case of thin-film technologies. In that case I funded two parallel programs. I funded IBM, because they were convinced that the parallel junction for thin-film SOI wasn't going to go on forever, and they wanted more thick-film SOIs for the company manufacturing purposes. And then I funded Lincoln Labs to do thin-film SOI.... I pitted Lincoln against IBM.... So, they both succeeded, and IBM is still manufacturing thick-film SOI today."[13]

He was doing that under Ronald Reagan. Imagine British officials with the self-confidence, technical grasp and political support to operate like that.

The British purists who do not think we can have any kind of industrial strategy are actually the creatures of very peculiar circumstances – the extraordinary good fortune of the American security umbrella over us. That means they we have not had to work out if some new technology is needed to help protect our security and hence our freedoms. But the only reason we can operate like that is because America protects us and one way they do that is by having an American industrial strategy. Our belief we can avoid having an industrial strategy is just free-riding on America's willingness to have one. That is a legitimate policy for a small open economy but inadequate for a medium-sized one and we certainly should not elevate it to a matter of high economic principle. The most significant shift in Government policy on technology over the past twenty years is the return of this security-oriented thinking, captured in the *Own, Collaborate, Access* approach of the Integrated Review.

America is a great power. The rise of China is creating similar anxieties today. However with such a large industrial base those they have a good chance of capturing domestically the economic benefits of new science and technologies. It is more difficult for us as a medium-sized economy with limited resources. We have an unusually broad science base for a medium sized economy which is in many ways an asset. But that just makes the decisions we have to make on how best to support commercialisation of

12. *Elon Musk hates Government subsidies. His companies love them.* Grid News 30.4.22 Good Jobs First estimated it was $5b of subsidy back in 2015.

13. Sharon Weinberger *The Imagineers of War: The Untold Story of DARPA, the Pentagon Agency that Changed the World* Penguin Random House 2017

these advances even harder. We need to focus rigorously on areas where we have a comparative advantage. The problem is even more acute for us because of our security dependence on America: the MoD is so aware of this dependence that they are ultimately always happy to buy American. And many of our policy-makers are so in awe of the American West Coast and East Coast that they cannot believe we could possibly do as well as them. Our leading research universities are exasperated by injunctions to learn from Stanford and MIT when, given the much more limited resources at their disposal they are doing a very good job – and I hear at first hand the enormous respect that America's leading universities have for ours.

4. The Eight Great Technologies

So there is a very tricky backdrop to any attempt at British strategic thinking about promoting innovation and backing key technologies:

- a fear amongst some policy-makers that it means propping up failed industries;
- a belief that science and technology just happens in unpredictable and mysterious ways;
- the failure to understand what America actually does combined with an inferiority complex and a security dependence that makes us believe we couldn't possibly do what they do anyway;
- fiscal constraints forcing tricky decisions on allocation of limited resources when there is great reluctance to think strategically.

So we end up in the deeply unsatisfactory position where Governments can't avoid having to take decisions which add up to a kind of industrial policy but where it is also hard to do it in a rigorous strategic way because of a reluctance to admit that such decisions are even being taken. Against that back-drop we can now look more closely at what I tried with the eight great technologies.

General purpose technologies are key to innovation. They are disruptive so they don't reward incumbents. And companies aren't ready to invest in them until specific applications are developed so there is a useful role for Government in the earlier stages of their development. That is when they are in the "valley of death" beyond pure scientific research but without yet sufficient proof of their viability at scale with clear applications to be commercially investible.

The Americans had a simple list of major areas of scientific and technological advance – Bio, Nano, Info and Carbo, or BNIC. An even simpler way of thinking of them is dry, digital technologies and wet, biological ones. But that is just a start. The next and crucial step is to identify some particular technologies within these very broad categories. But that is still not applications so specific that companies can see they are close to market and are ready invest themselves.

One way to identify where we have strengths in these potential applied technologies is looking where competitive research funding is being concentrated and patents are being applied for. Years ago we did not have easy access to these sort of data-sets but now the Office for Science and Technology makes heavy use of such analysis.

It is also useful to assess their progress through technology readiness

levels (TRLs) on a range from 1 to 10. This metric was first developed by NASA so they could assess how close a technology was to being available for use in a space mission. They can also be a good indicator of where targeted public support is of most value. If a new technology is at a low readiness level then if there is any funding it is for basic science. If it is at a high TRL then it is close to market and one is beginning to expect commercial investment, perhaps in a public/private mix. Public funding can have most impact in the middle where we are beyond basic science but not yet ready for market. This is where UK has been weak. It is not where academics do the most prestigious research which gets into prominent publications and wins prizes. Nor is it so close to market that even a British company looking for high rates of return in the short term will invest. It is the messy middle where the great American national labs help prepare technologies for market and where we have had little capacity. That is why at the same time as identifying these key technologies we were also creating Catapults to help plug this gap. It is where technologies are tested, developed and scaled up.

Just being at those technology readiness levels does not of itself justify further public funding. There has to be some extra reason. One argument is that this is a developing technology of such significance that we need to have some capacity ourselves, even if it is just so that so we can absorb and apply what is happening elsewhere. This is the absorptive capacity argument. Then there is the strategic security argument: this technology is so significant for our security that we need at least to have access to it. This is the requirement argument. It is the security thinking leading to the follow-up decisions of *own*, *collaborate*, or *access* which sets the framework for the Government's recent statements of its innovation policy and reveals the influence now of the security perspective. But I was really focussed on something else - comparative advantage. Have we got something distinctive which could give us a particularly strong position of economic value in a global market? And were there global commercial opportunities which could potentially be seized by British-based companies?

Comparative advantage comes in different forms. Here are some examples:

- an unusual geographical or other natural feature gives us a potential opportunity. We are a windy island so offshore wind and indeed tidal power make sense. Low earth orbit constellations of small satellites are often in Polar orbit so it is attractive to launch North from Scotland out over open ocean.
- a particularly dynamic applied research programme has been created by one or two visionaries which has in turn attracted others and created a world recognised cluster such as David Payne in photonics at Southampton or Colin Humphries in advanced materials for semi-conductors in Cambridge or Andre Geim and Kostya Novoselov in graphene at Manchester.
- our history has given us a distinctive asset. Victorian collectors

ranging across the world might have endowed us with a unique data base of types of wheat or other genetic material pre-dating the Nagoya protocol after which it would be the property of the country where it was found.

