Good Governance Project Working Paper

Unleash innovation to defend our freedoms:

Why we need US-style venture capital to make a UK DARPA work

Dr Radomir Tylecote
August 2020

Summary

UK innovation faces a number of crises. The UK's R&D spend per unit of GDP is now lower than the US, Germany, France, Japan, or China; UK patent registrations have fallen over the last twenty years despite increasing in most major competitor nations. Our corporates find the long-term investments needed for innovation especially difficult, yet these are a leading source of growth. This is helping to create the ongoing 'new normal' of low UK growth.

But this is not simply an economic crisis. In the Cold War, the USSR's launch of Sputnik created the sense of urgency in the US that caused the renewal of its defence-innovation ecosystem, with the side-effect of improved economic growth.

Today, China has adopted a more expansionist posture, and is investing increasingly heavily in defence innovation. Yet since the end of the Cold War, the UK has broadly failed to do this. It has merged and centralised its successful 'research establishments' and privatised research assets: but in the latter case, it has not created the incentives that are needed for investment in risky 'paradigm leap' technologies. Defence R&D expenditure has fallen 61% since 1990.

The UK's provision of over-five-year R&D financing is also poor and may be getting worse. This failure to invest means inability to create the technologies that lead to economic growth and military dominance. Failure to deal now with the structural gaps risks the UK slipping into an increasingly supplicatory position this century.

The government plans to help improve the UK innovation environment by creating a UK version of the Defense Advanced Research Projects Agency (DARPA) in the US, likely in its more generalist early form, ARPA (founded in 1958 and becoming DARPA in 1972). DARPA is an agency of the US Department of Defense (DoD), tasked with "making pivotal investments in breakthrough technologies"[1] for military use, many of which have had a profound impact on other fields. Reporting to senior DoD management, DARPA is highly independent, with a relatively small number of programme managers overseeing large R&D programmes. It is generally seen as having played a crucial role in US post-war innovation success.

However, our situation will not be remedied by fiat alone, such as simply creating a new UK DARPA. US innovation success relies on a system of investment incentives for non-state players that barely exists in the UK.

Most of the R&D spending increase we need must come from the private sector (one target proposed going from £32bn in 2015 to £54bn in 2027). Like DARPA, the vital innovation ecosystem has also rarely been created outside the US. Most importantly, this means:

- *Creating **hybrid venture capital funds** (featuring public & private finance) to allow the state to absorb risk and incentivise private finance towards long-term innovation*.

This is because:

- Studies show hybrids have led to *most* high-risk tech investment in the US;

[1] "DARPA mission" (https://www.darpa.mil/about-us/mission). Retrieved 03.07.2020.

- Google, Apple, FedEx, AOL, Sun Microsystems and many others had early-stage hybrid funding, often for defence objectives. Intel took a $300k hybrid investment in 1969, with under $570k in revenue. In 1971 it produced the single-chip microprocessor, leading to the PC.

This requires:

- An equivalent to the US Small Business Investment Act to establish specialist hybrid funds connected to procurement budgets, with follow-on investment past five years, and most funding allocated to defence (UK hybrids are currently limited, uncoordinated and thinly-spread);
- Clarifying that all firms have ownership of government-funded intellectual property (IP), also as in the US;
- Ongoing reforms to Venture Capital Trusts (VCTs) and the Enterprise Investment Scheme (EIS); and
- Securing backing for hybrid funds from defence incumbents (like Lockheed Martin and others in the US) as part of procurement contracts.

This paper focuses on the defence sector especially, but given the size of the UK's health and life sciences and energy sectors, innovation and productivity in these would also benefit from the funding approaches this paper describes. Therefore similar principles would apply to a more general UK ARPA and to other sectors.

In the *Introduction*, the paper outlines the current challenges. Section 2 (*Brief history of the UK government defence innovation system*) discusses how we arrived in the current situation, the challenges of which are discussed in Section 3 (*Innovation at the End of History: short-termism in the privatisation era*). Section 4 (*The US case: DARPA's VC ecosystem and why it works*) discusses the US defence innovation system, while Section 5, *The UK situation and necessary reforms*, draws out possible reforms for the UK. These are summarised in the *Conclusions and summary of recommendations*.

