A Resurgence of the Regions: rebuilding innovation capacity across the whole UK.

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1. Introduction

We should rebuild the innovation systems of those parts of the country outside the prosperous South East of England. Public investments in new translational research facilities will attract private sector investment, bring together wider clusters of public and business research and development, institutions for skills development, and networks of expertise, boosting innovation and leading to productivity growth. In each region, investment should be focused on industrial sectors that build on existing strengths, while exploiting opportunities offered by new technology. New capacity should be built in areas like health and social care, and the transition to low carbon energy, where the state can use its power to create new markets to drive the innovation needed to meet its strategic goals.

This would address two of the UK's biggest structural problems: its profound disparities in regional economic performance, and a research and development intensity – especially in the private sector and for translational research – that is low compared to competitors. By focusing on 'catch-up' economic growth in the less prosperous parts of the country, this plan offers the most realistic route to generating a material change in the total level of economic growth. At the same time, it should make a major contribution to reducing the political and social tensions that have become so obvious in recent years.

The global financial crisis brought about a once-in-a-lifetime discontinuity in the rate of growth of economic quantities such as GDP per capita, labour productivity and average incomes; their subsequent decade-long stagnation signals that this event was not just a blip, but a transition to a new, deeply unsatisfactory, normal. A continuation of the current policy direction will not suffice; change is needed.

Our post-crisis stagnation has more than one cause. Some sources of pre-crisis prosperity have declined, and will not - and should not - come back. North Sea oil and gas production peaked around the turn of the century. Financial services provided a motor for the economy in the run-up to the global financial crisis, but this proved unsustainable.

Beyond the unavoidable headwinds imposed by the end of North Sea oil and the financial services bubble, the wider economy has disappointed too. There has been a general collapse in *total factor productivity* growth – the economy is less able to create higher value products and services from the same inputs than in previous decades. This is a problem of declining innovation in its broadest sense.

There are some industry-specific issues. The pharmaceutical industry, for example, has been the UK's leading science-led industry, and a major driver of productivity growth before 2007; this has been suffering from a world-wide malaise, in which lucrative new drugs seem harder and harder to find.

Yet many areas of innovation are flourishing, presenting opportunities to create new, high value products and services. It's easy to get excited about developments in machine learning, the 'internet of things' and 'Industrie 4.0', in biotechnology, synthetic biology and nanotechnology, in new technologies for generating and storing energy.

But the productivity data shows that UK companies are not taking enough advantage of these opportunities. The UK economy is not able to harness innovation at a sufficient scale to generate the economic growth we need.

Up to now, the UK's innovation policy had been focused on academic science. We rightly congratulate ourselves on the strength of our science base, as measured by the Nobel prizes won by UK-based scientists and the impact of their publications.

Despite these successes, the UK's wider research and development base suffers from three faults:

- It is too small for the size of our economy, as measured by R&D intensity,
- It is particularly weak in translational research and industrial R&D,
- It is too geographically concentrated in the already prosperous parts of the country.

Science policy has been based on a model of correcting market failure, with an overwhelming emphasis on the supply side – ensuring strong basic science and a supply of skilled people. We need to move from this 'supply side' science policy to an innovation policy that explicitly creates *demand* for innovation, in order to meet society's big strategic goals.

Historically, the main driver for state investment in innovation has been defence. Today, the largest fraction of government research and development supports healthcare – yet this is not done in a way that most effectively promotes either the health of our citizens or the productivity of our health and social care system.

Most pressingly, we need innovation to create affordable low carbon energy. Progress towards decarbonising our energy system is not happening fast enough, and innovation is needed to decrease the price of low carbon energy and increase its scale, and increase energy efficiency.

More attention needs to be paid to the wider determinants of innovation – organisation, management quality, skills, and the diffusion of innovation as much as discovery itself. We need to focus more on the formal and informal networks that drive innovation – and in particular on the geographical aspects of these networks. They work well in Cambridge – why aren't they working in the North East or in Wales?

We do have examples of new institutions that have catalysed the rebuilding of innovation systems in economically lagging parts of the country. Translational research institutions such as Coventry's Warwick Manufacturing Group, and Sheffield's Advanced

Manufacturing Research Centre, bring together university researchers and workers from companies large and small, help develop appropriate skills at all levels, and act as a focus for inward investment.

These translational research centres offer models for new interventions that will raise productivity levels in many sectors – not just in traditional 'high technology' sectors, but also in areas of the foundational economy such as social care. They will drive the innovation needed to create an affordable, humane and effective healthcare system. We must also urgently reverse decades of neglect by the UK of research into new sustainable energy systems, to hasten the overdue transition to a low carbon economy. Developing such centres, at scale, will do much to drive economic growth in all parts of the country.

2. The UK's regional inequality

2.1 Two nations

In economic terms, the UK is two countries – a prosperous enclave in London and the South East, with the rest of the country lagging far behind.

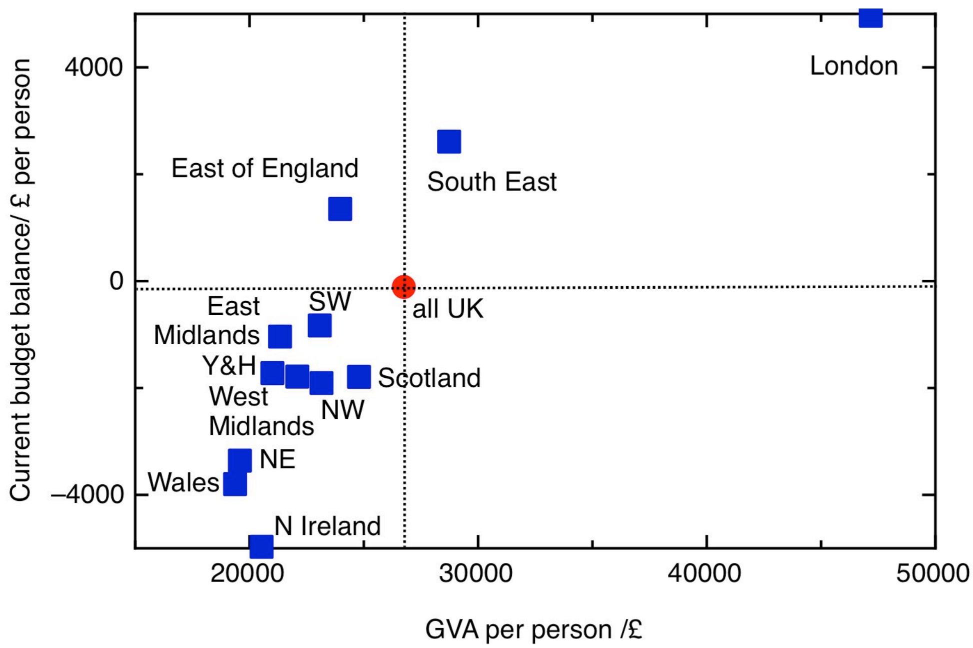

Figure 1. Most of the UK is below average in economic performance, and only three regions contribute to government more than they receive.
The difference between government revenue and current expenditure for NUTS1 regions, plotted against their regional productivity (GVA per person), both expressed per head of population. ONS data.

The South East corner of the UK – including London, the Southeast, and parts of the East and East Anglia – is a high performing economy, which compares favourably by measures such as GVA per person with the richest parts of Northern Europe. But the rest of the UK does much worse. Much of the Midlands and North of England, together with Wales and Northern Ireland, more closely resembles southern Italy and the formerly Communist East Germany (McCann 2016).

This regional disparity is often framed as a problem of equity. Northerners complain about the injustices that keep the parts of the country outside the prosperous Southeast poor. But, as figure 1 shows, only three regions of the UK pay out more in taxes than they receive in government spending: London, the South-East and the East of England – their inhabitants might think it unfair that it is their prosperity that props up the rest of the nation.

Fairness – and the perception of fairness - is important for maintaining the social cohesion of the nation, but a more constructive way of discussing these economic disparities is in terms of lost economic opportunity. Our aim should be for the rest of the UK to narrow the gap in economic performance with the prosperous Southeast, so that the whole country is fulfilling its potential. Rather than putting up with large scale transfers of funds from South to North continuing into perpetuity, we should make the investments that will allow what are now economically underperforming parts of the country be both wealthier and more self-sufficient.

2.2 Dimensions of inequality

Any plan to force a step change in the quality and quantity of economic growth must begin by addressing these regional economic disparities. These disparities have different dimensions (Industrial Strategy Commission 2017):

- Our core cities, outside London, underperform. In successful countries, cities are drivers of economic growth, their productivity boosted by agglomeration effects. In the UK, by contrast, of ten core cities outside London, only one - Bristol – is more productive than the UK average[1]. Great cities like Birmingham, Leeds and Manchester should be motors, not just of their regions, but of the national economy as a whole. Currently they are drags on national prosperity.
- Formerly industrialised areas have never recovered from the loss of mining and other heavy industry in the 1980's. Towns like Barnsley, in South Yorkshire, Dudley, in the West Midlands, Middlesbrough, in the Northeast, Blackburn, in the Northwest are seemingly locked into economic decline, with poor levels of educational attainment, low participation in higher education, poor social mobility, low investment and low rates of business start-ups and growth.
- The rural and coastal peripheries include some of the poorest and least productive areas of the UK, disconnected due to poor transport links from more economically dynamic areas.

These different kinds of place have different problems, and what works in one kind of place won't be appropriate in another. But it will be important that every part of the country should be able to identify some improvement in their economic conditions.

[1] The Core Cities group comprises the cities of Birmingham, Bristol, Cardiff, Glasgow, Leeds, Liverpool, Manchester, Newcastle, Nottingham and Sheffield. Productivity defined by GVA per worker (Centre for Cities 2018).

2.3 Different problems, different solutions

Different regions present different problems and will require different solutions. But many policy-makers agree that the key to economic prosperity must be the creation of tradable goods and knowledge-intensive services, whose value is being continuously driven up by innovation, spurred by open competition (OECD 2018, Swinney 2018).

I will discuss the relative contributions of different sectors of the economy to productivity growth in more detail below. But it is important to recognise that high productivity sectors producing tradable goods aren't the only parts of a local or regional economy that matter.

All regions have what has been called a *foundational economy* (Bentham 2013) - the essential infrastructure of a functioning modern society, comprising services such as health, social care and education. Overlapping with this is the so-called *everyday economy* (Reeves 2018) – sectors like retail and everyday services which have relatively low nominal productivity, but which both provide employment for many people and contribute to the essential infrastructure of everyday life.

What relative weight should we give to the high technology, knowledge intensive sectors producing nationally and tradable goods and services, compared to the foundational and everyday economies? There are at least two separate questions here.

The first is an essentially technocratic question – in devising measures with the aim of improving productivity, is it better to focus on already highly productive sectors, even though they might employ relatively few people, or on less productive sectors that form a larger part of the economy? The correct answer to this isn't obvious, despite some strongly held, but divergent opinions. It depends both on a judgement of the scale of likely productivity gains in different sectors, and an understanding of how value created in one sector spreads out across the whole economy. We will return to this issue below.

The second is a more fundamental one about value and how we measure it. A sector like social care has a value to society in excess of monetary measures of its value added, and we need to be able to take a systems-level view of this societal value to ensure that it isn't jeopardised by short-term value extraction in response to perverse financial incentives (as has arguably happened in the care sector (Burns 2016).

Shortcomings in the foundational economy will spread out to the rest of the economy. The UK has profound regional inequalities in health outcomes, with poorer regions having substantially sicker populations than rich ones. Poor health will by itself lead to less productive workers, leading to yet another way by which regional economic inequalities become further entrenched. The Marmot review (Marmot 2010) estimated the direct cost of health inequalities in the UK in 2010 as about £31-33 billion a year, the direct result of lost productivity.

Can a city or region to have a strong foundational or everyday economy, without a strong tradable sector? The evidence suggests not. For extreme examples, one can point to US cities such as Detroit, where the collapse of the tradable goods sector – in that case, the automobile industry – led to a near-complete implosion of the entire city economy, with a dramatic shrinkage of local services. No UK city has seen a collapse in this scale, because the degree of state redistribution of resources across the nation is greater in the UK than in the USA. Nonetheless, recent analysis suggests that for every additional job created in the tradables sector, one extra job is created in non-tradable sectors in the same city (Martin 2016).

Places that have successful sectors producing tradable goods and high value services have successful economies. What characterises such economically successful places, like Cambridge or Bristol, is a thriving innovation system – formal institutions for education and research and development, high performing companies both large and small, and networks of highly skilled people.

These innovation systems have been allowed to wither in other parts of the country. This can be partly due to the unintended consequences of wider shifts in the economy - changes in industrial structure may have led to the loss of anchor companies, and the movement away of skilled people. But it can also be the direct result of policy changes – in particular, the concentration of government R&D spending in London and South East England, which is discussed below. These innovation systems now need to be rebuilt.

3. Why productivity matters

3.1 The UK's once-in-a-century economic stagnation

The scale of the discontinuity in the UK's economic performance since the 2007/8 financial crisis is shown in figure 2, which shows the growth of real GDP per person since 1948. The economic disruptions of the 1970's and early 1980's, massive though they seemed at the time, led only to minor deviations from a long term trend of 2.3 per cent per annum growth. The financial crisis led to a one-off drop in level of GDP per person, but in contrast to previous recessions, the previously lost ground was not recovered, and the economy has settled into a lower growth rate. On present trends, this is likely to lead to a 21 per cent permanent loss of national wealth by 2020 (this, of course takes no account of any economic disruption that might follow Brexit).

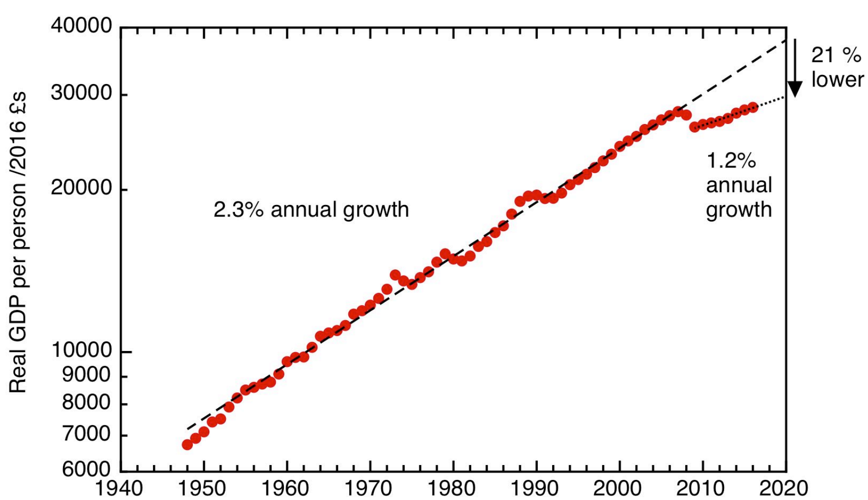

Figure 2. The global financial crisis led to the end of a growth trend in per capita GDP that had previously held since the second world war.
Real GDP per person, UK. Data from Bank of England OBRA dataset (Thomas 2017).