- our culture and legal system might have given us a particularly favourable regulatory regime such as our high levels of secularism making us more open to bio innovations from genetic modification – such as mitochondrial donation.

That is what the expert advisers and I were looking for. We knew these judgements were hazardous and could prove wrong, but I thought that if we pursued several different technology options we might get some right. The Research Councils and the then Technology Strategy Board (now renamed Innovate UK) came up with their ideas. I particularly drew on the Government Office for Science's 2012 refresh of its report *Technology and Innovation Futures- UK Growth Opportunities in the 2020s*. It was an excellent report: the only problem was that it had come up with 53 specific candidates and some were very narrow indeed. We needed something simpler and more coherent and usable. I spent the Summer of 2012 trying to boil this expert advice down into a coherent narrative with key priorities which made sense to a layman. I had my eyes on securing funding in the Autumn Statement, so I engaged the Chancellor in the process and indeed drafted a speech which George Osborne delivered at Royal Society in November 2012 setting out our thinking. We specifically invited comments and discussion on these key technologies – we were not announcing the conclusive result of a confidential official exercise. That test run went well and George Osborne announced £600m of funding for the eight great technologies in the 2012 Autumn Statement. But we still hadn't fully explained the logic of what we were doing. Nor had we allocated the total. That is what I did in my speech in Policy Exchange in January 2013 when the pamphlet outlining the eight great technologies was published.

That pamphlet sets out the thinking behind the Eight Great very clearly because I wanted to test this way of doing what one might call a form of Industrial Strategy. In particular it was a challenge to the sceptics who said Government could not be expected to identify key technologies that could be commercialised. After the failures of civil nuclear power and Concorde we had lost any confidence in our ability to get these judgements of key technologies right. The eight great technologies were dry (big data, satellites, robotics), wet (genomics and synthetic biology, cell and gene therapies, and agri-science) and foundational (advanced materials and energy storage). Quantum was then added shortly afterwards There was a narrative behind this list which went roughly as follows:

"The digital revolution is the big technological advance of this century and we will invest in key applications where Britain has distinctive strengths and there are global business opportunities such as AI and big data, Space and satellite data, and Robotics and autonomous systems. Also it so happens that the greatest scientific discovery of the past 75 years, genetic

code, itself comes in a digital form. So the future is the interaction of dry digital technologies and the wet biological world. Britain has invented every major genetic sequencing technology and has a good regulatory regime for applying engineering techniques to genetics. We will invest in new technologies made possible by these advances, notably genomics and synthetic biology, regenerative medicine and agri-science. But none of this will happen without also investing in foundational technologies – low carbon energy to drive it and the advanced materials without which the kit and the sensors won't work."

You must judge but I think that ten years on it is still not a bad list. My worst fear was that these technologies would go the way of the personal jetpack which Sean Connery used in Thunderball. When I saw that film as a boy I imagined it was how I would travel to work. Instead for me it is still either the train or the bike – two nineteenth century technologies which have not yet been replaced by the jetpack. (David Edgerton's *Shock of the Old* is a wonderful account of the long-lasting relevance of old technologies.) Ten years on I am relieved that none of my eight are as off beam as that. But also we can see how technology development has sometimes diverged from what I envisaged. That is to be expected provided that over the Eight have proved to be close enough to reality to help drive successful innovation. We can now look at the eight great technologies in a bit more detail, using the titles of the chapters in the original pamphlet, to see how they have stood the test of time.

1 The Big Data Revolution and Energy-efficient computing

I opened with the bold claim that "The next generation of scientific discovery will be data-driven as previously unrecognised patterns are discovered by analysing massive and mixed data-sets." (p11) Big data and the compute power to find patterns in it still seem the right place to start. I go on to identify two types of British comparative advantage – in "the algorithms needed to handle diverse large data-sets" and that "we have some of the world's best and most complete data-sets in healthcare, demographics, agriculture and the environment." I particularly identified opportunities in health care and administrative data. I said there would be "further investment in high performance computing."

I was probably too optimistic that Britain had a comparative advantage in smart software that would enable results to be achieved with less energy. Instead the sheer volume of the data seems to be key, together with the raw compute power to analyse it and find patterns. Predictive text captures a surprising amount of human accomplishment. As Stalin observed in a different context, quantity has a quality of its own. AI and Machine Learning have grown to be major economic engines in their own right. The data is just the raw material.

The UK has been able to take advantage of this trend. We are the second or third global destination for AI research after the US and maybe China.

The world's leading AI companies are OpenAI, Anthropic, Baidu, and the UK's own DeepMind, now part of Google. The UK has almost half of Europe's 130 AI start-ups[14].

But not all delivery has gone well. We still say the NHS is a key valuable data set but accessing and deploying it is proving very hard. I launched a new birth cohort study linking medical and social science data but it collapsed, partly because of the different conventions of medical researchers and social scientists in for example treating confidentiality of personal data. Administrative data has indeed proved to be as valuable as that speech suggested but actually harnessing it remains a work in progress.

Despite our sluggishness in opening up NHS data, the UK is still world-leading in healthcare data. The UK Biobank was set up in 2006 and has been used by researchers across the world. Part of its success has been because it has received ongoing government support: it has been linked with UK death records and NHS hospital patient records are being added. There are still tiresome defects in health data some of which were revealed during Covid. NHS data report when someone is pregnant but that coding does not include an entry for giving birth so women became permanently pregnant and health advice against taking the vaccine could last indefinitely.

Other countries are starting to expand their efforts in AI. Canada has launched a ministry of AI, Germany has earmarked £3bn of investment, and the French government is closely supporting Mistral AI, the French answer to OpenAI. They have not yet succeeded in developing major AI players and EU AI regulation may slow them down. We have said that we are going to reform GDPR now that we have left the EU but we have been slow to exempt businesses from the worst features of the legislation that mandate the deletion and ban the sharing of large libraries of useful data. Gridlock in the US Congress means that EU rules are increasingly applied even in the US so diverging from them may risk market access. Meanwhile we have created a range of tech start-ups, some becoming unicorns, with smart software and apps.

Compute supply chains are highly sophisticated and countries specialise in particular elements of chip manufacture. For example, Dutch company ASML is the only company making machines capable of one stage of the chip making process, and they sell their machines to all the major chip firms. Similarly, TMSC in Taiwan is crucial to compute supply chains, and while they have opened a US factory, they have not yet been able to replicate their work in Taiwan. The UK has a number of semiconductor and chip companies and whilst we are not world-leading there are some very interesting potentially significant players in for example compound semi-conductors. The Government recently launched its semi-conductor strategy with £1bn of support for the industry, though this is modest compared with the $52bn of spending from the United States and 43bEuros from the EU.