Contents

1. Introduction

Outlines

This paper proposes that for a UK Advanced Research Projects Agency (ARPA, or DARPA, depending on its level of defence specialism) to succeed depends on creating an innovation ecosystem which, like DARPA, has not been created outside the US.

DARPA has succeeded in large part because it exists within a system that creates incentives for non-state players, especially in innovation finance, which would not otherwise exist.

One factor in this ecosystem is especially important: *the creation of **effective hybrid venture capital funds** (public & private finance).*

Two others are: *the US **Small Business Investment Act**, and **patent reform**.*

The UK's strategic situation and lack of R&D incentives make re-organisation for defence innovation especially urgent. UK reforms have not yet addressed crucial problems, namely:

*Expanding the **quality of venture capital** (from early-stage funding through the investment life cycle), as well as its **quantity**, to engage **non-traditional, private-sector** actors.*

The reforms proposed for the UK are discussed in *Section 5: The UK situation and necessary reforms*, and summarised in the *Conclusions and summary of recommendations*.

The UK strategic situation: innovative stagnation and a new adversary

The fundamental crisis in UK innovation is increasingly clear. Patent registrations are falling behind many major competitors (UKIPO, 2017). Our corporates have particular difficulty making long-term investments for sustained innovation, which economists have understood since the 1950s are a vital factor in developed-economy growth. These failures are partially responsible for the ongoing economic crisis, sometimes called the 'new normal' of low growth.

However, the threat is not simply economic. During the early Cold War, the USSR's launch of Sputnik helped generate the necessary sense of urgency to reform the US defence innovation ecosystem, whose capacity to generate innovation and maintain growth became unrivalled in the second half of the twentieth century. Today, it is China that has adopted a more expansionist posture, while investing heavily in defence innovation.

Having learned from the Soviet experience during the Cold War, over the last generation and especially under the leadership of Xi Jinping, China has carried out what it calls a doctrinal 'revolution in military affairs' (RMA), led from the top. As a result, it has adopted an approach called 'asymmetric innovation' (discussed in speeches by Premier Xi himself, including in his comments on contemporary Chinese defence scholarship). Instead of attempting expensive catch-up with major 'big-kit' western defence systems, China is now employing a different strategy. This includes building some major systems by using its heavy manufacturing capability (such as submarines, warships, and strike aircraft, where China will have $1 trillion to spend on navy and air force procurement to 2030,[2] and inevitably featuring some IP infringement,[3] but focusing much of its innovation effort on 'asymmetric defence technologies'. These include but are not limited to: cyber-warfare capability including paralysing attacks on core infrastructure; satellite and anti-satellite weapons; submarine-launched systems; directed-energy and electromagnetic pulse (EMP) systems; and global logistics disruption systems.[4]

While this means that China is generally 'leveraging' what it can from its politico-economic system to generate defence innovation for power projection, since the end of the Cold War the UK has not generally managed to do the same. Defence R&D spending is down 61% since 1990 (ONS, 2019). Having centralised the often highly-successful 'research establishments' in the 1980s and 1990s, the large-scale privatisation of UK defence research assets since then has not been met by an equivalent 'system upgrade', in order to:

- First, generate the long-term R&D investment required for the 'paradigm leap' technologies we need, for which investment outcomes are often too uncertain for private-sector investors to justify;
- Second, avoid the 'salami-slicing' of R&D funding where it is allocated, meaning investment is too thinly and un-strategically spread; and
- Third, to create the regulatory and tax landscape that allows a venture capital (VC) ecosystem to develop these early-stage technologies for sustained growth for the civilian economy.