3.2 The stalling motor of productivity growth

At the root of our problems is a collapse in the rate of productivity growth. We have grown used to the idea that as technology improves, we should see year-on-year improvements in the amount of real value created by each hour of work. This is reflected in statistics for labour productivity, simply defined as the ratio of real GDP to total number of hours worked in the economy. As figure 3 shows, labour productivity grew at a remarkably constant rate of 2.3 per cent a year, from the 1970's up to the 2007 global financial crisis. Like GDP per capita, this crisis was marked by both a drop in absolute level and a move to a much slower rate of growth.

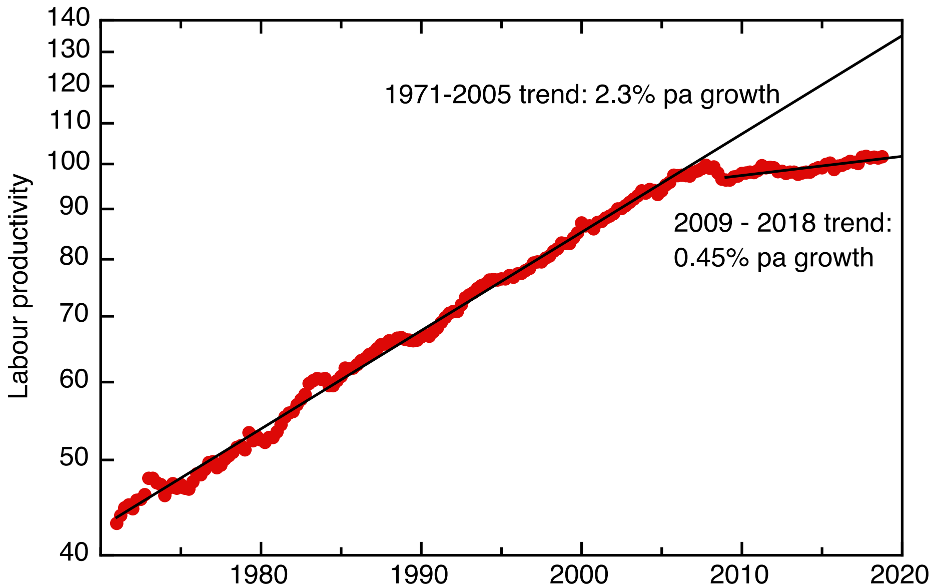

Figure 3. Following the global financial crisis, both the level and rate of increase of labour productivity have fallen substantially.
UK Labour productivity since 1971. ONS.

In the theory of growth accounting, what's left after accounting for increased capital inputs is known as *total factor productivity*, which is a measure of the way technological improvements, in the most general sense, contribute to increased output.

Can the situation really be as bad as the productivity statistics suggest? Measuring the size of the national economy has intrinsic difficulties, and these could lead to an overstatement of the decline in the growth rate. Given the pace of technological progress, it is possible that the deflator used to account for inflation isn't correct. Changing business models – for example the rise of cloud computing – arguably change what are included as 'intermediate goods'. More fundamentally, one can – and should – argue that GDP, as a pure activity measure, takes no account of the depletion of the natural balance sheet, for example through the extraction of natural resources like oil reserves, or damage to the environment through pollution and the emission of greenhouse gases.

3.3 From "your bloody GDP" to my shrinking pay-packet

If GDP is a potentially a flawed measure of the size of the economy, it also suffers in the public mind from being rather abstract. In the words of a famous heckler[2], "*That's your bloody GDP, not ours*". But the economic situation as experienced by people at large is as grim as the economic numbers suggest.

The impacts of the slowdown in GDP, flawed though it might be, do directly impact people's lives, in two key ways. There is a direct relationship between GDP per capita and average wages – so the dramatic slowdown in real wage growth we've seen since the global financial crisis is a direct consequence of stagnation in productivity. And the amount the government receives in taxes strongly depends on the level of activity in the economy as a whole - and thus on GDP. Given the goal of current and previous administrations to bring down the government's current deficit, there's thus a link between weakness in productivity growth and downward pressure on spending on public services.

On average, the growth of real wages tracks overall productivity growth (Pessoa 2013). As shown in figure 4, real wages have suffered a decade of stagnation, after a long period when they grew at around 2 per cent a year, reflecting the wider growth of the economy. People are now about 20 per cent worse off in real terms than they would have been if the pre-crisis trajectory had continued.

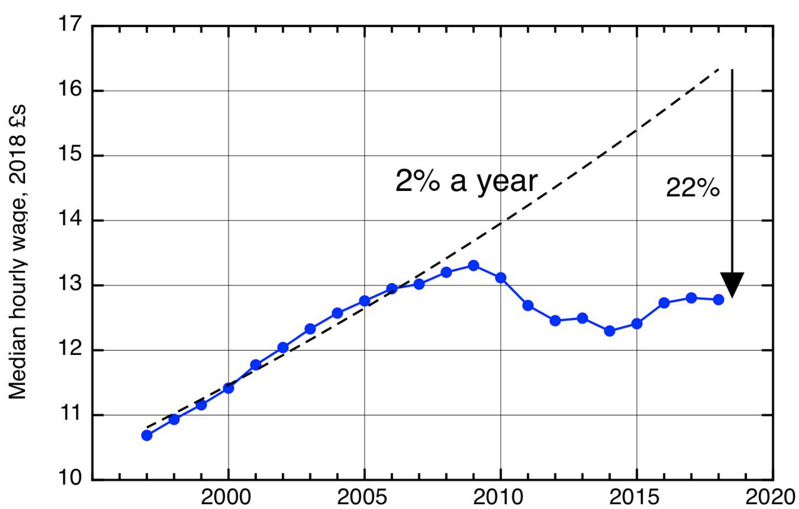

Figure 4. The UK's productivity slow-down has led to a decade of stagnation in real wages.
UK median hourly wage, corrected for inflation using CPI. ONS & author's calculations.

The relationship between wages and productivity growth at the city and firm level is less clear than it is for the economy as a whole. Recent results suggest that in the UK, since the financial crisis, productivity gains at the firm level don't get passed on to workers. More is passed on if a whole sector improves its productivity, or if productivity is increased in a city (Ciarli 2018).

[2] Quoted by Anand Menon in: http://ukandeu.ac.uk/2016-a-review/

Increasing productivity, then, is a necessary, but not sufficient condition, for improving wages – it needs to be supplemented by other labour market interventions to ensure everyone benefits from productivity gains.

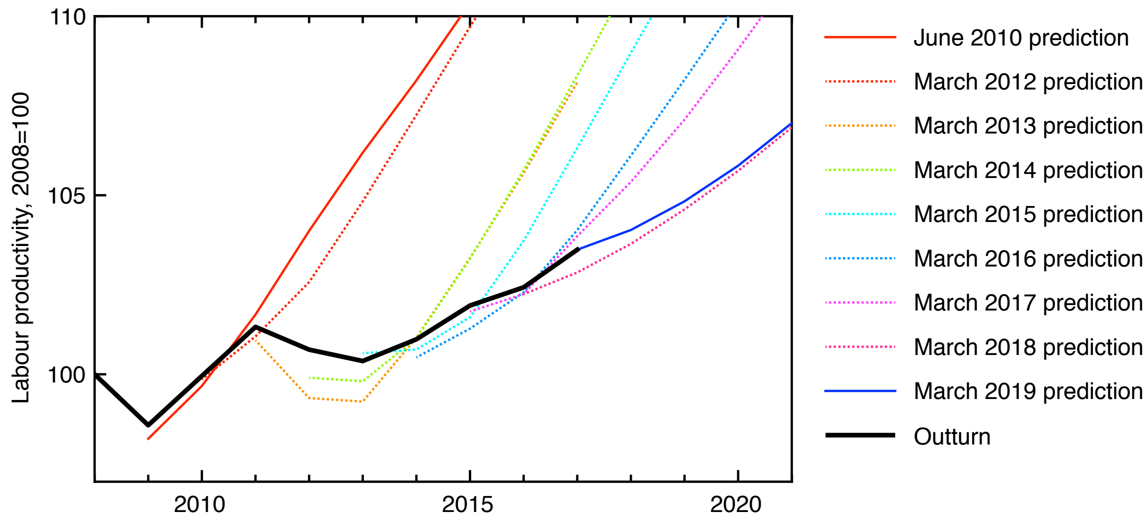

Figure 5. Forecasters have been consistently over-optimistic about productivity growth.
Successive predictions of labour productivity by the Office of Budgetary Responsibility. OBR Historical Official Forecasts Database.

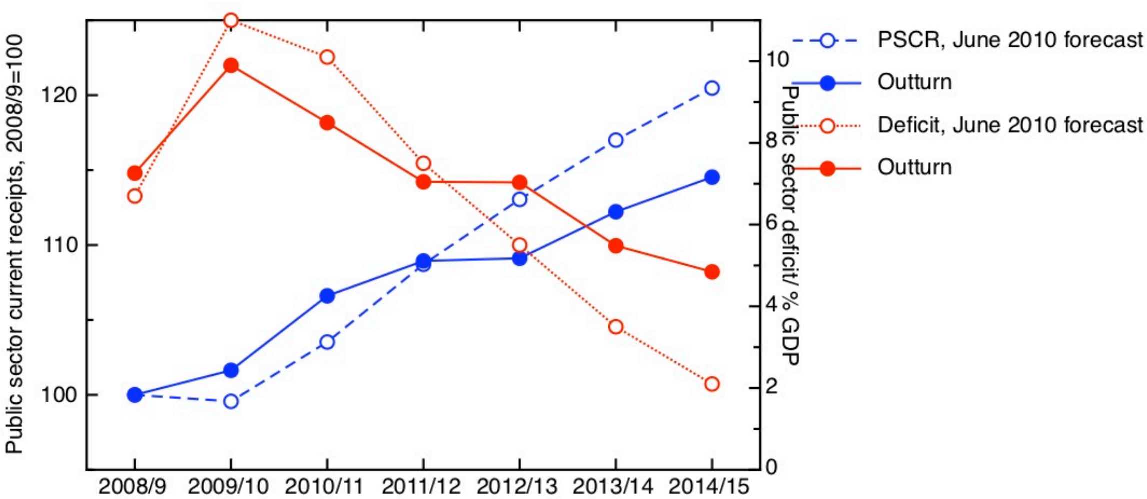

Figure 6. A failure by forecasters to appreciate the scale of our productivity problem led to over-optimism about the time needed to reduce the public sector deficit.
June 2010 forecasts of Public Sector current receipts (in real terms) and Public Sector net borrowing (in % of GDP), compared to outturn. OBR Historical Official Forecasts Database and author calculations.

Optimistic expectations about the imminent recovery of UK productivity have been consistently dashed. Economic forecasters, including the Office for Budgetary Responsibility, and policy makers have been very slow to recognise that slow productivity growth isn't a glitch – it's a new normal that reflects structural failings in the UK economy. As shown in figure 5, forecasters have persistently, and prematurely, anticipated that productivity growth would imminently bounce back to its pre-crisis level.

Unfounded optimism about productivity growth has directly translated into over-optimism about the pace of recovery of the public finances. Growth in real public sector net receipts has been slower than anticipated in 2010 (even though the shortfall in productivity growth was partially compensated for by a greater than expected increase in hours worked), as shown in figure 6. This has meant that, despite public sector austerity, the public sector deficit has been slower to close than anticipated.

Given the commitment of recent governments to shrinking and eliminating the deficit, the slowdown in productivity growth has thus been the ultimate cause of the prolongation of public sector austerity, leading in turn to a worsening of the living standards of those dependent on benefits and deteriorating public services.

One worry that people have about focusing on productivity growth is the fear that there is a trade-off between improving productivity and maintaining full employment. Will robots and artificial intelligence take our jobs? Here there is a gap between the classical view of economists that new jobs, often in entirely new sectors, will always arise to replace any lost to automation, and the apparently common sense position that mechanisation surely takes jobs away. There is a middle ground here, which is to accept that new jobs do arise, but to worry that these new jobs (e.g. in low value services) are worse paid and less secure than the ones they replace (e.g. in manufacturing).

A recent analysis studies recent data on this from the UK and similar countries (Autor 2017), and finds a rather nuanced picture – overall, productivity gains do lead to overall increases in employment – but that the extent of this depends on the sector in which the productivity gains take place. In mining, construction and utilities productivity gains do lead to overall losses in total employment, but across the whole economy this is counteracted by the effect of manufacturing – where productivity increases lead to modest increases in employment in other sectors – and services, where productivity gains lead to rather larger total increases in employment. But one key point emerges – the new jobs have, up to now, been likely to be higher skilled jobs than the ones they replace. Efforts to improve productivity must be accompanied by measures to respond to this increasing demand for highly skilled people.

Productivity may seem an abstract construction, but the consequences of the slowdown in productivity growth on people at large have been very concrete. Our productivity stagnation underlies a slowdown in people's wages and living standards, it has blighted the public finances, in response to which governments have responded with a squeeze on benefits and public services.

To finish with a more speculative point – over the last few decades, people have grown used to a certain level of continuing economic growth. The combination of these expectations with disparities in political power are likely to lead to growing inequality and increasingly bitter divisions between different groups in society about how resources are divided up – divisions between rich and poor, between old and young, between the prosperous parts of the country and those that are left behind.

As Sarah O'Connor observes (O'Connor 2019), *"When economic growth stalls and the pie stops getting bigger, the fights over how to divide it get fiercer and dirtier."* I don't think it's far-fetched to ascribe our current dysfunctional and bitter political environment, in large part, to a decade of stagnation in productivity growth.

4. The roots of the UK's productivity problem

4.1 Diagnosing the causes of the UK's productivity slow-down

The origins of this collapse in productivity have been much debated. In what is perhaps the most complete analysis (Goodridge 2016), it is demonstrated that the problem is largely one of *total factor productivity.* The problem is not primarily explained by a reduction in the capital intensity of the economy, nor is it explained by shifts in the overall balance of the economy, from more productive to less productive sectors. Our problem, then, is indeed a problem of innovation.

About one third of the problem is explained by weakness in two sectors – oil/gas, and financial services. Even more insight is provided by a detailed sectoral analysis (Riley 2018). This reinforces the conclusion that the problem is primarily one of total factor productivity, though it does identify capital shallowing in some service sectors. Its most striking finding is that a full three fifths of the productivity problem is associated with just six industry sectors, which between them account for only one fifth of value added in the market sector. It's worth discussing these industries in more detail, as this allows us to disentangle some global trends from UK specific factors.

- **Mining**. This is dominated by North Sea oil; production peaked in 2000; what oil is left is more expensive and difficult to get out. There needs to be more recognition that UK's prosperity in the 90's and early 2000's depended as much on the accident of North Sea oil as any particular strength of the policy framework.
- **Finance**. Post-crisis increased regulation and greater capital requirements have reduced apparent rates of return in financial services. This is, in my opinion, as it should be; calls to relax regulation should be resisted, and so-called 'innovation' that in practice amounts to regulatory arbitrage discouraged.
- **Energy.** Here, a post-privatisation dysfunctional pseudo-market has prioritised sweating existing assets over investing. Meanwhile there's been an unclear and inconsistent government policy environment; sometimes the government has willed the ends without providing the means (e.g. nuclear new build), elsewhere it has introduced perverse and abrupt changes of tack (e.g. in its support for onshore wind and solar). Innovation in this sector is crucial as we enter a period of transition to low-carbon energy sources. We will return to this issue below.
- **Computer programming.** It's possible that we're seeing the effects of increasing overseas outsourcing and competition, for example to India's growing IT industry. In addition, the effect of more commoditisation of computer programming, with new business models such as 'software as a service', may be growing in importance.
- **Telecoms.** Here it's likely that measurement problems – in correctly accounting for improvements in quality – will be most acute (Abdirahman 2017). The global background here is one of lengthening product cycles as the rate of growth of

processor power slows, combined with increasing overseas competition (for example, rapidly growing Chinese firms like Huawei) moving up the value chain

- **Pharmaceuticals.** Productivity growth in pharmaceuticals depends on new products being developed through formal R&D, their value being protected by patents. There has been a dramatic, long-term fall in the productivity of pharmaceutical R&D (as measured by the number of new drugs produced per billion dollars of R&D expenditure) (Scannell 2012), so it is unsurprising that this is now feeding through into reduced labour productivity. This is a global issue, but one that the UK is particularly highly exposed to, due to its specialisation in this sector.