14. Data compiled by Sifted cited by Anne-Sylvaine Chassany in the Financial Times 17/18 June 2023.

2 Satellites and Commercial Applications of Space

Second comes Satellites as collectors and transmitters of data. We set up the Centre for Environmental Monitoring from Space which is still thriving. I also said the trend was to small satellites where we are world leaders thanks to companies such as Surrey Satellites and Clyde Space – both now taken over. Our comparative advantage came partly from our not having big powerful rockets of our own which could launch big heavy satellites so we had to hitch a ride on other countries' launch systems – we were indeed hitch-hikers to the galaxy. That meant we developed special expertise in small light-weight satellites that cost less to launch and could be squeezed in around a big payload. Small satellites have indeed been the great growth story in Space and we remain a key player. But post Brexit we lost our role producing satellites for the EU's Galileo programme. Mass production of small satellites has also gone elsewhere – it would be great to regain it. When Airbus, the owner of Surrey Satellites, won the order to build satellite constellation for One Web, headquartered in the UK, the factory, with the world's first mainly automated satellite production line, was built in Florida with fall-back capacity in Toulouse. Now the focus is on ensuring Britain has a supply chain which can play a major role in the next generation of OneWeb satellites.

I also specifically referred to "opportunities for the UK to host a space port if we get the regulatory framework right." It was the first time a British minister had suggested such an initiative though at the time it was thought so far-fetched there was no media interest. We did get the regulatory regime in place for space launch by 2017 and moving fast has given us a competitive advantage. The UKSA has a Launch Strategy. The first ever orbital space launch from UK soil took place early this year. The real opportunity lies in the North of Scotland and two space ports are being developed there so we should expect to see more launches in the future.

Policy Exchange was the first UK think tank to have a dedicated Space Policy Research Unit and has been working to feed into this agenda and has made recommendations about what the government should prioritise. And meanwhile the Space sector has continued to grow strongly so overall it was not a bad technology to identify ten years ago and launch capacity has become a serious proposition.

3 Robotics and Autonomous Systems

This chapter focusses on self-driving cars and planes with a bold vision that "the plane of the future will be flown by a man and a dog - the man's job is to feed the dog and the dog's job is to bite the man if he touches the controls." I described robots as agents operating in the internet of things and investing in these robotic systems was paralleled with a strategy to move fast in 5G through a partnership between Vodafone and Huawei. That link to Huawei subsequently fell foul of US security concerns, slowing up the roll-out of 5G here which, together with issues on broadband access has created some problems. Nevertheless we have

seen the successful development of some autonomous drone services – including one delivering NHS supplies from Portsmouth to the Isle of Wight.

Autonomous vehicles have been a focus for Government support. The Centre for Connected and Autonomous Vehicles (CCAV) was set up in 2015. The government has strategically updated regulations and used pots of funding to promote the technology. For example, in 2018 it passed the Automated and Electric Vehicles Act which adapts the rules around vehicle insurance to allow for autonomous vehicles, though more needs to be done to implement this. £81m of funding has been awarded to industry partners to help create commercial public transport and freight services. And the government has supported the development of autonomous vehicles through the creation of testbeds and real-world testing environments, which involved upgrading 5G coverage across UK roads. Trials include projects like self-driving trucks on the Nissan Plant in Sunderland and delivery vehicles in Milton Keynes. California is still ahead of the UK in autonomous vehicle technology: San Francisco streets are full of Waymo's self-driving cars, delighting and angering locals. We are still waiting to see if UK businesses and customers are ready for self-driving cars and services.

Other countries were already far ahead of us in for example applying robots to manufacturing. That remains the case. The UK has only 85 robots per 10,000 workers, a low density compared with 200 in the USA, 240 in Sweden, 161 in Canada, 137 in France, and 172 in the Netherlands. These countries all have similar levels of manufacturing in GDP but significantly higher productivity[15]. There is even an interesting argument that countries with the most significant ageing have ended up moving most rapidly into robotics to offset these demographic pressures. Britain has so far had rather more favourable demographics and this may have reduced the incentives to automation and application of robotics – look at the return of the hand car wash. Acemoglu and Restrepo find that countries experiencing a greater degree of demographic aging have higher levels of RAS adoption and that industries that are more exposed to demographic aging, because they have an older workforce, also have higher RAS adoption[16].

We were aware we were unlikely to be a leader in robotics for manufacturing. I did go on to identify some specific areas of British comparative advantage - marine robotics, medical robotics, and nuclear decommissioning. Professor David Lane, of Edinburgh Centre for Robotics, whose own expertise was sub-sea vehicles for the North Sea,. led the group developing our first Robotics strategy. Managing and dismantling some of our complex old infrastructure such as North Sea oil rigs and ageing nuclear power stations do appear to be an area where we have a distinctive advantage. This led to an industrial strategy challenge fund focussed on robotics for extreme environments.

15. Data gathered by International Federation of Robotics

16. Acemoglu & Restrepo *Secular Stagnation? The Effect of Aging on Economic Growth in the Age of Automation*

So the focus on robotics and autonomous systems does not look strategy but the full benefits are still to come through.

4 Where Dry meets Wet- life sciences, genomics and synthetic biology

This is a very broad grouping which begins with Britain's unique achievement not just in discovering DNA but also then developing the technologies for sequencing genetic code. We have the opportunity of linking these advances to our unique NHS patient data to develop innovative new medical treatments. That life sciences challenge remains key today, with interest further rising after the COVID-19 pandemic, where genomic sequencing played a pivotal role in tracking variants of the virus. The Government published an implementation plan for Genome UK in 2022 which earmarked £178m of funding.