Like Sputnik, the crisis of Covid today demonstrates the potential technological impact of an adversary on our national security and national life and means continuing with 'business as usual' may not be advisable. UK defence innovation faces comparable challenges to those it faced during the Cold War, in particular:

- Expensive, incumbent-led, procurement, despite smaller firms in civilian life outpacing the military innovation complex in many domains;
- Emerging threats from military innovation by a poorly-understood adversary;
- Failure by major corporates to invest in long-term R&D;
- The need to boost innovative SMEs following, in this case, the burden of EU-imposed regulation.

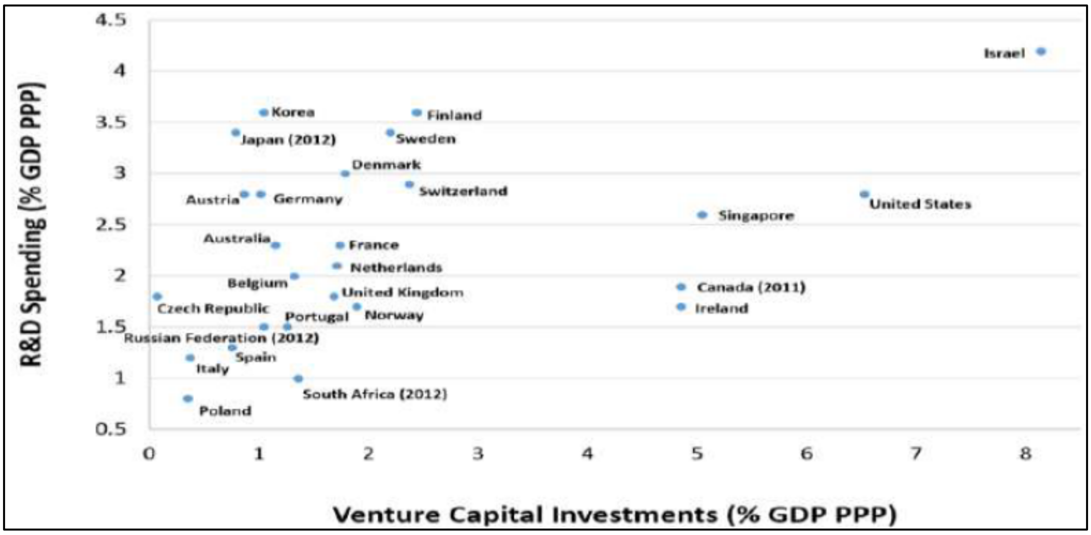
[2] Crane, K. et al (2005).
[3] The Washington Post reported in 2013 a classified study by the US Defense Science Board that outlined how cyber intruders had accessed over twenty-four US weapons system designs, including the Patriot missile system, the Aegis missile defence system, the F/A-18 fighter, the Osprey multirole combat aircraft and the Littoral combat ship (Nakashima, 2013, in Pillsbury, 2015).
[4] Discussed in Chang Mengxiong, 'Weapons of the 21st Century', *China Military Science*, 30:1, 1995, pp.19-24.

In geo-strategic terms, the growing reach and innovation capacity of China especially should prompt a comparable response by the UK and others to the Sputnik launch that led to US reforms like DARPA.

But this needs to include economic-strategic reforms. ‘Financialisation’, or preoccupation with short-term performance, also appears to push corporates away from investing in research within Pasteur’s Quadrant (useful activity at the frontiers of research). UK private finance has retreated further from early-stage VC since the financial crisis, and the ‘Rowlands Gap’ (in over five-year R&D financing) has grown (Baldock et al, 2015). As RAL Jones (2013, 2019) and others describe, poor productivity goes uncorrected because we do not deal with the structural failings.