4.2 Technology leaders and laggards and the diffusion problem

Why might we have a total factor productivity problem? Economists stress that total factor productivity measures innovation in its widest sense. That includes the introduction of the kinds of new technologies that might be created by formal research and development processes. It must also encompass learning from experience, adopting suggestions from users, copying better practices from competitors, transferring new technologies from other sectors, and devising more effective ways of organising and distributing work.

The rhetoric of innovation currently stresses the importance of 'disruption' – the emergence of new, fast-growing companies selling entirely new products or services, enabled by new information and communication technology. These firms are the focus of venture capital, which hopes to recoup many multiples of their original investment, from the small fraction of successful firms that become 'unicorns'. In the UK context, this focus is accompanied by regret that no new firms on the scale of Google or Facebook have emerged. Yet this is a relatively small part of the economy, which probably reflects a particular historical situation, which may not persist.

A related tendency is to focus too much on new firms spun-out from universities on the basis of protectable intellectual property (IP), driven by individual academic entrepreneurs. This leads to a bias in policy towards the idea of entrepreneurship and new business formation as the driver of economic growth. Yet most SMEs occupy a relatively restricted niche, have relatively low productivity, and are unlikely to grow (Nightingale 2014) - the perception of the importance of this sector is biased by a small number of spectacular successes.

In contrast, the underrated backbone of productivity growth is the relentless incremental improvement of existing products and processes. Some of this is visible, in the form of better aeroplanes and new car models, or mobile phones with better cameras and brighter screens. Some is less obvious: new household products, higher performance medical equipment, the re-engineering of existing products to meet higher environmental standards. And much of this kind of innovation is totally invisible to the outsider, such as better ways of organising production or service provision, reducing costs and improving quality.

Some of this innovation is carried out within large firms with formal research and development functions – the idea of 'research and development' was itself an important social innovation of the 'second industrial revolution' of the late 19^{th} century, and it is difficult today to imagine complex and expensive development processes, such as bringing a new drug to market or developing a new model of electric vehicle, without the structured environment of a large company R&D department.

Some incremental development takes place indirectly in sophisticated supply chains in which primes impose demanding requirements on the smaller companies, which supply them, acting as drivers of innovation, and much takes place with the help of specialised service companies supplying technical consultancy and contract research.

Innovation also takes place by the adoption of existing technologies right across the economy, including the foundational and everyday economies – for example, in the adoption of mobile phones and computers for the optimal scheduling and booking of services. This kind of technology diffusion is a crucial mechanism for ensuring that productivity growth has a wide base across the economy.

There is a wide dispersion of productivity levels amongst firms. The most productive firms in the world are large, capital intensive, and highly innovative (as measured, for example, by rates of patenting) – they are on average 10 times higher in labour productivity than firms which lag behind the technology frontier (McGowan 2015).

This gap between technology leaders and a long-tail of less productive firms is common to all countries, but there is evidence that in the UK the gap is larger than in the USA, France or Germany (Haldane 2018). This suggests that measures to improve the diffusion of technology from the technology leaders to the laggards should be a key part of industrial policy.

On the other hand, recent analysis from the Bank of England finds that even amongst the technologically leading firms, there has been a falling off of the growth rate (Schneider 2018). We have a dual problem – technological innovation in our best firms is tailing off, and at the same time the UK's long-standing problem of a slow rate of take-up of new technologies in a long-tail of less productive companies persists.

4.3 Skills and the human dimension of productivity

The fundamental mechanism by which new technologies are developed and spread are through people – creative, knowledgeable and adaptable workers operating in frameworks which encourage and reward productive innovation. Our productivity problem is, in part, a problem of skills.

The relative weakness of the UK economy in skills is long-standing, but progress is stagnating, with particular gaps for mid- and higher-level technical and vocational qualifications (Henehan 2019). It is in intermediate level skills that the weakness of the UK is particularly marked – according to the 2015 UKCES Evidence Report (Bosworth 2015), *"with respect to Intermediate skills, attainment the UK is ranked 25th currently and is projected to fall to 28th place by 2020* [relative to other OECD countries]*".*

This weakness has a pronounced regional dimension, a low level of skills in a region is strongly correlated with economic performance (Green 2012), and these regional imbalances persist in time. It's tempting to assume that poor economic performance in places like Dudley and Barnsley is a result of low skills levels, and that focusing on improving people's skills levels would necessarily improve their economies. But demand for skills in such places is weak, too; why would people invest time and money acquiring more skills if there are no rewarding jobs to use them in? These places are locked in a low-skills equilibrium, where the lack of productive businesses leads to weak demand for skilled people, resulting in low supply.

Another important dimension of skills is to be found in the management of firms. A study from the USA found that 20 per cent of the variation in productivity between firms could be ascribed to differences in management practices (Bloom 2018), while a cross-country comparison reveals a significantly larger long-tail of very badly managed companies in the UK compared to the USA and Germany (Bloom 2007). Management is a technology, too.

4.4 Clusters and commons – the spatial aspects of innovation policy

The environment in which innovation takes place must involve more than a single firm – it comprises the formal institutions in which research and development takes place, including the R&D facilities of commercial enterprises, public sector laboratories and research universities. It also must include institutions for the development of skills, and the informal networks by which ideas and practices are exchanged.

It's well known that clusters of high-tech industries like biotechnology and knowledge intensive services depend on successful innovation ecosystems. How important is this kind of regional clustering for other parts of the economy? US researchers Pisano & Shih have drawn attention to the importance of this kind of soft infrastructure for all kinds of manufacturing industry. In their view, any successful regional cluster draws on a set of collective resources and knowledge that they call the *'industrial commons'* (Pisano 2009).

A successful industrial commons is rooted in large anchor companies and institutions, networks of supplying companies, informal knowledge networks, and formal institutions for training and skills at all levels.

Innovation ecosystems and industrial commons are localised and place specific. When they work well, the benefits of individual innovation activities spill over to the wider economy, leading to an overall increase in productivity. Despite advances in modern communication technologies, the evidence shows that these so-called knowledge spillovers are largely confined to their geographic region – distance is not dead (Lychagin 2016). Knowledge transfer is still most effectively carried out person-to-person.

The growing importance in the economy of intangible assets (Haskel 2018), such as design, branding, software, business systems and research and development may, paradoxically, be making geography more, rather than less, important, because of the importance of human networks in sustaining and developing the stock of knowledge, often tacit, that the intangible economy depends on.

The UK has some examples of very effective innovation ecosystems – in Cambridge and London, for example. But these are highly localised in the prosperous part of the UK – London and the Southeast. The lack of regional hubs of productivity and innovation of the kind that are seen in Germany (Bernick 2017) is a direct cause of the UK's regionally imbalanced economic performance.

In many parts of the UK those ecosystems have been allowed to wither; deindustrialisation has caused particularly bad damage to the 'industrial commons' of regions that formerly specialised in manufacturing. These are the regions that are currently economically lagging, locked into a low-skills, low innovation, low productivity equilibrium. Here weak demand for skilled people means that the rewards for being skilled are lower, leading to a self-reinforcing dynamic of relative decline. Nor can – or should - we rely on people moving away from these lagging regions to more productive places: despite the potential wage gains available, regional employment mobility in the UK is low and falling (Clarke 2017), leaving workers trapped in poorly rewarded and low productivity jobs in lagging regions.

This cycle of decline must be broken. Not everywhere in the country will be able to (or indeed should) have a biotechnology cluster, but we should be able to rebuild innovation ecosystems and industrial commons appropriate to their existing capacities and local history, new business opportunities and national needs. It is by rebuilding these systems we will be able to help these regions contribute at their full potential to the national economy.

5. From science policy focused solely on 'excellence', to an industrial strategy that will develop the UK's regions

5.1 The UK's declining R&D intensity

Over the last thirty years, the UK has slipped from being one of the most research intensive developed economies in the world, to being one of the least. As figure 7 shows, as measured by the ratio of total R&D expenditure – public and private – to GDP, the UK has been left behind not only by traditional competitors like France, Germany and the USA, but by fast developing countries of East Asia like Korea and China.

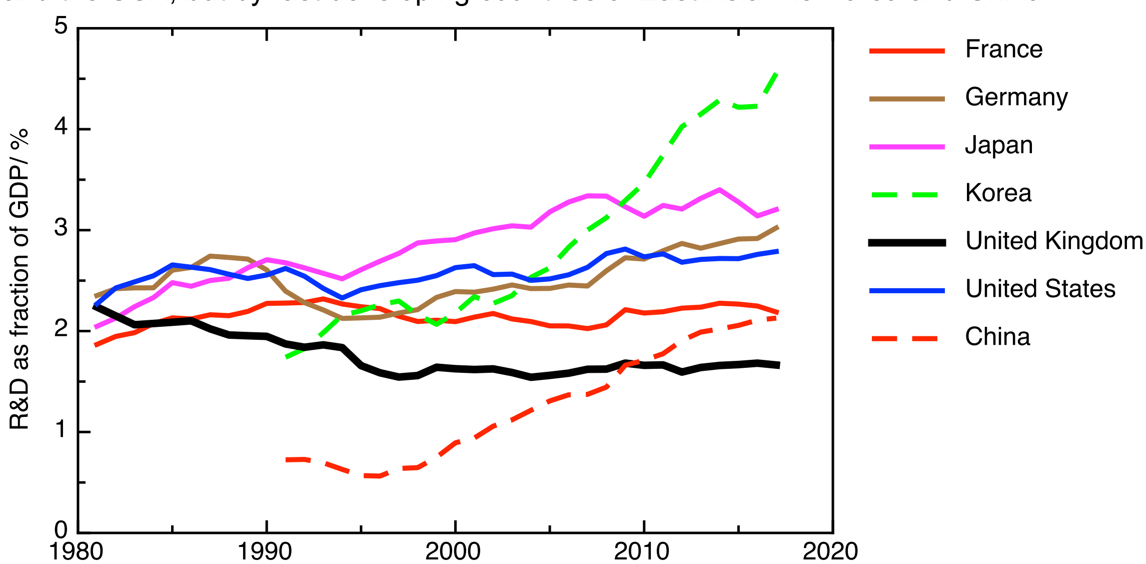

Figure 7. Since 1980, the UK has slipped from being one of the most R&D intensive large, developed economies in the world, to one of the least.
Research intensity of selected countries, expressed as gross expenditure on research and development as a percentage of GDP. Data: OECD main science and technology indicators, April 2019.

Does this matter? As discussed above, the innovation that underlies productivity growth comes in many varieties, only a fraction of which is driven by formal research and development. Indeed, in the 2000's, a view developed that the UK's low R&D intensity was not a matter for concern, given its strong record of productivity growth (see e.g. NESTA 2009). Our subsequent productivity stagnation makes that argument less compelling. Other types of innovation are certainly important, but the central role of R&D in driving productivity growth in firms at the technology frontier, in those sectors that have historically shown the highest long-term rates of total factor productivity growth means that the UK's mediocre R&D record is likely to have made a significant contribution to the country's productivity problem.

5.2 Rebuilding the UK's R&D capacity

There is now a wide degree of consensus that the R&D intensity of the economy now needs to be increased. The government committed, in its Industrial Strategy White Paper (HM Government 2017), to increase the R&D intensity of the economy to 2.4 per cent, the current OECD average, by 2027, a target support by bodies such as the CBI and the Royal Society. The policy of the opposition Labour Party is to go further and faster.

This target includes both private sector and public sector R&D. Under plausible assumptions, to reach this target would need an increase in total R&D spending from its 2015 value of £32 billion to £54 billion in 2027. Assuming the current split between public and private funding of roughly 1:2 is maintained, public spending needs to increase by about £7.4 billion from its 2015 value of £10.7 billion[3].

The bulk of the increase in R&D spending needs to come from the private sector – and it is this investment that is likely to lead most directly to the new products and services that are needed to drive future economic growth. To meet this target, business spending on R&D needs to rise by about £14 billion from its £21 billion 2015 value.

For its size, the UK's science base currently performs excellently (BEIS 2017). But as the nation's R&D capacity is increased to a scale more appropriate to the size of the economy, two of its failings need to be corrected. Firstly, translational research is underdeveloped, and secondly, the science base is far too regionally concentrated in London and the Southeast.

5.3 A new focus on translational research is needed

Translational research has been relatively neglected, because of the supply side focus of science policy to date, following an explicit policy of withdrawal of the state from the support of strategic and near-market R&D by successive administrations from the 1980's onwards (Agar 2011). This did not happen by accident – it was deliberate policy. As Jon Agar writes (Agar 2017), *"The critical point was that Guise [Thatcher's science policy advisor] and Thatcher regarded state intervention as deeply undesirable, and this included public funding for near-market research. The ideological desire to remove the state's role from funding much applied research was the obverse of the new enthusiasm for 'curiosity-driven research'."*

[3] Increases to 2021-22 already announced by the Government amount to around £2.3 billion.

This was driven by a view that state spending crowds out private sector investment. Since then it has become clearer that the reverse is true. As figure 8 shows, the decline in government R&D intensity was matched by a corresponding decline in business R&D intensity. Rather than 'crowding out' business R&D, state spending on R&D 'crowds in' further investment by the private sector (Economic Insight 2015).

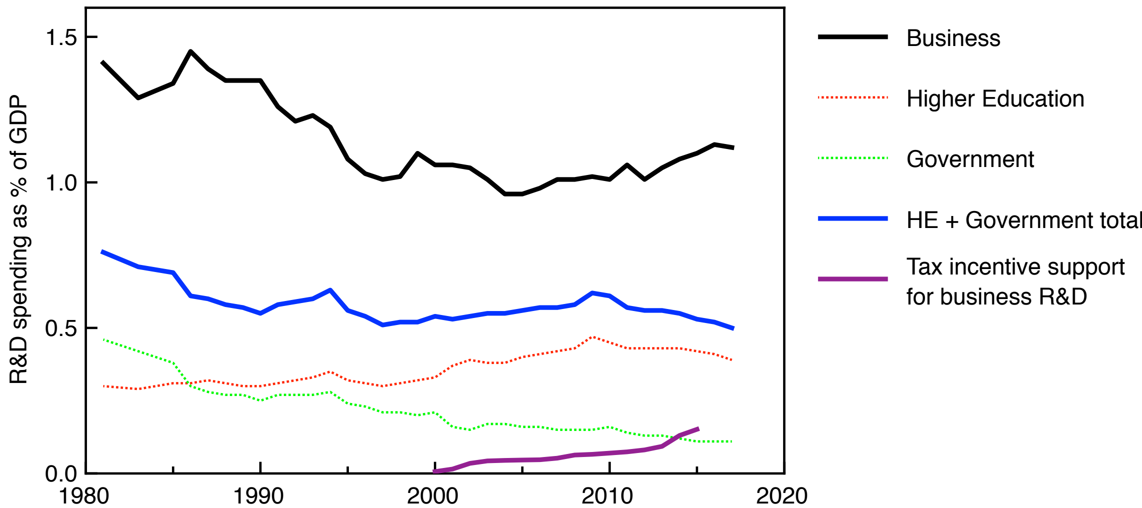

Figure 8. UK Business R&D intensity fell in step with falling government R&D spending, recovering slightly with the introduction of R&D tax credits.
Business, government and HE expenditure on R&D in the UK since 1981. Includes tax incentive support for business R&D between 2000 and 2015. Data: OECD Main Science and Technology Indicators.