Synthetic biology applies this understanding beyond human medicine to redesigning biological systems for new uses. It is one of the Government's five key technologies listed earlier this year. In the pamphlet I picked out one company as an example - Green Biologics which tries to use engineering of biology to modify an organism so it makes key chemicals. I did though warn that after development of such an organism "The next stage is just as tricky – the steps between an organism in a lab and a full-scale industrial process." Green Biologics closed down in 2019 and one report on its demise explained that the company never got to a full-scale industrial process: "Green Biologics developed a modified strain of a *Clostridium* microbe that can efficiently produce acetone and 1-butanol from sugar….The company raised roughly $100 million in 2015 from investors keen on the market for renewable, biobased chemical ingredients for consumer products. But it was unlikely that small-volume fermentation-based production could compete with fossil-fuel versions on cost."[17]

In 2012, the UK government announced it was investing £50m in synthetic biology, now sometimes called engineering biology. The UK's research councils subsequently put forward a further £50m. Six synthetic biology research centres were set up around a hub, SynbiCITE at Imperial College, led by Professors Dick Kitney and Paul Freemont. The UK is now a strong player in synthetic biology. SynbiCITE estimates that the companies it has supported already have a market value of over £750m. We lead in European synthetic biology start-ups and are home to about half of them. Indeed I personally co-chair with Sir David Harding a small fund investing in synthetic biology. There is a school of thought that the next industrial revolution will see the use of biological processes, based on specially engineered cells, replacing conventional manufacturing.

17. Chemical and Engineering News 12.7.19.

5 Regenerative medicine

This involves stem cell therapies and is an example of our comparative advantage from being a secular country with a sensible regulatory regime. The US by contrast banned the use of federal funds for embryonic stem cell research and the EU was also quite wary because of the power of Christian confessional parties. We set up the Cell Therapy Catapult devoted to this technology. There has been an important shift in thinking away from the cell to the gene as the key unit so it became the Cell and Gene Therapy Catapult. It is a good example of the need for a bit of flexibility as a technology develops. It has had some of the most striking commercial successes with several unicorns. Wellcome's Syncona took the very smart business strategy of investing in several of the start-ups in this technology emerging from the Catapult.

After the Eight Great Technologies were announced £80m was provided for regenerative medicine research and technology. The UK has been successful at growing regenerative medicine companies, nearly one in three SMEs advanced therapy medicinal companies are British[18]. Unfortunately, the UK has been slow to exploit these therapies for the NHS. British companies giving evidence to the Science and Technology Select Committee revealed concerns that while the technology had been developed, the NHS was slow to adopt[19].

This too fits into broader trends where the UK continues to have superstar companies that are able to develop cutting-edge technology – especially in the Life Sciences – but we are poor at applying these technologies for patient benefit.

6 Agri-science

I acknowledge in the pamphlet that this is not strictly a general purpose technology like the others. It is really about applying advances in life sciences set out in the previous two sections to agriculture. The agenda set out in this section does sound very relevant still – from the backing for vertical farming through to the bold statement that the "biggest future Health threat is diseases crossing the species barrier from animals to man." We have excellent centres for agricultural research such as the John Innes Centre and the National Institute of Agricultural Botany. But DEFRA was notorious for cutting its R&D spend so when I secured further funding from the Treasury as part of the 8GT initiative one of the conditions was that it was not to go straight to DEFRA but instead to the Science Budget and allocated by a group I co-chaired with a DEFRA minister. It was a vivid example of the wider problem that departments cut their own R&D spend and then looked to the Science budget to plug the gap.

Britain has historic strengths in plant and animal breeding together with intensive agricultural practice and expertise in genetics. But the productivity of British agriculture and the hope was that a burst of support for agricultural innovation could get our performance back on track. There was also funding for agricultural technologies to try to replace manual labour in vegetable and fruit picking. Currently 53% of UK farmers are

18. Departmet for International Trade *Regenerative Medicine, cell and gene therapy.* 01.12.21
19. House of Commons Science and Technology Committee. *Regenerative Medicine. Fifteenth Report of Session 2016-17*

prioritising increasing productivity in response to the change in farming subsidies and a decrease in cheap agricultural labour. One of the key advisers pressing this agenda was George Freeman and it is great to see that now he is Science Minister he continues to argue we should take advantage of historic strengths and double down on Agri-tech[20].

7 Advanced Materials and Nano-technology

Advanced materials is a broad foundational technology applied to many different technologies and sectors. The scientists who discovered graphene had just won the Nobel prize so that gets a mention in the pamphlet. So does using innovative new materials to boost performance in Formula 1 racing, offshore wind and nuclear fusion. So does advances in LED lighting and gallium nitride to enhance the performance of silicon chips. I cite a revived Plessey and Thomas Swan as companies well-placed to lead in this technology and ten years on both continue to thrive.

The Henry Royce Institute for advanced materials was announced in 2014 with £250m of funding to reinforce the effort on advanced materials and in 2022 it received a further £95m. In Manchester, the National Graphene Institute was opened in 2015. Imperial College's Institute for Molecular Science and Engineering was founded in 2015. In 2021, Advanced Materials was chosen to be one of the seven technology families as part of the UK's innovation strategy. From 2015 to 2023, the amount of commercial funding to European Advanced Materials companies steadily increased, with the UK one of the leaders[21].

8 Energy and its storage

Ten years on this is a surprisingly topical account focussing on small modular reactors and improvements to or replacements for lithium ion batteries. There is a discussion of promoting battery technologies for electric vehicles and a re-design of the electricity grid with greater and more diverse inputs.

Energy and storage have been at the heart of government strategy as Net Zero has risen up the agenda. Over the past decade we have pursued an aggressive decarbonisation strategy as part of our commitments to addressing climate change. The currently plan is for the electricity grid to have zero-emissions by 2035, with wind and solar contributing an increasing proportion of our electricity mix[22]. However we have done better at shifting to these greener sources of energy than we have been in promoting energy storage so there is a problem of intermittency with substantial use of gas as well. This in turn has been a key driver of the surge in British energy prices since Russia's invasion of Ukraine.

Assessment

Looking back over the last ten years there is good news and bad. The good news is that the list of eight key technologies does not look eccentric. Indeed it is striking how topical it still is. If the test is Government's capacity to identify key technologies relevant to the UK then it does suggest the

20. Fresh Produce Journal 12.1.23
21. Data gathered by Sifted. *Advanced Materials.* 4.5.23
22. Raugei et al. *A Prospective Net Energy and Environmental Life-Cycle Assessment of the UK Electricity Grid.*

sceptics are wrong and it can be done, even though not perfectly of course. It is not easy and involves openness and discussion and adjustments as the path of technologies changes.

We have also seen the emergence of new British companies in these areas, though the process for turning a key technology into serious successful companies is long and messy. There have been British tech unicorns in some of these technologies notably AI/compute and Biotech. Some have then been bought up, though often with key functions remaining in the UK which was always one of our objectives. But most of our surviving start-up unicorns are in tech not the deep tech of many of the eight great technologies. And that may be partly because the bad news is that Whitehall found it quite hard to stick with the list. George Osborne provided ring-fenced funding for five years and we were able to use that to give them a real push. But there was more subsequent policy churn than I had hoped or expected. Now let's turn to that.