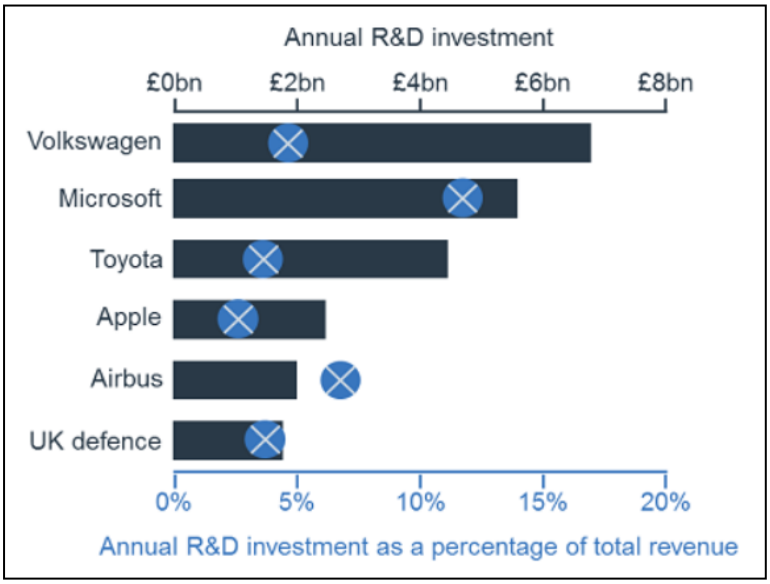
Meanwhile, although the UK has a developed VC sector, the UK lags in R&D intensity.

Figure 1: Venture capital investments as % GDP PPP vs. R&D as % GDP PPP (select countries, 2013)



The UK also performs poorly in defence R&D in particular. By way of illustration:

Figure 2: UK defence annual R&D investment as a percentage of total revenue (2018)



(Source: PA Consulting, 2018)

Government R&D spending, including on defence, should increase, but because the bulk of increased R&D spending needs to come from the private sector, if UK ARPA and associated reforms are to succeed, the UK needs incentives for non-state players to invest[5] in innovation.

[5] The original Industrial Strategy target proposed going from £32bn in 2015 to £54bn in 2027.

2. Brief history of the UK government defence innovation system

Much research has focused on the US experience and the emergence of DARPA. However, a number of studies analyse UK defence innovation history and the importance of defence-specific commitments, including when the system faces a serious adversary. Studies have also proposed that defence-specific research organisations better retain funding than generalist alternatives because they allow politicians to leverage commitment to the nation state itself. In this discussion of how the current UK defence innovation system has emerged, we outline how government has at certain times been an effective strategic partner for long-term defence innovation.

Pre-Cold War outlines

Defence has always drawn on innovation, but deliberate, systematic, government-led attempts to create new defence technology systems arguably began with the Admiralty Compass Laboratory in the 1830s, with the larger Admiralty Experimental Works founded in 1870 for the scientific design of ships' hulls (Wright, 1999). Government defence R&D "came ashore" from its primary naval orientation from the eve of WWI, with a realisation in Whitehall that the UK had become dependent on Germany for many technologies prompting a more systematic approach (comparable, up to a point, to the 2020 reassessment of dependence on China).

The government R&D initiatives of WWI broadly had two defence-economic purposes:

- First, to create institutions to carry out urgent defence R&D which the private sector had not yet done;
- Second, to break existing monopolies for better technological provision.

Winston Churchill as First Lord of the Admiralty established the Admiralty Engineering Laboratory established in 1915 to break the monopoly of Vickers in submarine engines (becoming the Admiralty Research Laboratory in 1921 to build on the experience of WWI); the Royal Aircraft Factory was also launched (called the Royal Aircraft Establishment from 1918, relinquishing manufacturing activities to focus on research) (Bud and Gummett, 1999). In 1915 Churchill also founded the Landship Committee to develop what became known as the tank. It consisted mainly of Navy staff, with an Armoured Car Squadron commander, former Royal Engineer, and a director of the London Omnibus Company. It was hidden from the Army for whom it created its machines, which was thought likely to block the project on the grounds of waste.

This research core would seed much commercial activity and arguably the early airliner industry itself,[6] and crystallised the approach of using core state research bodies and private-sector development, much of which would last until the privatisations of the 1990s.