This should not be a surprise – the nature of new knowledge is that it is not possible for a single firm to capture all the benefits of the R&D it funds and carries out. The return to society at large on private sector R&D is larger than the private return – by one recent estimate (Bloom 2018a), much larger, with the social return being 57.7 per cent, compared to a private return of 13.6 per cent. This means there is a systematic tendency for the private sector to invest less in R&D than would be optimum for the economy as a whole.

This market failure is well recognised, and the policy response has been focused on the supply side. The assumption has been that given a strong basic science base and a supply of well-trained people, the key role of policy is to reduce frictions impeding knowledge transfer between universities and businesses.

Meanwhile, changes in the relationship between public companies, their shareholders, and intermediaries in equity markets have led to a further significant loss of business R&D capacity. For example, a series of corporate misadventures led to the demise of two leading UK science based companies, ICI in chemicals, and GEC in electronics. As noted by the Kay Review (Kay 2012), the common factor in the collapse of these companies was the view that success was to be achieved by corporate reorganization, mergers, acquisitions, and divestments rather than through researching and developing innovative new products.

To build innovation capacity and speed up the diffusion of technologies into the business base, translational research institutes have a key role. These typically bring together academia, large firms operating at the technology frontier, and SMEs (often part of wider supply chains). They focus as much on developing know-how, learning-by-doing and process improvement as on protectable intellectual property, with an emphasis on implementing innovation at industrial scale. As they grow, they often take on responsibility for technical skills development at all levels, as well as for innovation.

Overseas models for such institutes include Germany's widely admired network of Fraunhofer Institutes, which were the inspiration for the UK's Catapult Centres, launched in 2011. Another less well known, but very important, example is Taiwan's Industrial Technology Research Institute (ITRI), which played a central role in building up Taiwan's leading position in the microelectronics industry. One spin-out company from ITRI – TSMC – began by developing a manufacturing process licensed in from a US company, and has now grown to be one of the top three microelectronics companies in the world, with a market capitalisation of $190 billion.

The UK's Catapult Centres represent a positive step, but their scale does not yet match the UK's challenge. A comparison with Germany's Fraunhofer Society illustrates the gap; the Fraunhofer Society's total budget (Fraunhofer 2017) is €2.2 billion (£1.88 billion), of which €700 million (£600 million) represents baseline funding from Federal and State governments, with the rest representing competitive R&D contracts from government and industry. The core funding for the Catapult Centres is £237 million (InnovateUK 2018); the aspiration is to match the Fraunhofer model of one third core funding, one third collaborative R&D, and one third direct industrial contracts. So far only the High Value Manufacturing Catapult has met this target (Ernst & Young 2017).

5.4 Rebuilding R&D capacity outside London and the Southeast

The other current failing of the UK's science base is its geographical concentration. Currently, just three sub-regions of the UK - Oxford and its environs, Cambridge and its sub-region, and inner West London – account for 31 per cent of all R&D spending in the UK. Public sector R&D is even more concentrated – 41 per cent takes place in these three regions (Eurostat 2019). The strong science base of these regions has been a major contribution to their economic success, which now needs to be spread out to the rest of the country.

The regional dimension of science spending – both public and private - is illustrated in figure 9[4]. This demonstrates two things:

- very wide disparities in public investment between the regions of the UK, with significant underinvestment in the poorer regions,
- a mismatch between where the public and private sectors invest.

[4] This powerful way of visualising the data was introduced by Tom Forth: https://www.tomforth.co.uk/researchingresearch/

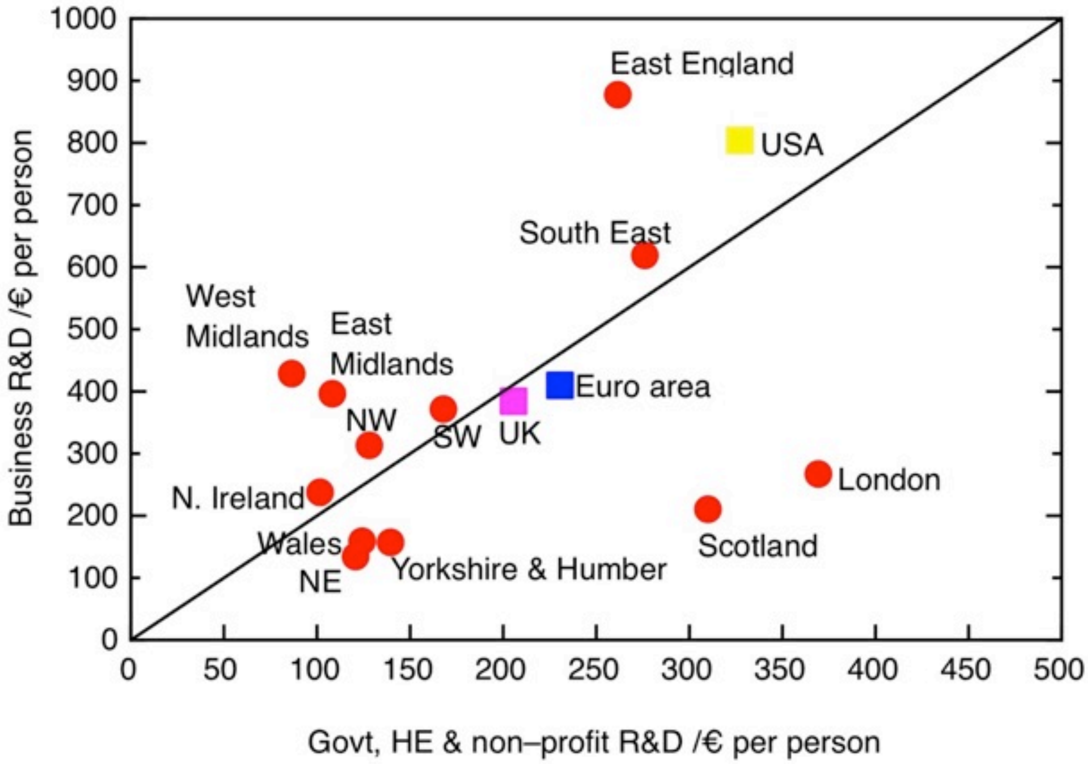

Figure 9. Government investment in R&D is highly regionally imbalanced, and is mismatched to where business invests.
Per capita investment in research and development by the public and private sectors by NUTS1 regions, 2014 data from Eurostat.

This analysis suggests a fourfold classification of different regions, each with a different policy driver for future investment:

- The *East of England and S.E. England* have high public spending on R&D, matched by high private R&D investment. This is what successful knowledge economies look like.

- *London and Scotland* have high public spending on R&D, but with relatively low private R&D investment. Here the emphasis needs to be on driving up business R&D.

- *East Midlands, West Midlands, Southwest and Northwest England* have relatively low public spending on R&D, but disproportionately high private sector R&D investment. Government investment should support & grow existing private sector innovation capacity and productivity.

- *Wales, Northern Ireland, Yorkshire & Humber, and Northeast England* all have a combination of low public spending on R&D and low private sector R&D investment. As the economically weakest regions of the UK, there is a compelling case to increase public investment, but this must be carefully targeted to those areas that are most likely to grow business R&D capacity and lead to increases in productivity.

We do have some models for successful translational research facilities in the UK. For example, two of the most successful Catapult Centres built on existing initiatives – these are the Warwick Manufacturing Group (WMG) at the University of Warwick and the Advanced Manufacturing Research Centre (AMRC) at the University of Sheffield. These have a strong sector focus – automotive, for WMG, and aerospace for AMRC. They both are based around strong core partnerships with large companies - Boeing and Rolls-Royce in the case of AMRC, and Jaguar Land Rover for WMG.

One measure of the success of AMRC has been the way it has attracted new, high value, manufacturing facilities (from Boeing and McLaren) into an economically lagging, deindustrialised region, while WMG, through its partnership with Jaguar Land Rover, has had a central role in the revival of the automotive sector in the West Midlands.

This kind of inward investment from international companies at the technology frontier has both direct and indirect benefits. The direct effect is to introduce new, higher productivity, economic activity to the region. The indirect benefits are to raise the productivity of the indigenous business base. This happens through engagement of local firms in the supply chains of the incoming businesses, and by raising the level of skills in the region – including the quality of management (Bloom 2018).

Translational research centres such as AMRC and WMG have become more directly involved in skills at all levels, including management training, and through apprentice programmes, developing high quality intermediate level skills.

These centres have acted as the nuclei for rebuilding their regions' *industrial commons,* creating new networks to promote innovation, to diffuse new technologies, and raising skills levels, both directly and indirectly. They help create more demand for higher levels of skills, giving a route for lagging regions to break out of the low-skills/low-productivity equilibrium, and offering people in the region better rewarded and more satisfying jobs.

Regional economic policy should consciously attempt to rebuild the *'industrial commons'*. But how should one choose the area or industry sector to focus on? One needs to embrace the opportunities of new technology, yet work with the grain of the existing industry base. The aim must be to grow the productivity of the local business base and create value, often through exports. This requires a good understanding of the role of the region in the wider national and global economy.

The process of identifying the potential areas of specialization of different regions will require considerable analytical capability – this will involve a combination of detailed local knowledge with an appreciation of the national and global landscape in the candidate sectors.

This was the motivation behind the 'Smart Specialisation' agenda developed as part of the EU's regional support programmes (OECD 2013). InnovateUK's Smart Specialisation Hub[5], now discontinued, was a useful start as a central resource to support bottom-up approaches such as the Government-sponsored Science and

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[5] Website at:http://smartspecialisationhub.org

Innovation Audits (BEIS 2016). Processes of this sort will need to be applied with even more rigour to make sure that the necessary, substantially increased, public investments in translational R&D in the UK's underperforming regions are wisely made.

6. The limits of sector-based industrial strategy

6.1 A brief history of industrial strategy in the UK

The industrial strategy of the Conservative administrations between 1979 and 1997 was not to have an industrial strategy – the very idea was associated with the economic failures of the 1970's, when, the rhetoric went, failing industries like British Leyland were kept afloat with taxpayers cash, producing uncompetitive products. This consensus was broadly shared by the New Labour government of 1997.

Within this consensus against industrial strategy, there was particular resistance to so-called 'vertical' industrial strategy, involving specific measures in support of particular industrial sectors. 'Horizontal' strategy – less specific measures aimed at improving the environment for business more generally – found more favour.

This changed after the global financial crisis; Peter Mandelson, returning to government in a newly expanded and empowered Business department, introduced what amounted to a sector-based strategy for the automotive industry as part of a move back towards a more overt industrial strategy (HM Government 2009).

The renewed acceptability of sector-based industrial strategy survived the creation of the Coalition Government in 2010, with eleven key sectors – including automotive, aerospace, life sciences and professional and business services – singled out for special support. This approach continued in the post-2015 Conservative administration, albeit with a short lacuna while industrial strategy sceptic Sajid Javid held the post of Business Secretary.

Current government policy continues the sector based approach – the White Paper (HM Government 2017) proposed 'sector deals' negotiated between government and representatives of sectors including (once again) life sciences, aerospace and automotive.

6.2 The strengths and limitations of sector-based industrial strategy

Sector based industrial strategy, at its best, allows an economic sector which is well-defined, well-organised, and facing a significant external challenge, to accept the help of the government in coordinating its response, by collaborating on innovation and skills provision to drive up productivity and create value for the whole economy.

An excellent example of a successful sector strategy comes from the USA, in the response of the government to a growing perceived competitive threat from Japan to the US semiconductor industry. In response to the Japanese government's VLSI initiative, the US government in 1987 founded SEMATECH, a public-private partnership involving 14 US semiconductor manufacturers. Supported by a relaxation of anti-trust law, this consortium supported collaborative R&D, helped the industry develop its supply chains and, through the creation of the National Technology Roadmap for Semiconductors, produced a powerful tool for coordinating the innovative activities of semiconductor manufacturers, equipment suppliers and academic researchers to sustain the stunning rate of technological change summed up in Moore's law.

In the UK, sector based support of the automotive industry since 2009 has been a success, as measured by the remarkable growth in production, productivity and R&D capacity in the UK industry. Of course, conditions never remain static, and the industry now faces new challenges, from potential post-Brexit disruption of supply chains, the rapid fall from grace of diesel engines, and the technological challenge of a transition to electric vehicles.

At its worst, sector based industrial strategy helps failing incumbents resist competitive pressures, giving them the space and resources to avoid innovating and suppressing the rise of more productive newcomers, producing both a cost to the tax-payer and a net drag on the economy.

Between these extremes lie some pitfalls around the way sectors are defined. Category errors in defining sectors can lead to incoherent and ineffective policy; I will argue in more detail later that the idea of a 'Life Science sector', so dominant in recent UK industrial strategy, is just such an error.

Another common error is to mistake an exciting emerging area of science with a future industrial sector. Thus there will, in the future, be no new 'nanotechnology industry', no 'graphene industry', no 'artificial intelligence industry' – instead, these new technologies will contribute to existing industry sectors, which will be defined by the need for the products or services they provide. It will be largely the innovation capacity of existing industry and their ability to respond to new opportunities that will determine how much the economy can benefit from these new technologies.

Nonetheless, sectors will evolve, in response to new technologies. The boundaries between categories will blur; a well-known example is the rise of 'servitisation' (Helo 2017), whereby manufacturing companies increasingly create more value from the ancillary services they provide than from the physical products themselves. Thus a focus on sectors risks always being backward looking, constrained by the categories statisticians devised in years gone by.

6.3 The long term drivers of total factor productivity growth

Different parts of the economy grow at different rates. Technological advance is uneven. In some areas – such as information and communication technologies - progress has been very fast, while in others – often those that depend on personal service – progress is much slower. Notwithstanding the shortcomings of sectors as a lens through which to look at the economy, it is helpful to understand where in the economy, over the medium and long term, productivity growth has been concentrated.

Figure 9 illustrates such an analysis. Here, aggregate total factor productivity growth over the period between 1998 and 2015 is plotted on one axis – this represents the degree to which output has increased over that 17 year period, beyond the growth that would have been expected from increasing inputs of labour and capital. It is a measure of the amount of technological innovation – in the broadest sense – in each sector, allowing us to identify the parts of the economy in which technological progress has been most effective in driving productivity growth.