5. After the Coalition

The 2015 reversal

I wrongly thought that the Coalition's rather successful if eclectic and occasionally improvised mix if policies to promote innovation was stable and secure. However when I and then Vince departed from the scene Sajid Javid as the new Business Secretary tried to dismantle most of what he regarded as "industrial strategy". It was a reversion to the purist strand of thinking that Government couldn't and shouldn't be doing any of this. He did not believe Government should back key general-purpose technologies so whilst the funding I had secured lasted for several years he was disinclined to support any further activity. The expert technology teams at Innovate UK were disbanded and many left the organisation. The Green Investment Bank was privatised and shifted its focus to later stage investments. One of the weaknesses of British business is a long tail of under-performing companies where management is relatively weak and under-professionalised: initiatives to try to do something about this were closed down. The UK Centre of Employment and Skills had been set up to develop really granular data on skill shortages and low productivity sectors and propose specific interventions to tackle them. But its Chair Sir Charlie Mayfield was providing uncomfortable evidence of how poor our productivity was in some areas so UKCES was also closed down.

Innovate UK provides grants for proof of concept and proof of market to small business to help them in turn secure private funding: Innovate UK's budget was cut substantially in the Autumn 2015 Comprehensive Spending Review. One senior Treasury official subsequently told me that the Innovate UK cuts were the worst mistake of that exercise. Innovate UK and the Catapults were further hobbled by review after review – one of the ways Governments can weaken entities it does not like and then use that weakness to attack them further. That period of just over a year (May 2015- July 2016) is the most powerful evidence of the policy churn which concerns the critics.

The Return of Industrial Strategy – Challenges and Missions

However that period of disruption did not last long. Theresa May became PM and installed Greg Clark as Secretary of State (2016-2019) Together they led a refreshing new approach. There were explicit references to Industrial Strategy – going beyond what the Coalition would have been

willing to commit to, at least in public. It was not however a return to the old model. It was a new model based above all on Challenges. The influence of the charismatic Mariana Mazzucato had now reached the top of Government. Greg Clark embarked on an exercise – in which I was closely involved – to identify key national challenges which would be at the heart of a new Industrial Strategy. They were:

- Put the UK at the forefront of the artificial intelligence and data revolution
- Maximise the advantages for UK industry from the global shift to clean growth
- Become a world leader in shaping the future of mobility
- Harness the power of innovation to help meet the needs of an ageing society

Challenges are an important instrument of policy. The Industrial Strategy Challenge Funds were explicit partnerships with industry and some have delivered significant results. Moreover some of them were deliberately devised to continue funding some of the eight great technologies. The original idea was to model them on DARPA programmes and after travelling to the US to see how that was done the team came back and proposed a regime very much like DARPA with powerful programme directors free from some of the Treasury controls. This approach was rejected however in favour of heavy-handed controls with overlapping committees meeting frequently to assess how each programme was doing with constraints on the powers of the outside experts appointed to lead the individual programmes. It was an early unsuccessful attempt to set up something more like ARIA within the framework of Innovate UK.

Challenges should be part of the framework of Innovation policy. But there are risks too. Challenges can appeal to that anxiety about actually knowing real stuff about real things by enabling policy to float above those key decisions. And they could be over-interpreted as meaning there was no need to invest in the underlying science and technology – not least so as to give us the capacity to set future challenges. I co-chaired a Commission on the whole issue with Mariana Mazzucato. We agreed the following statement of our position:

"Missions are not a replacement for support to sectors and technologies. The work we have done on challenges and missions again shows there is a distinct role for public agencies in supporting sectoral capabilities and, in particular, general-purpose technologies in their long journey to market and before their main applications are clear. This must be done in parallel with a challenge-based approach. This is a precondition of its success because, otherwise, there will not be the underlying technological and sectoral capability on which to draw in order to deliver challenges and missions – America had been developing rockets before President Kennedy defined the mission of going to the Moon."[23]

This period also saw the creation of UK Research and Innovation (UKRI)

23. UCL Commission for Mission-Oriented Innovation and Industrial Strategy. May 2019

bringing together the Research Councils, Innovate UK and Research England. UKRI, on whose board I sit, is the national agency for R&D. It links up-stream research with down-stream applications. UKRI should not just be seen as delivering the core science budget but is also available to help Departments spend their own R&D budgets well. The Strategic Priorities Fund was a significant attempt to fund UKRI to work on specific research questions immediately relevant to Government departments. It is not going to continue though UKRI continues to work with Government departments to help deliver their research priorities and could be used more to do this

Back to the Future – Technology and the security agenda under Boris Johnson and Kwasi Kwarteng

Explicit Industrial Strategy fell out of favour again under Kwasi Kwarteng who decided to wind up the Industrial Strategy Council which Greg Clark had set up. This was a mistake as the Council could have become a serious player evaluating how Industrial strategy was doing. Industrial Strategy is not guaranteed to succeed. The Council could operate with full awareness of all the risks and scrutinise performance to check it was being well done. It would not penalise risk-taking but actually provide cover for deliberate risks. It would however protect rigorous policy from being undermined by chasing baubles or bailing out hopeless cases. It could have assessed what worked and keeping ministers and policy honest. Nevertheless it has now gone. But at least the Industrial Strategy Challenge Schemes run by UKRI continued and are just coming to an end now. And Kwasi Kwarteng could be pragmatic, partly influenced by his experience as an Energy minister. He saw how successful Vince Cable's Aerospace Technology Institute and Advanced Propulsion Centre (for the automotive industry) had been in promoting private investment alongside public funding for R&D and in the Spending Review put more money into them as an effective way to boost applied R&D spend. The Catapults got a big increase in funding too. The lesson is that if institutions embedding Industrial Strategy can survive their first few years even sceptics begin to see their value. They can last longer than particular programmes without an institutional embodiment. Institutions matter, as Conservatives are supposed to understand. Meanwhile, whatever the specific agenda of individual ministers, policy was really being shaped by three powerful forces.