[6] The Royal Aircraft Factory's first designer was Geoffrey de Havilland; John Kenworthy became chief designer at Austin Motors; Henry Folland became chief designer of Gloster Aircraft and founded Folland Aircraft.

Despite funding cuts, the interwar period maintained much of the structure of substantial government establishments, which came to be overseen by larger ministries. From 1919 to 1938, requests to research 'technical interests' were made to the 'research establishments', but with limited central coordination (Uttley, 1999), allowing them to coordinate R&D contracts directly with firms. Between the wars the Air Ministry, for example, also launched dedicated early-stage research stations: in the helicopter field, to maintain a lead over Germany, it sponsored three commercial projects (however, with the UK "on the verge of leading the world" by 1940, these were abandoned due to the need for aeroplanes, and a decision taken to rely on US production).

Although this paper does not aim for a detailed discussion of the WWI military research effort, this was generally divided into four ministries: the Ministry of Supply (for the Army, with a Controller General of R&D from 1941); Ministry of War Production; Ministry of Aircraft Production; and the Admiralty. Defence advisors (including the Chief Scientific Advisor Solly Zuckerman) were expected to possess technical knowledge commensurate with their impact, in areas from regular kit to the later atomic bomb; their regular 'Sunday Soviets' (Bud and Gummett, 1999) featured brainstorming with officers from the outset of war. Research establishments continued to be run with 'leapfrogging' in mind. In the decade after WWII, the UK maintained a high military R&D spend, including launching major programmes in atomic weapons, new aircraft, and guided missiles.

The Cold War paradigm and institutional system

The renewed urgency created by the Soviet adversary allowed most of the UK (and US) government R&D budget soon to be channelled once more into defence: this is why the Cold War has been called an "R&D War" (Agar and Balmer, 1998) and R&D sites like Farnborough and Malvern, many since lost, have been called "superweapons".

However by the 1950s three problems had been detected. First, growing technological complexity discouraged private investment (e.g. in aircraft R&D); second, major companies (like GEC) became concerned that being too strongly involved in military contracts would see them fall behind in private markets; third, the 'salami-slicing' of R&D funding and the "project cancelled paradigm", illustrated by UK helicopter R&D: by 1965, government R&D funding had sharply increased, but "the dispersion [of] resources across a spectrum of aircraft development meant that *aggregate* funds [were] limited [and] dispersed in support of [16] projects at the UK's six helicopter firms." (Uttley, 1999).

Despite these challenges, specific Committees created the intellectual hubs that communicated the priorities of the 'research establishments' to government, and vice-versa. Though later re-organised, these were the Defence Research Policy Committee (DRPC) from 1947, including strategic monitoring of technological development in universities and government establishments; then from 1958 the Committee on Management and Control of R&D.

Meanwhile, the wartime and post-war defence research establishments (or DREs) kept a culture of strong military involvement, researching "as close to the frontiers of science as possible”. While these fell briefly into decline after 1945, they became a central feature again during the Korean War (Spinardi, 1999) (at first in missiles and radar especially). One study of the Royal Aerospace Establishment (RAE) analysed this commitment given the “genuine discontinuity of knowledge [with] the approach of the speed of sound [so that] the solutions were in the hands of the scientists”. The RAE approached this as “a highly integrated community” that prioritised “conserv[ing] contact with RAF personnel at a practical and experimental level” (Nahum, 1999).

One of the most successful DREs was the Royal Radar Establishment (RRE), formed during Churchill’s second term in 1953 by merging the Air Ministry's Telecommunications Research Establishment (TRE)[7] and the Army's Radar Research and Development Establishment (RRDE). With technical departments grouped initially into six Divisions (airborne radar, ground radar, guided weapons, basic techniques, physics, and engineering), RRE from the 1950s included leading scientists with the time and resources for leading-edge, fundamental research.[8]

In policy-making and interface with industry, some of its divisions were “major players in the defence community”. Private companies’ staff were regularly on site. This continued through the 1960s policy-shift from fighters to guided weapons for air defence: RRE had the technical expertise to argue for maintaining strike aircraft and for the radar research this required (policy later reverted to its position). RRE merged in 1976 with the Signals Research and Development Establishment (SRDE)[9] to form the Royal Signals and Radar Establishment (RSRE), making major contributions to radar, LCDs, thermography, touchscreens, and computer science. The first email sent by a head of state was from the RSRE over the ARPANET by the Queen on 26 March 1976.