Scale is important, as well as rate of growth, so on the other axis is plotted the relative importance of each sector to the economy as a whole, as measured as the fraction of gross value added each sector contributes.

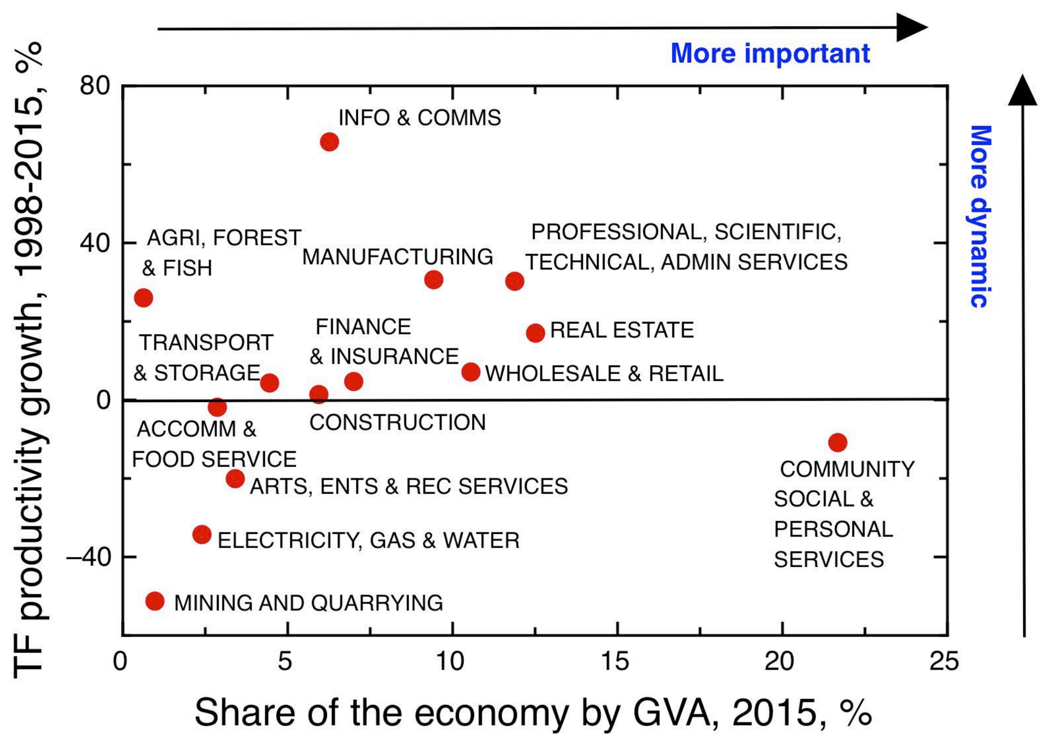

Figure 10. The UK's economic sectors, mapped by their contribution to the economy and historical total factor productivity performance.
Sector percentage of 2015 economy by GVA contribution versus aggregate total factor productivity growth from 1998 to 2015. EU KLEMS Growth and Productivity Accounts database (Jäger 2017).

As always, we need to be aware of potential issues of mismeasurement. As mentioned above, problems of correctly accounting for quality improvements are likely to be especially marked in the information and communications sector (Abdirahman 2017), meaning that productivity improvements here – which are already larger than any other sector as presented - may actually be understated.

On the other hand, the method used to estimate the contribution of financial services to GDP – "Financial intermediation services indirectly measured" – has in all probability, materially overstated their contribution by failing to handle risk appropriately (Akritidis 2017).

From this analysis, we can see that three sectors - information and communications, manufacturing, and professional, scientific technical and administrative services – have shown very significant improvements in total factor productivity over the period. It has been ICT, manufacturing, and knowledge-based services, accounting for about a quarter of the economy, that have done most of the work of driving the UK economy over this period.

Another sector - community, personal and social services – comprises a very high proportion of the economy, yet has demonstrated slightly negative total factor productivity growth over the period. The size and importance of this sector – including education, health and social care – suggests that even small increases in total factor productivity (if correctly measured) would yield big benefits. I will argue in a later section that we have not devoted anything like enough attention to the kinds of technological innovation in the health and social care sectors that could deliver both increases in productivity and better outcomes for people at large.

Finance and insurance represent 7% of the economy – a significant fraction, yet despite its perceived importance as a driver of the UK economy in recent years, its overall, long-term increase in total factor productivity is unimpressive, and probably overstated.

The largest fall in total factor productivity – 50% - has come from mining and quarrying. Production of North Sea oil peaked around 2000, and has since been rapidly falling. As the most accessible oil fields have become exhausted, it takes more resources (and indeed better technology) to extract what remains. This stresses one major failing of GDP as a measure of economic progress – it does not take account of the degree to which we deplete our balance sheet of non-renewable natural resources in creating that economic activity. With North Sea oil now substantially gone, more innovation in other sectors will be needed to counteract this ongoing headwind to the UK economy.

This sectoral breakdown is very coarse, and within each sector average values of productivity growth will conceal very wide dispersions of growth between subsectors and indeed between individual firms. To get a sense of this dispersion between sub-sectors, figure 11 shows a similar plot for manufacturing subsectors.

The traditional high-value parts of manufacturing – transport equipment, including automotive and aerospace, and chemicals and chemical products, including pharmaceuticals and speciality chemicals – are both significant in terms of their fraction of the overall economy and dynamic in terms of accumulated total factor productivity growth. Rather less to be expected, perhaps, is the good total factor productivity performance of textiles and apparel, a sector often thought of as part of our industrial heritage. Perhaps this reflects the importance of intangibles like design and branding, emphasizing that productivity-improving innovation goes well beyond the application of science and technology.

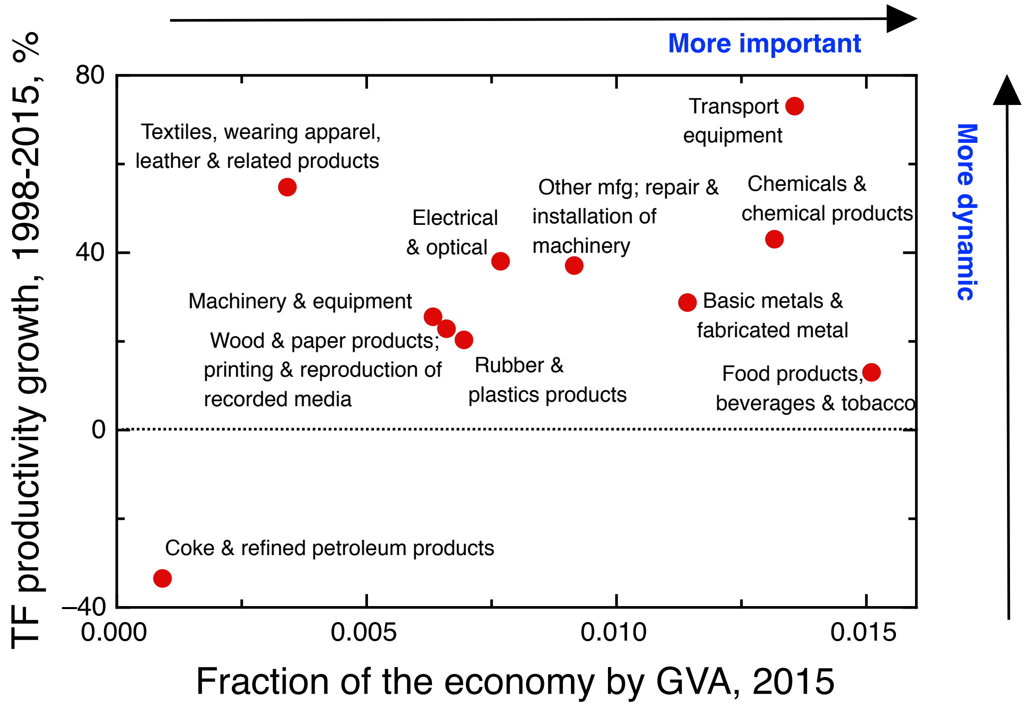

***Figure 11. Subsectors of UK manufacturing, mapped by their contribution to the economy and historical total factor productivity performance**.*
Manufacturing sub-sector percentage of 2015 economy by GVA contribution versus aggregate total factor productivity growth from 1998 to 2015. EU KLEMS Growth and Productivity Accounts database (Jäger 2017).

This is a crude and preliminary analysis – but it provides an entry point into some of the most important questions in industrial strategy. Should we focus on promoting the high growth sectors, or on the diffusion of existing technologies through slower growth sectors?

There is a role for both. Some areas of historically low productivity growth – often in sectors that form part of the foundational economy – because of their size, offer the potential for driving significant GDP growth from relatively small improvements in productivity, and we will discuss this in the context of the health and social care sector below. Meanwhile, the value created in high growth sectors spreads out across the economy as whole.

6.4 What will drive productivity growth in the future?

Looking at how different sectors have performed in the past can only get us so far; technological change will certainly lead to changes in the shape and structure of the economy in the future. But we should guard against excessive neophilia (Edgerton 2008). Most technologies are very persistent and our infrastructures are very long lasting. Labour market disruptions do happen, and will continue to happen, but many jobs don't change that fast. What we should anticipate is the diffusion of new technology and working practises into the same broad areas of economic activity – building and maintaining the infrastructure of a complex modern society, making things, looking after people and so on.

It's important, for example, to resist the cycles of excitement that develop around *'emerging technologies'.* We have a tendency to be excited by the 'new, new thing' – and this tendency is naturally exploited by journalists, promoters of new companies, venture capitalists and academic entrepreneurs, to talk up the revolutionary potential of a new technology (Nuffield Council 2012). The last couple of decades have seen enthusiasm for nanotechnology, synthetic biology and graphene, come and go. Such technologies may well find useful economic niches, albeit after a longer development period than initially anticipated, but it is now clear that the original projections of multi-billion dollar markets and transformational effects on society have proved to be exaggerated. Time will tell whether objects of current enthusiasm, like AI and machine learning, will fall into the same category.

It's certainly true that progress in information and communication technologies has been transformative, and has reset our expectations of the pace and impact of technological change. A high-end microprocessor today has nearly 50,000 times the performance of a 1978 mini-computer, at perhaps 0.25 per cent of the cost: the remarkable period of exponential growth in computing power summarised in 'Moore's law' has been a powerful driving force for economic change. But this period of exponential growth has now come to an end. Between 1986 and 2003 computer power increased at an astonishing 52 per cent a year, a doubling time of just a year and a half. The pace of advance slowed in 2004 to 23 per cent a year up to 2011, but since then it has slowed even more, to just 3.5 per cent a year since 2015 (Hennessy 2017).

This doesn't mean that innovation in information and communication technologies will come to an end – it will change in character, driven by very much cheaper commodity integrated circuits on the one hand, and specially designed custom chips at the other. In the future, it will make much less sense to talk about a specific 'tech sector'; as barriers to entry are lowered through falling costs and the availability of cloud services every industry will have the opportunity to be a 'tech industry'.

We may see more stories like Stoke-on-Trent's Bet365 – a company which grew very rapidly using new technology in a very old business (albeit one that some may have ethical reservations about), outside what are thought of as the traditional tech clusters, with a material effect on a struggling, de-industrialised local economy. Meanwhile, quite simple innovations using mobile computing have the potential to make substantial impacts on foundational economy industries such as social care.

Technological progress will continue. But commentators who invoke 'Moore's law' as a basis for continuing technological optimism are behind the times.

7. Exploiting the state's role in creating markets and driving innovation

7.1 Supply side innovation policy is not enough

We must rebuild local and regional innovation systems, using new translational research institutions as nuclei, and selecting areas on the basis of what innovation capacity exists already, while identifying economic sectors on the basis of a combination of their importance to the economy as a whole, and the scale of their historic and likely future productivity growth.

Given the scale of the productivity problem outside London and the South East, this will not be enough by itself to achieve the step change in economic growth that is required. For this, entirely new innovation capacity needs to be built. This needs the more direct exploitation of the substantial capacity the state has to drive innovation directly by creating new markets.

7.2 Innovation and the 'three player game'

Modern states have played a central role driving innovation (Mazzucato 2018), recognising that it is only through innovation that their strategic goals can be realised. Their purchasing power – comprising a significant fraction of the whole economy – can be a powerful force for directing innovation in both the public and private sectors.

The scale of the UK state's purchasing power is huge. It's estimated that the public sector spent £255 billion with external suppliers in 2016/17 (Booth 2018) - about one third of public spending, 13 per cent of the whole economy. In addition to this direct spending, much additional spending on infrastructure is carried out by the private sector, but heavily regulated by the state. For example, over the three years 2018/19 - 2020/21 it is anticipated that £51.7 billion will be spent on energy infrastructure and £35.4 on utilities (including energy transmission and distribution), with a further £137.5 billion of energy infrastructure investment planned beyond 2020/21 (HM Treasury 2018).

There is a strong argument – powerfully made, for example, by David Connell (Connell 2014) - that the UK fails to use its purchasing power effectively to drive the innovation we need. This is in contrast to the situation in the USA, where government spending on defence has been a powerful driver of the information technology industry. The first mass produced computers based on integrated circuits were procured as the guidance systems for the Minuteman II Intercontinental Ballistic Missiles (Kilby 2000), while GPS (the Global Positioning System) was invented as a solely military technology, and implemented at US government expense – but many everyday uses of smart phones now rely on it.

The way government sponsored defence technologies diffuse into the civilian world and are subsequently developed should not be oversimplified. In Janeway's compelling description of the US ICT industry (Janeway 2018), this is a 'three-player game' in which government, the market economy, and financial capitalism have to come together.

7.3 The shifting strategic goals of the state

But what are the strategic goals of the state? In post-war Britain, maintaining domestic industries like steel, coal, electricity and telecommunications was considered part of the strategic role of the state, but the privatisations of the 1980's marked a new view that these parts of the economy were better off in the hands of the market.

The defence of the realm remains a key state responsibility, but here too the approach has changed. The post-war period marked the apogee of the British 'Warfare State' (Edgerton 2005); since the end of the cold war the scale of the UK's military establishment has substantially decreased.

These changing priorities have been reflected in a change in the objectives for government supported research and development. Privatisation of the utilities and energy companies led to a substantial fall in corporate research and development in those sectors, and in the 2000's research funding was transferred from government departments to research councils.