First is the pressure to tackle the biggest challenge of the lot – climate change. Alok Sharma during his time as Secretary of State had already refocussed the department on the green agenda. It is understandable that this existential challenge should be the overwhelming priority for the R&D effort. But it is also an example of the dangers of an exclusive focus on Challenges. Synthetic biology, for example, is one of the most exciting general-purpose technologies and was funded as one of the eight great technologies and, sometimes renamed Engineering Biology, appears in the new list as well. But funding for it was coming to an end with no sign

of a follow-on. When I asked if this was wise I was told that it couldn't be funded because "it is a technology not a challenge." However, UKRI did keep on with some funding and subsequently it became clear that promising applications of this technology directly help tackle climate change by displacing heavy energy-intensive manufacturing processes. Technology push can complement the pull of a Challenge.

Covid also taught us very important lessons. It is great to have deep scientific capacity such as vaccine research at Oxford. But the key issue was the capacity to produce vaccines in which a policy of promoting vaccine manufacturing played a role. And without such capacity we had crises such as PPE. National capacities and robust supply chains turned out to matter as well as brilliant original research. (And sometimes the research can approach a problem tangentially – the UKRI funded RECOVERY trial of using dexamethasone to treating Covid was estimated to have saved a million lives around the world in its first nine months.)

The third factor is the most significant of the lot. Whilst BEIS had been prevaricating about any attempt to back key technologies and had run down the technology expertise of Innovate UK, the defence and security agencies were getting more and more focussed on them, partly influenced by the American model. A Cambridge tech entrepreneur put it very clearly when he asked me a few years ago: "How is it that the security services are so clear about the significance of my technology that they don't want me to have anything to do with Chinese investors but the Treasury and BEIS are so doubtful that anyone can possibly assess if this technology is of any value that they won't put in any British public support?" Scepticism about Industrial Strategy collapsed under the growing influence of the security and defence experts who set up and staff the Government's new Science and Technology Council. The new more turbulent global scene has brought security considerations to the fore. This is a really significant long-term shift of policy and it is a reminder that innovation is often driven by war and national security. The most important recent statement of industrial strategy is not from BEIS or DSIT. It is the Integrated Review of Security, Defence. Development and Foreign Policy. It sets out a Strategic Framework with four objectives of which the first is:

"Sustaining strategic advantage through science and technology: we will incorporate S&T as an integral element of our national security and international policy, fortifying the position of the UK as a global S&T and responsible cyber power."[24] We have seen that is what America does. It is what we used to do and we are reverting to it now.

A vivid example of the way these security issues have reshaped policy is the National Security and Investment Act 2021. An open market in company control had been a fixed feature of British policy for many years. The only reason Governments might intervene was if there was a threat to a competitive market – and the relevant market was usually seen as domestic not global hence some of the calamitous decisions set out in Section below. But the new legislation changed all that and polices all bids for companies across wide swathes of the economy. The new regime is

24. *Global Britain in a competitive age: the Integrated Review of Security, Defence, Development and Foreign Policy*. CP 403 March 2021 p18

clear:

"Subject to certain criteria, you are legally required to tell the government about acquisitions of certain entities in 17 sensitive areas of the economy (called 'notifiable acquisitions').The 17 areas of the economy are:

- Advanced Materials
- Advanced Robotics
- Artificial Intelligence
- Civil Nuclear
- Communications
- Computing Hardware
- Critical Suppliers to Government
- Cryptographic Authentication
- Data Infrastructure
- Defence
- Energy
- Military and Dual-Use
- Quantum Technologies
- Satellite and Space Technologies
- Suppliers to the Emergency Services
- Synthetic Biology
- Transport

The list mixes together key technologies and sectors and indeed the responsibilities of entire Government Departments. It includes six of the original eight great technologies. It is a dramatic reversal of one of the tenets of the free market model of the past forty years. That doctrine was suddenly abandoned with very little controversy.

Rishi Sunak and a new Department for Science Innovation and Technology

The trends already apparent under Boris Johnson and Kwasi Kwarteng are now reinforced with a powerful push from Rishi Sunak's Government. The Prime Minister has created a new Department with a focus on innovation separate from the wider business agenda. Alongside the return of the security agenda this is another example of a return to historic models. DSIT is closer to the old DSIR the Department of Scientific and Industrial Research, created after the First World War and lasting until Harold Wilson replaced it with the Ministry of Technology. More recently Gordon Brown had an experiment with a Department of Innovation Universities and Skills.

The new department corrects David Cameron's mistake in taking media and digital technologies off the Business Department back in December 2010. It was a collective punishment on the department for Vince Cable making some disobliging remarks about Rupert Murdoch when Vince was acting in a semi-judicial capacity to assess a takeover bid for Sky.

Splitting off digital to DCMS caused problems for a decade. Software was in one department and hardware in another- impeding progress in key technologies. It was hard to promote quantum (a DCMS responsibility) by investing in photonics (a BEIS responsibility). That divide between two departments is one reason the Government took so long to come up with a semi-conductor strategy. One of our worst problems is the distinction between "tech" which tends to mean software whereas the hardware is now called "deep tech". Dividing them between different departments exacerbated the problem. The new Department at last puts an end to this.

There is one further step however which really would mean we had a unified approach to the science superpower agenda – bringing universities into the new department too. Universities are where a lot of the crucial research happens. They also train the researchers and technicians we need. They also attract them from abroad. But whereas the new Science Department will have responsibility for university research, the DfE will continue to responsibility for teaching in universities. This division of responsibility is very dysfunctional as it means nobody has an overall view of the funding and performance of our universities, a key national asset receiving significant public funding.

It may seem obvious that universities should fall under the Education Department but originally they were funded direct by the Treasury. In his great report on higher education Lionel Robbins warned against moving universities to the Education Department because he feared that such an interventionist Department would not understand or value the autonomy of universities. His warning has proved accurate. The DfE treats universities like poorly performing secondary schools and intervenes in them heavily via the Office for Students. There is even a risk that they could be reclassified as part of the public sector: that would be a massive change for Britain's research effort as suddenly our universities would face control over their capital borrowing and the pay of their star researchers. (I sometimes found that the same universities with social scientists making the case for more equality were also emphatic on the need to pay high salaries to get the internationally mobile Nobel prize winners of the future.)

Universities earn significant revenue from overseas students which they have used to cross-subsidise research. But the fees for domestic students (which of course students don't pay up-front – it is a graduate repayment scheme) have remained frozen at about £9,000 for a decade. (There was one increase to £9,250.). So the real resource for educating students has fallen below the cost of educating them. As a result revenues from overseas students are being diverted from funding research instead to subsidise teaching costs for British students. The DfE is therefore in effect driving a cut in research funding because it won't properly fund British students. This is only possible because nobody in Government has to look at universities as a whole. The Government says good things about universities as places for research but not much good about them as places where most young people go for education. It has one foot on the accelerator trying to grow research and another on the brake cutting

funding for teaching and trying to limit student numbers. Driving a car like that normally causes it to stall. So why not develop a single coherent agenda by putting overall responsibility for these key national institutions in one place? This could ensure a balanced approach including vocational and technical training for adults were also transferred.