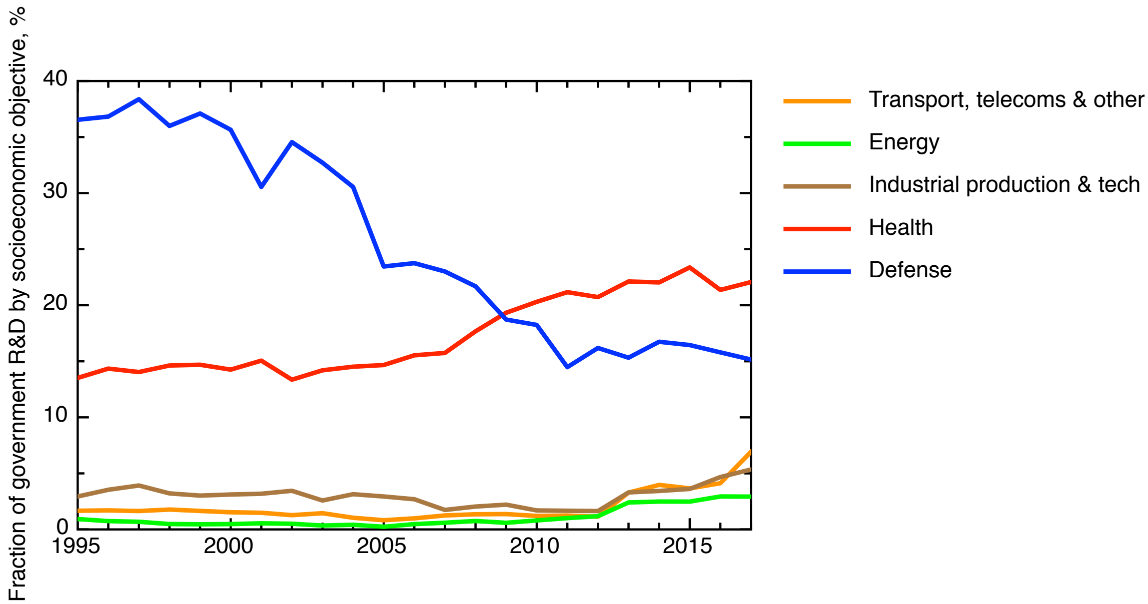

Figure 12. The primary goal of UK government funded R&D has shifted from defence to healthcare, with energy research remaining underfunded.
Fraction of UK government R&D allocations by socio-economic objective, for selected sectors. Data (OECD 2019)

Figure 12 shows the way the balance of objectives for UK government R&D has shifted since 1995. The end of the cold war initiated a substantial relative decline in defence R&D, with the privatisation and run-down of a number of military research establishments. Defence still provides the motivation for 16 per cent of government R&D; in a world of increasing insecurity, it's not clear that this figure should fall further, though in the future the emphasis may turn more to cyber-security than warships and missiles.

The major beneficiary of the decline in defence R&D spending has been health, which overtook defence in 2009 to become the largest single objective for UK government research, accounting for 21 per cent of R&D spending. Given the increasing demand on our health and social care services caused by a combination of rising expectations and demographic change there is a clear need for innovation here. What is less clear is whether this very substantial slice of R&D spending is optimally allocated.

But perhaps the most important – and neglected – area where the government needs to promote innovation is in the transition to a sustainable, low-carbon, energy economy. Until 2010, only 1 per cent of the UK government's spending on science and technology was for energy. This fraction has now crept up to 3 per cent, but given the scale of the problem this is still scandalously low. Nor has the private sector done any better – the whole utility sector, including electricity, gas and water supply, accounted for only 0.5 per cent of the R&D carried out by business in 2017 (ONS 2018).

The energy industry is privatised, but through a piecemeal and unplanned process, the UK government has ended up, in effect, back in control. As the economist Dieter Helm writes (Helm 2016): *"Every single investment in electricity generation in this country is determined by the state. It comes with either a capacity contract or a feed-in tariff."* Having taken back control of the energy economy, the government now needs to use its power to drive the innovation we need.

Low carbon energy research in the UK needs to be scaled up by an order of magnitude, if the UK is to meet its own carbon reduction goals – and if it is to benefit from the worldwide business opportunities that this massive energy transition will offer. But choices will be necessary, on what areas to focus on and on the right balance between research, development and deployment. This represents an opportunity to use R&D investments to attract inward investment, create new high value businesses and increase productivity – and there is no reason why this should not happen in the less well-performing regions of the country.

8. Decarbonising Energy

8.1 Getting serious about the scale of the decarbonisation problem

Modern societies like the UK depend on access to cheap and abundant energy. Fossil fuels have given us this access, but the reality of climate change means that we – and the rest of the world - need to move away from our dependence on fossil fuels fast.

We are currently on a trajectory that locks in damaging climate change. Even if countries meet their commitments according to the 2015 Paris Agreement, the world is on track for global warming of about 3°C by 2100, with warming continuing afterwards (UNEP 2018). According to the recent IPCC special report (IPCC 2018), the world needs to be approaching zero net carbon emissions by 2050 to limit global warming to 1.5 °C; even the less ambitious goal of limiting average temperature rises to 2 °C would require net zero carbon by 2070.

The UK is committed to reducing greenhouse emissions through the 2008 Climate Change Act, which sets out a legally binding target for 2050, of reducing greenhouse gas emissions by 80 per cent compared to a 1990 baseline. Even though this target is less demanding than net zero carbon emissions by 2050, the UK is not on track to meet it (CCC 2018). Emissions have been reduced – but this has been achieved largely by a combination of shifting electricity generation from coal to gas, and by importing more manufactured goods, shifting their embodied carbon emissions to exporting countries. Both routes to reducing the carbon intensity of our economy have now run their course.

More than 80 per cent of the energy we use still comes from fossil fuels - and 60 per cent of our total energy comes from directly burning oil and gas, the petrol and diesel to run our cars and trucks, and gas we use to heat our homes and power heavy industry[6].

Achieving net zero carbon emissions will involve completely decarbonising our electricity supply, electrifying transport and as much as possible of other domestic and energy use,

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[6] All energy statistics in this section are 2017 figures, derived from the Digest of UK Energy Statistics (BEIS 2018).

together with substantial progress on home energy efficiency. Carbon capture and storage may be needed for otherwise hard to decarbonise industrial sectors such as steel and cement making, while decarbonising air travel may only be possible through the development of zero-carbon liquid fuels.

We have made progress in decarbonising our electricity supply. In 2017, of a total of 350 TWh of electricity generated and used, 61.5 TWh came from rapidly growing wind and solar capacity; the largest source of low-carbon electricity remains nuclear power, which contributed 70 TWh. In the decade to come, we can expect further expansion of wind and solar – particularly offshore wind. But much of the expansion in low carbon electricity from solar and offshore wind is in danger of being cancelled out by the imminent retirement of most of the existing nuclear power capacity – the fleet of Advanced Gas Cooled Reactors (AGRs), which in 2017 generated 60 TWh of low-carbon electricity.

Reversing this situation will take a rebooting of the currently stalled nuclear new build programme, which, if the original plans were realised, would roughly double the current nuclear capacity. Together with a substantial expansion of solar and wind, and continuing improvements in energy efficiency, this would bring the total decarbonisation of the UK's electricity supply within sight.

But decarbonisation of our electricity supply is only an essential first step on the way to net zero carbon emissions – the biggest challenges to decarbonisation come from those sectors – transport and domestic heating - relying on directly burnt oil and gas.

A very rapid expansion of electric vehicles is needed. The limiting factors here will be economics, the world capacity to produce batteries, the relatively long life-time of our vehicle stock, and the difficulty of electrifying heavy goods vehicles. Reductions in the domestic consumption of gas will require a serious programme of home energy efficiency, including much more stringent conditions on new build.

The challenges of getting to net zero carbon emissions by the middle of the century are both technological and economic. The problem is urgent, so there must be a focus on technologies that can be translated and deployed at scale, at prices that will compete with fossil fuels without subsidy.

8.2 Beyond research tokenism

Economic theory has a ready solution to the problem of climate change. Firstly, we should fund more research and development to drive down the cost of low carbon energy. Some of this funding must come from the state, because of the known market failure that causes the private sector to underinvest in R&D. Then, we must impose carbon taxes, imposing previously uncosted externalities of burning fossil fuels on the people who consume it, encouraging the market to develop and deploy low-carbon energy sources.

These measures are necessary, but in practise they won't be sufficient by themselves. The realities of political economy make it very hard to impose carbon taxes at the level that would be required to fully account for the damage of climate change in a consistent way across different countries. Nor is it straightforward to calculate what that correct level should be – such a calculation has to account not only for the inherent uncertainty of climate forecasting, but also the difficult issue of principle of what the correct discount rate is to apply to damage that may not materialise for many decades.

More research and development on energy is certainly necessary, but caution is needed here too. As David Edgerton has written about an earlier period (Edgerton 2018): *"Not all research was done to effect great changes. Some was done to avoid it."* Calls for more research are easy to make, but don't always translate into outcomes on the scale of the climate change challenge. Research, being relatively cheap, can be a substitute for action.

To be serious, in the face of the urgency of the climate change problem, there needs to be a clear path from research, through development, to deployment. This may require a much more focused and directive approach to national research management than we have grown used to in recent decades.

The problems of climate change and the transition to net zero carbon energy are global in scope, and the UK, on the global scale, is relatively small. This means that hard questions have to be asked about where the UK can best contribute, and where can the UK realistically hope to create value from the innovation needed.

The urgency of the problem also poses a problem for the UK, whose innovation system is stronger in basic research than in translational research. There needs to be an understanding of the life cycle of low-carbon innovation, and a willingness to invest in new capacity to translate and deploy low-carbon technologies.

8.3 Understanding the low-carbon innovation lifecycle

Low carbon innovations can take many years between early research and deployment at scale. The state needs to intervene – but what the most appropriate interventions are will depend on what stage the technology finds itself on this lifecycle (Breetz 2018).

At an early stage, when costs are much higher than incumbent technologies, support needs to be given to research and development, leading on to prototyping and pre-commercial installation. R&D investments made at this stage will not recoup their costs on the timescale demanded by venture capitalists, so this part of the cycle cannot be left to the market.

This lesson was learnt the hard way in the USA. In 2006, the belief that new 'clean technologies' offered the next great growth opportunity took hold amongst venture capitalists in the USA, following the end of the dot com bubble. In that year $1.75 billion was invested in 'cleantech' companies, developing new technologies like solar panels, batteries, and biofuels. By 2011, the VC industry had invested $25 billion in cleantech. But more than half of this money was lost in company failures, and the unsurprising result was that subsequent investment dried up (Gaddy 2016). Timescales for developing new technologies in the material world – as opposed to the world of software – are too long, and the rewards too uncertain, to fit the VC model.

When this early stage R&D and prototyping has brought costs down enough to permit niche adoption and the initial formation of markets, government support needs to move onto fiscal incentives (i.e. subsidies) for deployment, regulatory support (eg renewable obligations) and the development of any necessary infrastructure.

Subsidies for deployment without an industrial strategy that develops supply and production may not lead to benefits for the industry of the country making the subsidies, however. In 2010, Germany introduced a policy calling for a massive transition from electricity generation from coal and nuclear to renewable sources such as wind and solar – the 'Energiewende'. However, the industrial benefits of the deployment subsidies went, not to German industry, but to China; Germany spent €25 billion on the import of solar modules (Fraunhofer ISE 2018).

China used subsidies and cheap loans to make a very rapid expansion of their solar module manufacturing industry. The scale of this expansion was huge – in 2010, the top five solar companies in China received $31 billion in soft loans from the state owned China Development Bank, with additional direct support coming from city and provincial governments (Haley 2013). The result of this was a world glut of solar cell modules, and a collapse in price, rendering the existing, initially rather strong, German solar cell industry uncompetitive, and unable to take advantage of this huge expansion in domestic demand.

The deployment of a technology at scale should bring the cost down through incremental process improvements and 'learning by doing', as has happened in the solar cell industry. A dismal counter-example comes from the recent history of civil nuclear power, where escalating, rather than reducing, costs seem to be the rule. Part of this issue has probably arisen from a need to meet very stringent safety standards, but poor programme design also plays a big role.

The UK's approach to new nuclear build might well have been designed to maximise the cost to UK energy consumers, while minimising the benefit to UK industry. The cost of nuclear power is dominated by the financing cost of the upfront cost of construction, and private sector investors naturally demand a much higher rate of return on their capital than the cost of government borrowing, so the price for keeping the costs off the government balance sheet, to be paid by future consumers, run to tens of billions.

Because the projects are both run and financed by overseas companies, the UK government has no control over supply chains the consortia develop – in effect, all the power of procurement that the government might have used to develop innovation and skills in the sector have been renounced. Moreover, the plan to build four distinct designs of reactor mean that most of the opportunities to bring about efficiencies and drive down costs through 'learning by doing'.

The financial backers for three of the UK's nuclear new build projects have now pulled out, and the whole programme is now stalled. This offers the opportunity to rethink the whole approach. The UK should learn from Korea, the only country to implement a significant programme of nuclear power in which costs have been significantly driven down as more reactors were built (Lovering 2016). The key to doing this was a insistence on the sequential installation of identical, proven designs on different sites, retaining the learning of the construction teams, and developing proven and reliable supply chains and a skilled workforce.

At all stages, the key question that the government needs to consider is the degree to which UK industry can capture the benefits of the new technology. Deployment of a low-carbon technology is good in itself, but the goal of a low-carbon industrial strategy should be to use government expenditure – or private sector expenditure under the regulatory control of the government – to develop new, high added value, tradeable sectors of the economy.

This is the classic 'protecting infant industry' approach to industrial strategy. It is difficult to think of a more appropriate sector to apply this policy to than low carbon energy, threatened as it is by an enormously powerful and well established incumbent industry – fossil fuels.

8.4 Understanding the UK's place in the world

Industrial strategy is about making choices – many other countries will be making investments in low carbon energy, and it is important that the UK is able to make realistic judgements about where it can best contribute and where it will be able to create value for the economy. It needs to identify niches that it has particular advantages in, or places in wider global supply chains.

This must begin with choices of investment focus for publicly funded research and development. The choice of topics needs to account for UK's academic strengths, but also the capacity of UK industry to build or participate in the necessary supply chains. There needs to be realism about the UK's competitive position in the world – decades of neglect of energy R&D in the public and private sectors leaves it weaker than it should be. Choices need to be made in the context of worldwide competition.

For example, the world landscape for solar cells is now dominated by China, following their massive investments in production capacity; five of the top six global solar cell manufacturers are Chinese. China has been investing aggressively in other areas of low carbon technology too; seven of the top 15 wind turbine manufacturers are located there (Geall 2017).

China is increasingly dominant in lithium-ion batteries; by 2020 it's expected that 84 per cent of the battery manufacturing capacity in the world will either be in China or the USA (Sanderson 2017). China's expansion in battery production is part of a wider programme of industrial strategy to promote the development of electric vehicles.

It will be important to understand this international environment is important if the UK is to make the right choices of priority. For example, a key pillar of the Automotive Sector Deal (HM Government 2018) is a focus on battery research. But as Geoffrey Owen writes (Owen 2018):

"The government wants to ensure that the UK "leads the world in the design, development and manufacture of batteries for the electrification of vehicles". Given the strength of international competition and the current state of the UK battery sector, that hope seems unrealistic. Asian companies have a twenty- year lead in current battery technology, and they are spending heavily on research and development to stay ahead."

One recent analysis relied on patent data to find areas of UK comparative advantage (Martin 2019); this found strengths in efficient aviation, marine energy, and wind, but concluded that the UK's position in batteries and hybrid vehicles was not strong, and its position was weakening.

These judgements may be too pessimistic, and it is certainly true that patent data is only one indicator of relative strengths of R&D capacity and potential market position. Meanwhile the importance of the automotive industry as a driver of productivity growth is a strong countervailing argument. But it is important to make clear-eyed judgements, informed by data, about these issues.

8.5 What must be done, and where

The scale of the problem of decarbonising our energy supply is daunting, and choosing the areas where effort should be focused needs to be done very carefully to avoid some of the pitfalls I've discussed. The necessary careful evaluation of technical and market opportunities and the UK's competitive position is well beyond the scope of this piece, but some preliminary comments to illustrate some of the issues follow.