Nevertheless we can now develop effective policies to promote innovation and growth within a framework set by national security, the lessons of the Covid crisis and the Climate Emergency. The old taboos and inhibitions have been swept away – just as Quintin Hogg the first Science Minister wanted 60 years ago and his successors Michelle Donelan, Chloe Smith, George Freeman and Paul Scully are now attempting. The Government calls it an agenda to make us a "Science Superpower". A good starting point would be to draw on the economic appraisals of these initiatives which have already been tried to identify the most cost-effective measures and use them to boost innovation and growth.

6 What we can do to promote key technologies and scale them up

Security issues have meant there is a greater political recognition of the significance of Science and Technology and a willingness to back them. And we have a new Department focussed on them. But we haven't yet got a rigorous assessment of which are the key technologies where we have a comparative advantage and which should be backed with public funding. There is the list of seventeen key sectors and technologies in the National Security Investment Act set out above. Kwasi Kwarteng also revived and up-dated the eight great technologies The Government's Innovation Strategy of 2021 listed seven key technology families:

- Advanced Materials and Manufacturing
- AI, Digital and Advanced Computing
- Bioinformatics and Genomics
- Engineering Biology
- Electronics, Photonics and Quantum
- Energy and Environment Technologies
- Robotics and Smart Machines[25]

And there are also now five key technologies to be the focus of the new department:

- Quantum
- AI
- Engineering Biology
- Semi-conductors
- Future Telecoms

This is in danger of getting a bit erratic, especially as some of these lists emerge without proper buy-in or consultation with key sectors and experts. Kwasi Kwarteng's list was probably the most substantial resting on the most rigorous analysis. But it was in alphabetical order which is a bad sign: it suggests the lack of any coherent thinking about how they link up. The more recent list of five is very "dry" with the sole exception of engineering biology. This is very odd given the salience of life sciences and its appearance in separate lists of key future sectors. Nor do they link

25. *UK Innovation Strategy: leading the future by creating it*. BEIS July 2021

very well to climate change and the need to invest in green technologies. And the funding behind them is modest compared even with what we were able to come up with a decade ago – apart from Quantum which continues to enjoy special favour. Although we do have some exciting start-ups in compound semi-conductors and there is ARM it is hard to see that we have much of a comparative advantage specifically in semi-conductors. Its appearance in the list seems more evidence of the rise of the security mind-set – it is more about strategic significance for the West than hard British economics. Future Telecoms also looks a bit odd. The suspicion is that three technologies on which a lot of work was done by the old BEIS have had added to them two from DCMS where they had teams of experts (Telecoms and Semi-conductors) to create a mixed portfolio for the new Department. However it is useful to have something. It is not a bad list. There is no perfect list out there which means the current exercise should be abandoned. But we should aim for an up-dated rigorous technology-horizon scanning exercise to contribute to the next Spending Review, which shows what are the key technologies where we have a comparative advantage and where they are heading.

Despite the anxieties about policy churn we can see the outlines of a long-term and sustainable policy to boost innovation and growth. The re-emergence of the security perspective on science and technology policy is the most important development of the past few years. The challenge is to find ways of bringing security and civil considerations together in a shared framework. This is not easy. The MoD is not keen on working with civil partners in Government on a shared programme to exploit new technologies with both defence and civil applications. Defence people think for example of "requirements" which is not quite how commercial investors may see things. But linking them together would provide a good fresh way of promoting key sectors and technologies. We saw earlier how security experts have identified 17 key technologies and sectors which are so important to us that any takeover requires review. If they are so important surely the Government should also have some kind of plan for sustaining and growing each one. It need not be comprehensive or claim knowledge of the future. But it would be reasonable for the Government to have some kind of plan to promote innovative national capability and commercial opportunities for each one. Here are the outlines for such a plan. There are five key high level policy proposals and a check-list of ten measures to back specific technologies.

Five policy proposals

1 Reform Business Cases

The Treasury business case framework is pervasive and has become a real barrier. The methodology was developed for procurement but is now applied mechanically to innovation for which it is less well suited. Preparing and clearing business cases can take over a year. Separate officials may evaluate the five criteria- strategic, commercial, economic,

financial and management. The underlying model is one of market failure. The model has become so pervasive that start-ups companies apply it to themselves to assess their chances of getting public funding. The model assumes a predictable and stable world better suited for producing a stretch of motorway than an investment in a new technology. We need an updated method for appraising innovation programmes which allows for risk and uncertainty and gives proper scope for real strategy. Moreover the narrow slices of spending subject to individual business cases makes it harder to run a portfolio in which it is recognised that some technologies will succeed but others won't. I negotiated with the Treasury about the overall package for eight technologies. Nowadays some of the individual technologies would each have required their own business case further exacerbating the problem of risk aversion. **The creation of the new Department is an opportunity for a radical simplification of the Business Case rules applied to innovation.**

2 Give Public Sector Research Establishments their freedoms back

Catapults are in the private sector so as to avoid public controls which impede their ability to move fast. Universities are currently outside the public sector too – giving them freedoms on pay and borrowing which have made them such a large part of our innovation system. Our public sector research establishments (PSREs) by contrast are heavily regulated and as a result are an unusually small part of the nation's R&D effort compared with most other advanced Western countries. Paul Nurse's recent report explained the issues very clearly. **PRSREs should once again enjoy the freedoms which George Osborne and I negotiated for them in 2014 and which were removed by the Treasury when UKRI was created in 2017.**

3 Liberalise Procurement Rules and encourage departments to use them

Public procurement is a great form of non-dilutive financing for start-ups. It also signals there has been some basic technical assessment which boosts the confidence of private investors and purchasers. Our SBRI (Small Business Research Initiative) is a pale imitation of America's SBIR (Small Business Innovation Research programme) which is described by their Small Business Administration as "America's Seed Fund." New procurement legislation is currently going through Parliament but there is still more to be done**. We ought to liberalise the Treasury rules which currently stop public procurement of innovative new technologies before the product has been finalised.** Meanwhile it is worth identifying key public agencies which should be encouraged to buy an innovative new product or service but are failing to do so through caution/ignorance/ fragmentation of purchasing decisions? A useful role for UKRI is to

help get the responsible department excited by the opportunity of new technologies to deliver its services and help overcome the barriers to using them.

4 Reform the regulators

Quasi monopoly industries have historically created their own research labs such as Xerox's PARC and Bell labs. Our nationalised industries used to be heavy funders of R&D but privatisation changed that in ways we did not expect. The new regulatory regime for them was supposed to stop "gold-plating" of expenditure so capital investment and spend on R&D was restricted. The regulatory regime should be reviewed to ensure it is not a barrier to investment in R&D. **Regulators of utilities should be given a clear responsibility actively to promote investment and innovation.** Competition policy is a problem too as it is too focussed on domestic markets and insufficiently focussed on growth and innovation. The terms of reference for the Competition authority should be revised so as to make promoting innovation part of its remit

5 Create a leadership council to promote each technology

There needs to be some kind of entity with a responsibility for promoting each individual technology. I used to have leadership councils co-chaired by a minister and ideally a tech savvy person with business experience. Some of them still exist such as the Synthetic Biology Leadership Council. They can then draw on a range of practical ways of promoting each technology. Here is a check-list of the kind of measures which add up to a practical policy agenda.

1 A technology road map.

Convene a small group of trusted experts to outline where the key technology may be heading and the research that is currently being conducted both publicly and privately funded. Then you can see if there are gaps which could be plugged by public funded research or where the public research has already got so far that business can take over. So for example Sir Keith O'Nions, former Provost of Imperial, produced a very useful Space technology road-map which enabled the Space Leadership Council to see how best to spend limited public funds to advance the sector and also promoted funding by business partners.

2 Scale-up facilities

The scale-up challenge is often seen as about funding. But it is equally about the technical challenges of moving from the lab to prototyping and small-scale production before getting to fully commercial scale. This is a weakness of the British system as we are so focussed on the exciting new idea and the start-ups. We provide much less support for the next stage than the US. So it is important to ask if there an expensive piece of kit

for prototyping new products which no one business or academic player can afford but which could be funded by private and public agencies and then be rented out cheaply to lower costs of entry for start-ups. The Cell and Gene Therapy catapult began at Guy's and St Thomas's in London so individual patients could be treated. But then it added a set of very high spec clean rooms out at Stevenage which enabled start-up companies to move to larger-scale production of cells. It has been key to the surge of unicorns in the sector.

3 A Catapult.

We now have a network of Catapults bringing together public and private investment to promote R&D in key sectors and technologies. There are similar initiatives in aerospace and automotive power systems. We should grow the network and invest in more of them – provided the private sector does as well. Is the key technology already backed with a Catapult Centre? If not instead of losing time on specific tailor made initiatives we should set up a new catapult as a template to move rapidly to back it.

4 Plug skills gaps by over-training

Are there specific skill shortages – for example in technicians to operate new kit? Research grants should include an account of the skills technicians needed to deliver them and how they will be trained. Follow the excellent example of the advanced manufacturing catapult and use the Catapults not just for R&D but also for more technical training.

5 A Centre for Doctoral Training

Often there are shortages of very high-level skills. We now have a network of mixed public/private funded doctoral training centres where the doctoral student can investigate an issue of direct relevance to business. Is it worth setting up a Centre for Doctoral Training in this technology? There are also knowledge transfer networks in which graduates get work experience in a company which needs their specific expertise.

6 Support a local cluster through a Launchpad competition

Is there a part of the country which has a cluster of expertise in a business sector or new technology? We can use the increasingly detailed data-sets tracking patents and R&D grants to spot such Clusters. Does it get any recognition? Are the local councils and universities all backing it? Can we run a Launchpad competition funding innovative small businesses in this area?

7 Plug funding gaps with a catalyst fund

Are there financial barriers to entry for new players such as need for proof of concept or proof of market which you can fund? The Biomedical Catalyst Fund was created to link MRC and Innovate UK funding in a

single grant helping ideas all the way from lab to market. Sarah Gilbert in Oxford had two grants in 2015 to run early clinical studies with adenoviral vectors – this technology ended up in Covid vaccines. The Government commissioned an evaluation of the Biomedical Catalyst published in June 2019[26]. It was very positive and concluded:

"A cost-benefit analysis of the grants awarded to businesses by Innovate UK related the benefits of the programme embodied in the increase in the value of businesses supported suggested that the BMC also offered strong value for money, with a central estimate of the benefit to cost ratio (BCR) of £4.72 per £1 invested. This substantially exceeds the hurdle rate of return typically applied in the approval of the Business Cases for these types of scheme."

But that has not protected it from funding cuts and policy uncertainty – though it has survived. Expanding the Catalyst fund model would be a good example of investing in programmes which have evaluated well.

8 Ask the British Business Bank to promote a focussed VC fund

The British Business Bank (BBB) has increasingly been liberated from the pure Treasury doctrine described earlier. It will invest in new funds focussed on a key technology. So liaise direct with the BBB to explain the significance and commercial opportunities in your technology so it is on the lookout for opportunities to invest in new VC funds devoted to it.

9 A sand-box to assess IP and the regulatory regime

The long journey from the lab to the market involves prototyping and demonstrator facilities. It is much easier to get regulatory clearance if there are safe spaces and sand-boxes such as those for FinTech. We need more of that in Deep Tech – trialling drone services or producing new organisms on a larger scale than a petri dish in a lab. Developing more such facilities in key technologies is often the best way to help with the scale-up challenge.

10 Getting the right regulatory regime

Are there regulatory barriers to innovative new providers? Are UK regulations/standards up to date and do they reflect the way the technology/industry is heading or can we get a market lead and attract overseas investment by drafting innovative new ones? Is there an international regulatory body we should lobby so that its standards support what we are doing?

26. Ipsos Mori and George Barrett

Conclusion

That exercise identifying eight great technologies ten years ago yields some important lessons today. It is not a silly list. Technology foresight exercises are not hopeless in the face of radical uncertainty. And although the exercise subsequently was exposed to subsequent panics about industrial strategy and picking winners there has been sustained support. George Osborne's original package lasted five years and support continued to be provided for many of them, using whatever badge was politically expedient at the time. The whole exercise prompted a wide range of practical policy interventions which have been tested and can be applied again. And there are British unicorns and tech start-ups which would not be around but for this initiative. Such an agenda is key to boosting Britain's economic performance.

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