In recent decades, a substantial fraction of UK's energy research has been focused on nuclear fusion. This has resulted in the UK having real technical capabilities – JET, a European collaboration hosted at Culham, in Oxfordshire, holds the world record for the amount of energy produced in a controlled fusion reaction. There are potential technical spillovers from this capability – in robotics and advanced materials, for example. But daunting technical obstacles still stand in the way of commercial deployment of this technology – even on optimistic projections it's difficult to imagine this happening before 2050. This may be too late.

New capacity for energy R&D needs to focus on technologies that are closer to deployment, and should be developed in parts of the UK that are currently economically lagging, creating new clusters of high value industry. Some candidate areas would include:

- *Marine energy (waves & tides).* The UK has a potentially competitive world position on the basis of the size of the resource available, but development has been slow. Wales and Scotland would be obvious locations for developing an industry.
- *Wind*. The size of the resource and the scale of existing planned investments should give the UK a comparative advantage, though non-UK companies are currently dominant in the market. The development of affordable deep-water wind resources would be an obvious priority, with a geographical focus in Scotland, Northern Ireland, and the north of England.
- *Solar.* Here the UK has real academic strength in emerging solar technologies (e.g. the perovskite solar cells invented by Oxford University's Henry Snaith), but the dominant position of the Chinese industry and more favourable markets in sunnier parts of the world present a challenge.
- *Carbon capture and storage*. The UK has the advantage of having a number of empty geological gas reservoirs in the North Sea, conveniently located to sequester CO_2 produced by nearby heavy industry, making the North East Yorkshire and the Humber a rational location for a new industry. But the business logic for this technology will only work with much stronger government intervention.
- *Civil nuclear power*. The UK is one of the few countries in the world with a major nuclear new build programme planned; with a more considered approach this investment could drive significant innovation and skills development in the supply chains. Currently the UK has no position in conventional large scale light water

reactors. There is an opportunity for the UK to develop a smaller scale light water reactor, using modular manufacturing techniques to drive down capital costs, using expertise the UK has retained to build submarine reactors. Looking forward, new reactor technologies – so-called Generation IV reactors – could play a role, but given the UK's weak current position international collaboration may be the only way to participate in the development of these.

- *Energy storage and electric vehicles.* An organised automotive sector has already convinced the government to prioritise the development of electric vehicles, which form the focus of the Faraday Battery Challenge, whose £246 million government investment will include a translational research centre at the Warwick Manufacturing Group in the West Midlands.
- *Domestic heating.* About 14 per cent of the UK's total energy consumption is burnt as gas to heat people's homes. Much of the technology already exists to reduce this substantially, through better home insulation. Given that the UK already has a chronic shortage of housing (Barker 2014) – especially in the social sector, we should be embarking on a national programme of new building, incorporating high standards of energy efficiency.

9. Health and Social Care

9.1 Health-care is the largest driver of government supported R&D, but there's a lack of clarity about its purpose

The past fifteen years have seen big increases in funding for R&D directed towards healthcare in the UK. These reflect the UK's very strong academic base in fundamental life sciences, and the position of the pharmaceutical industry as the UK's leading R&D intensive industry. However, in a recent report (Jones 2018), James Wilsdon and I argued that the strategy that has underpinned this expansion is incoherent, resulting in an unbalanced research landscape which overemphasises fundamental biomedical research, in support of the pharmaceutical and biotechnology industry, while underplaying the quite different types of research that would be needed to drive innovation in the health and social care system and support the health of the population more widely.

Rather than talking about a 'life sciences sector', we should separate out three distinct goals for the healthcare R&D we do.

1. *Industrial strategy for the pharmaceutical and biotechnology industry.* As we've seen, the pharmaceutical/biotechnology sector has been one of the UK's most highly productive sectors of the economy, and it is its most R&D intensive. But it is one of the six sectors whose recent productivity weakness has contributed most to the economy's overall productivity slow-down.

2. *Raising the productivity of the health and social care sector.* Health and social care constitutes a very significant part of the economy in itself. The size and importance of this sector – as well as pressures of affordability on our health and social care system – mean that improving its productivity should be a priority.

3. *Improving the health of the people of the UK.* Despite substantial increases in real spending on healthcare related research, measures of overall population health, such as the rate of improvement of life expectancies, have stalled in

recent years. Moreover, shocking levels of regional health inequalities persist across the nation. Quite aside from the issues of equity and social justice this raises, there are strong links – in both directions – between regional health inequality and regional economic inequality. Poor places produce unhealthy populations, and unhealthy people are not as economically productive as they would be if they were in better health.

9.2 Pharmaceuticals & biotech are an important sector for the UK, and a legitimate object for industrial strategy

The pharmaceutical and biotechnology industry is an important area of specialisation for the UK, and as we've seen, falling productivity in the sector has made a material contribution to the UK's overall productivity problem.

The worldwide situation of the pharmaceutical industry is very serious. Between 1950 and 2010, real terms cost of developing a new drug increased exponentially, doubling every 9 years (Scannell 2012). In 2000, this cost passed the $1 billion per drug milestone. A recent estimate puts the rate of return on R&D investments in large pharmaceutical companies at 1.9 per cent, far below their cost of capital (Deloitte 2018). Unsurprisingly, this has resulted in a fall in R&D spending by UK pharmaceutical companies; this peaked in 2011, and is now 20 per cent lower in real terms.

There were hopes that this sector would be transformed by a biotechnology revolution, with fast-growing start-ups supported by venture capital exploiting the new discoveries of academic science. While in the USA a successful tier of mid-sized biotech companies did arise, this did not happen in the UK (Owen 2016), where, despite some isolated successes, the sector is still dominated by the two traditional 'big pharma' companies, GSK and AstraZeneca.

We now need an industrial strategy for the pharmaceutical and biotechnology industry that squarely faces up to this crisis in R&D productivity.

While the pharmaceutical industry is of great importance to the UK economy, its priorities are not set by the needs of the UK healthcare system, or the burdens of ill-health faced by the UK's population. Its major market is the USA, and its priorities reflect the particularities of the USA's healthcare system, with a focus on (very expensive) cancer drugs. These now account for 39 per cent of the late stage pipeline, with only a fraction of that devoted to big killers like cardiovascular disease.

The justification for supporting the pharmaceutical industry comes from its importance for the economy, not, primarily, for the benefits it provides for the UK's health and social care system or for its people's health.

9.3 Health and social care is a massive sector in its own right

Health and social care represent about 10 per cent of the economy. It is necessarily rather evenly spread across the country, so it tends to be proportionally more important in parts of the country where the market sectors of the economy are weaker. It represents a substantial portion of the foundational economy. Such a large part of the economy deserves an industrial strategy of its own.

Productivity is not easy to measure in health and social care, because changes in quality are difficult to account for. On the one hand, advances in medical science – and, perhaps just important, the effect of public health measures – have resulted in better health outcomes, which should be incorporated in any definition of healthcare productivity.

On the other hand, human factors are important – reduced duration of visits by care workers may allow an apparent increase in productivity, while resulting in a service less rewarding both to carer and patient. Financialisation of the residential care industry may have led to higher profits for investors, but this has come at the cost of poorer care outcomes and the financial fragility of the sector (Burns 2016).

The ONS estimates that quality adjusted total factor productivity in public service healthcare grew at 0.9 per cent a year between 1995 and 2016 (ONS 2019a). On the other hand, demand for healthcare services has been increasing at a faster rate, driven largely by an ageing population. For example, admissions to hospital have been rising at 3.6 per cent a year (Kings Fund 2016).

This inexorably growing pressure on healthcare services can only be resolved through innovation – innovation in new technologies such as medical informatics and ICT enabled assistive technologies, but also new ways of organising services. Public health measures are crucial too – more attention needs to be paid to effective preventative approaches that address the social, behavioural and wider determinants of health. These new research agendas need to be set with more engagement with clinicians, caregivers and patients (Bland 2015).

9.4 The imbalance between where healthcare research takes place and where the ill people are

The geographical concentration of biomedical research is even more marked than for R&D as a whole. As shown in figure 13, more than half - 55 per cent - takes place in Oxford, London and Cambridge.

This reflects the current focus on biomedicine in support of the pharmaceutical and biotechnology industry. If the major way by which research is converted into better healthcare outcomes is through the development of new medicines, then it can be argued that it doesn't matter where the research is carried out, as the resulting drugs will be available all over the country.

But if we accept the arguments that more emphasis needs to be placed on research on the wider determinants of health and well-being, and that those delivering healthcare, caregivers, patients and the wider public need to have more influence on the priorities of healthcare research, then there needs to be a better match between where the burden of ill-health is greatest and where research takes place. The paradox is that now, the places where health related research is currently concentrated – London, Oxford and Cambridge – are among the healthiest parts of the UK, as well as being among the most prosperous.

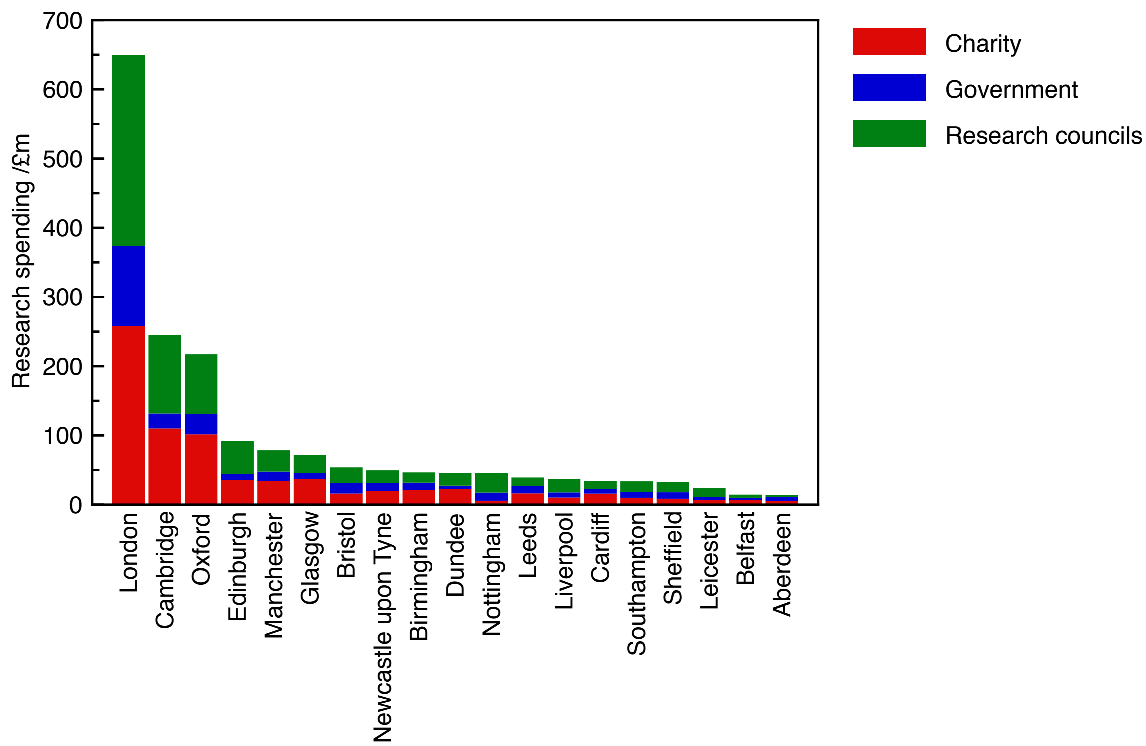

Figure 13. Public health-related research is geographically highly concentrated, with 55 per cent going to London, Oxford and Cambridge.
Geographical distribution of health-related research supported by government and charities.These 19 cities receive more than 90 per cent of total funding. Data taken from the UK Health Research Analysis 2014 (UK Clinical Research Collaboration, 2015).

The UK is scarred by pronounced health inequalities – people living in the most deprived local authority districts can expect to live up to nine years less than those in the most prosperous. As figure 14 shows, the regional economic inequalities I discussed in section 2, between a prosperous London and the South East, and a lagging Wales, Scotland, Northern Ireland and the Rest of England, are mirrored in these health inequalities.

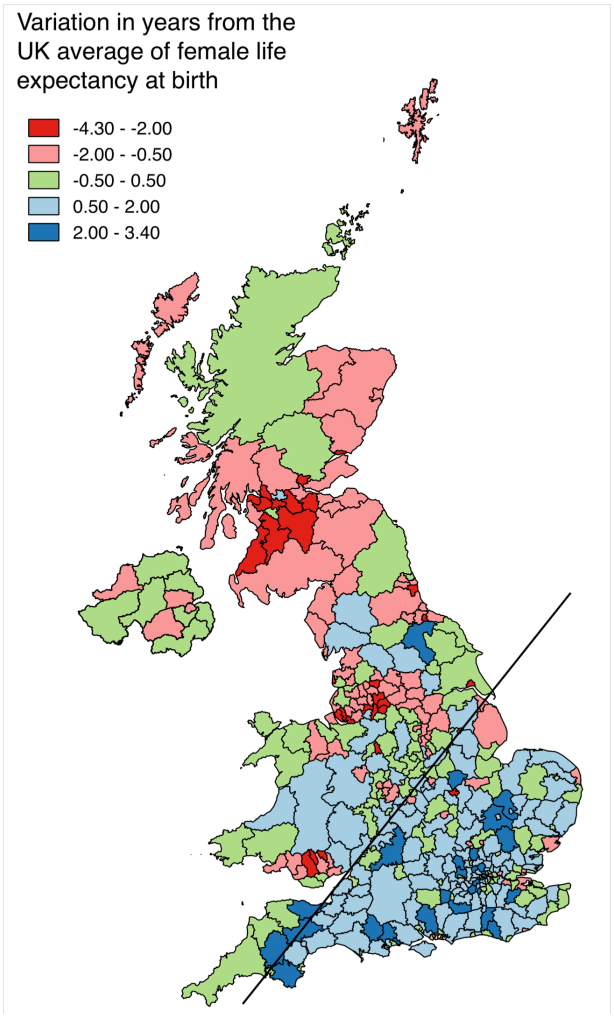

Figure 14. Life expectancies vary by as much as 9 years across the UK, with the highest longevities in London and the South East.
Regional variations in life expectancy across the UK, by local authority district. Life expectancies at birth, females, 2012-2014. Data: ONS (ONS 2019).

Poor health in economically lagging regions contributes to their economic underperformance. The costs of health inequality have been estimated (Marmot 2010), for England alone, as of £31-33 billion in productivity losses, £20-32 billion in reduced tax revenue and higher welfare payments, and increased treatment costs well in excess of £5 billion.

9.5 Towards a more broad-based translational healthcare research system

The geographical concentration of healthcare research reflects an overly narrow conception of what this research is for, with too exclusive an emphasis on fundamental biomedical research in support of the pharmaceutical industry. It's true that this has led to a world-class biotechnology cluster in Cambridge, reinforced by the recent move of AstraZeneca's R&D there from the Northwest. But broadening our conception of what healthcare research is for, giving more explicit recognition to its role driving up productivity and innovation in the wider health and social care system, could let us develop new clusters of high value industries in currently economically lagging areas.

To form these new clusters, there needs to be a three way collaboration between new centres of research and innovation, private sector industry, and local NHS organisations, together with the councils responsible for social care. The involvement of health and social care providers is needed to make sure that technological innovation and the organisation of care are co-developed, and that private sector partners can be assured that there will be markets for the innovations being developed. In this way the NHS's huge procurement budgets can be used to drive innovation.

Examples of such clusters could include:

- The use of devices supported by information and communication technology to support independent living, and distributed healthcare in rural areas;
- New medical devices, including robotic aids for surgical procedures and new diagnostic and imaging methods;
- New materials and manufacturing methods for implants and prosthetics, such as 3-d printable nanomaterials;
- The effective and ethical use of large scale population health data;
- Understanding the wider social and behavioural determinants of health and the most effective interventions to improve public health.

These clusters should all be outside London and the South East. An existing specialism in medical devices exists in Leeds, for example, and the devolution of a combined health and social care budget to Manchester provides an opportunity to experiment with new models of better integrating acute and social care.

In addition to the direct economic benefits, a more innovative and productive health and social care sector will benefit every part of the country, bringing better quality and more rewarding jobs to this important part of the foundational economy, and better health outcomes for all.

10. Mechanisms and institutions

10.1 Empowering sub-national government to drive productivity

The goal of a new industrial strategy should be to raise the productivity of the economically lagging parts of the UK by rebuilding their innovation systems, helping them break out from their current low innovation, low skills, low productivity equilibrium.

This will need institutional and cultural change at all levels of the UK government. A vital first step is for more decentralisation in what is now an overcentralised state. As the IPPR Commission on Economic Justice argued, *"Driving equitable and sustainable growth across the country cannot be done from Whitehall; it requires the decentralisation of economic powers and resources."*

Such decentralisation as has happened so far has been uneven and patchy. To be able to drive growth effectively, devolved authorities need three characteristics. They need:

- *political legitimacy*, in order to make decisions and be held accountable for their outcomes.
- *analytical capacity*, in order to accurately assess their current situation and articulate a sound evidence base for those decisions.
- *power to deploy resources* on a scale to make a difference.

The degree to which national and regional administrations meet these criteria differ. The Scottish Government clearly meets all three, and is thus well placed to develop and implement a coherent economic plan. Northern Ireland – despite remarkable progress since the Troubles – still has political issues, and faces the uncertainty of its post-Brexit relationship with the Republic of Ireland.

Wales has a functional devolved administration, but has difficult problems to overcome. It is the poorest part of the island of Britain, with problems both in its rural and coastal peripheries and in the de-industrialised areas of its former coal-fields. Difficulties also arise from the lack of match between its cultural and political geography and its economic geography.

But the biggest institutional problems remain in the regions of England outside London and the Southeast, badly served by national institutions concentrated in the capital. Recently there's been an a patchwork of different approaches applied inconsistently across the country, from Regional Development Agencies, through Local Enterprise Partnerships, to Metro Mayors and Devo Deals, supplemented by Powerhouses and Engines of uncertain constitutional status. This is all superimposed on layers of actually existing local government, whose ability to act has been substantially weakened, having borne the brunt of austerity-driven funding cuts.

The rest of England needs a more coherent policy of devolution of economic power (and respite from further central government imposed austerity). The ultimate solution probably needs the political capital of the UK to be moved out of London – perhaps to Birmingham or Manchester. In the meantime, the piecemeal, city-based devolution programme needs to be accelerated and more uniformly applied. There is economic logic in taking the City Region as the right unit for developing analysis and strategy, and having an elected Mayor to give this process political legitimacy makes sense as an initial step.

The current policy of inviting regions to develop local industrial strategies is a worthwhile first step; these should include specific targets and roadmaps for R&D intensity, with cases for new investment by government in translational research, innovation and skills linked directly to the potential to grow existing private sector R&D capacity and build new capacity, especially in healthcare and low carbon energy. Better data at a local and regional level of granularity is a prerequisite for good analysis, and as part of this new types of data sources (NESTA 2019) should be explored.

10.2 A financial system that supports innovation and value creation

I discussed the financial services sector in section 6.3 in terms of its own direct contribution to productivity and growth. But in addition to this direct contribution, it makes a vital indirect contribution to the economy. A well-functioning financial system should direct resources and capital to those parts of the economy best placed to grow, guaranteeing the owners of the money it holds in stewardship the best long term returns, and supporting a dynamic and productive economy.

A well-worn critique of the UK financial system points instead to a record of persistent underinvestment, a symptom of chronic short-termism. The Kay Review (Kay 2012) presented a compelling analysis of the structural issues that have led to this situation, including a number of case studies of UK companies, formerly household names, that came to grief by focusing too much on mergers and acquisitions, and too little on developing their businesses by creating valuable new products and services.

The call for "less financial engineering, more real engineering" was first made by Peter Mandelson after the global financial crisis, but little progress has been made towards realising this goal. Revisiting the recommendations of the Kay Review would be a good start.

10.3 Making UK Research and Innovation work for the whole UK

At central government level, the UK's apparatus for supporting research and innovation has recently been through its most comprehensive reorganisation for decades. Seven Research Councils, the research arm of the Higher Education Funding Council for England (now Research England), and InnovateUK have been combined to form a single agency, UK Research and Innovation, controlling a £7 billion budget.

As we have seen, government funding of R&D is highly concentrated in London and the Southeast of England. The combination of a new agency with a commitment on the part of government to raise the R&D intensity of the economy from 1.7 per cent to 2.4 per cent offers a new opportunity to change this.

However, there are structural barriers to this that will take a conscious effort to overcome. UKRI itself is based in London, with a governing body that is, with a single exception, based in London and the South East. It's perhaps inevitable that UKRI will look rather London-centric, as long as the UK's capital remains there. But there is a need for UKRI to adopt its structures to take more account of voices from outside London and the Southeast. A simple first step would be to establish an advisory committee incorporating representatives of the devolved administrations and English Metro Mayoralities.

The seven research councils have long operated a policy of not having a regional policy, instead being committed to distributing research funds solely on the basis of excellence as measured by peer review, a process that through the 'Matthew Effect' is always likely to reinforce existing inequalities. InnovateUK's strategy is to be 'business-led', which will naturally lead to a focus on regions that already have strong private sector R&D capacity.

The exception to this tradition of 'place-blind' policy is Research England, which (beginning with its previous incarnation as HEFCE) has long taken consideration[7] of the economic role of universities and their research in their cities and regions. As UKRI

[7] In England only – this responsibility is devolved in Scotland, Wales and Northern Ireland.

develops, this expertise in 'place based' research policy should be developed and shared with the research councils and InnovateUK.

The other way in which research investments have an obvious impact on regional economies should be through the location of new, free-standing, major research and innovation facilities. These include central facilities for fundamental science, such as the Diamond synchrotron light source and the ISIS neutron source, both in Oxfordshire, and translational research facilities, such as the new Catapult Centres. The process by which these decisions have been made in recent years has been heavily criticised by the National Audit Office (NAO 2016). There will need to be a much more robust and challenging framework in place to make good decisions about the new translational research centres that my plan proposes.

In the future, priority for new capital investments should be given to translational research centres that will boost innovation and skills in the economically lagging parts of the UK, and business cases should include as their central criterion the effect of the new facility on regional economic inequalities.

10.4 Putting productivity and innovation at the heart of central government

Who in central government is ultimately responsible for solving the UK's productivity problem? At the moment, this responsibility is divided between the Department of Business, Energy and Industrial Strategy (BEIS), which has responsibility for the science and innovation budget and relations with industry, and the Treasury, with its general oversight of the whole economy.

The role of BEIS is an important one, but the urgency of the productivity problem means that it should not be considered as solely the responsibility of the business department. I have stressed the importance of driving innovation in low carbon energy and health and social care as key ingredients in turning round the productivity problem; the recent folding in of the Department of Energy and Climate Change into the BEIS is a positive step, and should be built on by developing a plan for decarbonising the energy economy and explicitly linking this to an industrial strategy.

In the Department of Health and Social Care (and the corresponding departments in devolved governments), the urgent immediate problems of the healthcare system have tended to take priority over longer-term goals of driving up productivity. This should be the focus of the National Institute of Health Research, which should lead on translational research for the UK population's health and for driving up productivity in the health and social care system, leaving the Office of Life Sciences entirely focused on industrial strategy for the pharmaceutical and biotechnology sector.

One of the outcomes of the recent Industrial Strategy white paper was the creation of an Industrial Strategy Council. This is a positive step, but to give this body more teeth and a truly cross-government brief it should be placed on a statutory basis and work under the auspices of the Treasury (in a similar way to the Office for Budgetary Responsibility), holding the government, stand-alone agencies such as UKRI, and regional government and devolved adminstrations, to account for progress in improving productivity and reducing regional economic disparities.

10.5 A culture of government activism

To change institutional arrangements is straightforward compared to changing culture, which is where the biggest challenge to the programme I outline will come from. The Treasury favours supply side approaches, in the belief that this gives the decision-making initiative to the market. Thus, while the Treasury is deeply sceptical of direct government intervention in the economy, it seems comfortable with very substantial public expenditure in support of private sector R&D, innovation and entrepreneurship through mechanisms such R&D tax credits, tax breaks for venture capital and entrepreneurs, and indeed direct financial subsidy for Venture Capital.

This approach has not been successful by itself, and more direct intervention is now needed. There is, though, a sound basis for the Treasury's reticence – the state currently does not have the expertise and capacity to plan and make technical decisions of the kind that this programme demands. But the urgency of issues like climate change, and the need to plan long-lived infrastructure with long lead-times demands that the government develops that capacity, urgently.

This is not a proposal to reintroduce nationalised industries – on the contrary, it is a question of the state giving a strong lead to the private sector, of setting the objectives, and commissioning the private sector to deliver them, having set up the infrastructures needed to generate the skills and innovation delivering these objectives will require.

11. A plan for a productive, innovative, (and) United Kingdom

This proposal presents a plan to build up the innovation capacity of those regions of the UK which currently are economically lagging,

The goal is to drive up productivity across the regions, reducing the gap between the most productive and the least, and helping lagging regions break out of the low innovation, low skills, low productivity equilibrium that they are trapped in.

The primary mechanism will be the establishment of new centres of translational research, thereby nucleating new clusters of innovation and skills, both driving up the productivity of the existing business base and attracting and creating new high value businesses.

The models for these centres should draw on the experience of the most successful overseas models, such as Taiwan's ITRI and Germany's Fraunhofer network, and successful UK centres such as Sheffield's Advanced Manufacturing Research Centre. The key ingredients should be close involvement of private sector partners, a research programme that is avowedly translational, but maintains strong links to the academic research base, and an explicit involvement with skills at all levels, including at intermediate levels (through high quality, innovation focused apprenticeship programmes developed in partnership with local businesses and FE providers) and management education.

Stable funding should be provided for stability and to fund a core research programme; this needs to be supplemented with competitive collaborative funding with industry, used explicitly as a mechanism to grow private sector R&D, to meet roadmaps in local industrial strategies which, combined, will give a route to achieving the target of 2.4 per cent R&D intensity nationally. Further funding should come through direct contract research for industry, allowing companies to benefit from expensive capital equipment and expertise that they wouldn't be able to afford on their own.

The outcome should be increased regional productivity, through the attraction of inward investment by technologically leading international firms and the development of the indigenous business base through the diffusion of new technology and best business practise. Some spin-out companies should result too, but these are less likely to be IP based, VC backed start-ups than know-how based 'soft spin-outs' such as technical consultancies and business services firms.

These centres will act as nuclei to develop the innovative capacity of regions, build demand for skilled people and help meet that demand, and re-establish formal and informal networks of expertise. In deindustrialised areas, this will amount to recreating the 'industrial commons' that those areas have lost.

In some cases the areas of focus will be chosen to build on the existing potential of each region, with local areas working with central government agencies to identify sectors with realistic potential to drive productivity growth.

However, new innovation capacity – leading to new businesses and industries - will also be needed, and this should be in areas of societal priorities, where innovation is required in order for the state to meet its strategic goals, and where the government can use its substantial powers to create new markets. Health and social care, and the transition to low carbon energy, are two of the highest priority areas.

In research and innovation in support of health, there needs to be more focus on the kind of research that improves the productivity of the health and social care system, in addition to the current heavy emphasis on biomedical science in support of the pharmaceutical and biotechnology sector. These research agendas – in some cases involving new technologies, sometimes concerning new ways of organising services, and not neglecting the wider social and environmental determinants of health – should be set in consultation with clinicians, caregivers, and patients. The new clusters of healthcare innovation will be much more broadly based, geographically, than the current situation.

Innovation will be crucial if the UK – and the wider world – is to avoid the worst effects of climate change. The UK's research capacity in energy has been allowed to fall to very low levels, but decisions about where to create the necessary new research and innovation capacity need to be taken with care. There must be a good understanding of the path to deployment, and realism about the UK's position in the world.

These interventions will need to be made on a material scale if they are to make an impact on the UK's problems. A starting point is provided by the new funding that would be needed to meet the government's own target for R&D intensity – to reach 2.4 per cent of GDP by 2027 implies raising government R&D spending by around £7 billion a year, with an expectation that this would be matched by around £14 billion a year new private sector investment. This direct spending should be backed up by more strategic use of the government's procurement budget, and a more directive approach to private sector infrastructure in regulated sectors such as energy.

The degree to which this plan is delivering should be closely monitored. Important early indicators might be progress towards a more regionally balanced R&D intensity and of increasing demand for skills in lagging regions. Ultimately success should be revealed by the GVA per head and the fiscal balance of all regions in the UK approaching current national averages, closing the gap with the leading regions.

The UK's failure to recognise and confront its stagnating productivity performance since the global financial crisis has already imposed significant costs on the country. Wages are at least 20 per cent less in real terms than if pre-crisis trends had continued. Public sector deficits have persisted much longer than anticipated, and governments have responded with continuing public sector austerity that has resulted in a deteriorating public realm. It's not surprising that politics has turned sour.

If we continue doing the same things, there's no reason to think that the current trend will change. The problems of the UK economy are structural, with much of the UK outside London and the prosperous South East trapped in a low innovation, low skills, low wage equilibrium. There's now no justification for thinking that productivity growth will, without intervention, bounce back to a pre-crisis trend that we haven't seen for a decade.

Conversely, the more successful we can be at raising productivity growth, the faster wages will grow. In the Resolution Foundation's latest analysis (Corlett 2019), the central projection is that median non-pensioner household incomes after housing costs will have risen from its 2015-16 value of £23,400 by just £400 by 2023-24. The main drag on wage growth in this projection is weak productivity growth; if this were restored to its pre-crisis value the projected increase in median income would be £1590, nearly four times bigger.

A return to the pre-crisis expectation of year-on-year real income growth would be welcome, but perhaps it is even more important to make the transition to a sustainable energy economy before the impacts of climate change become catastrophic.

All parts of the UK will benefit from this programme. New clusters in tide and deep-water wind power might bring new prosperity to coastal regions of Wales and Scotland, new high value manufacturing specialities will emerge in northern towns, and the development of ICT enabled distributed healthcare could bring new opportunities to rural areas. This plan would speed a necessary transition to low carbon energy and humane, affordable and lead to a more effective health and social care system everywhere. Our goal should be a more prosperous, equal and united country.

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