While the atmosphere of adversarial ‘urgency’ helped sustain this culture through much of the Cold War, the shift back to naval warfare at the centre of Western strategy as a result of the Polaris nuclear submarine (Hennessy and Jinks, 2015) helped create the ‘systems integrator’ defence giants of today, due to the demands of nuclear submarine engineering and building (carrying out early-stage research, then building and launch, and with clear economic and political clout in defence provision).

i. Civilian spin-off

The Cold War also saw the development of the National Research Development Corporation (NRDC), then later the Defence Technology Enterprises (DTEs) as vehicles for spin-off into the civilian economy.

[7] The American group within the TRE at Malvern became the Lincoln Laboratory near Boston, taking the lead in radar research worldwide.
[8] Including on radio-navigation, and thermodynamics (RA Smith), semiconductors in infra-red detectors (RP Chasmar), lasers (Alan F. Gibson), heat thermodynamics (Leo Pincherle), and through the TREAC digital computer early contributions to cybernetics (Albert M. Uttley).
[9] SRDE had carried out cutting edge research into infrared detection for guided missiles, satellite communications, and fibre optics (Smith, 1956).

The NDRC was established in 1949 to promote technology transfer, especially patenting and exploitation, handling licensing of inventions from research establishments with possible civil applications (e.g. semiconductor technologies and carbon fibre). However, the Royal Signals and Radar Establishment (RSRE) at Malvern demonstrates one of the persistent challenges. Despite being the leading source of liquid crystals breakthroughs (having recruited George Gray of Hull University), the UK did not become the commercial leader. Although the commercialisation of LCD *materials* was a success, *devices* became a mainly Japanese industry. Under NRDC guidance, licensing arrangements were sought with Japanese firms instead, providing limited commercial value for the UK and essentially zero income for Hull University (or the city of Hull), where research began (Spinardi, 1999).

The reduction in R&D budgets from the 1980s was also intended to be balanced by civilian spin-off. While the NRDC had been central to technology transfer, it was merged in 1981 with the National Enterprise Board to become the more generalised British Technology Group (BTG) (privatised in 1991); also in the mid-1980s, the Defence Technology Enterprises (DTEs) were founded to exploit the research establishments' innovations. Yet by the early 1990s these were seen to have had only limited success: the impending creation of the Defence Research Agency (DRA, below) from the establishments cause access to be delayed for potentially greater returns later on (when establishments' assets would become a resource for DRA's commercial use) (Spinardi, 1999). Numbers of research staff in the establishments were also steadily cut through the last twenty years of the Cold War (with two-thirds of R&D going private by 1991). This meant the establishments' role became limited to specification-setting, limited research, and evaluation.

End of the Cold War: the government retreat after the 1980s

In 1991, the core establishments were merged through partial privatisation into the Defence Research Agency (DRA, which merged the research sections of the Admiralty, Signals, and aircraft after the Cold War), creating added pressure to generate annual returns (*Ibid*.).[10]

Next, in 1995 the DRA became the Defence Evaluation and Research Agency (DERA), incorporating DRA and the Chemical and Biological Defence Establishment (CBDE).[11]

[10] The extent of the merger was huge: DRA merged the Royal Aerospace Establishment (RAE), Aeroplane and Armament Experimental Establishment (A&AEE), Royal Armament Research and Development Establishment (RARDE), the Royal Signals and Radar Establishment (RSRE), and the Admiralty Research Establishment (ARE). The constituent parts of the ARE alone, for example, had been: the Admiralty Surface Weapons Establishment (ASWE); Admiralty Signals and Radar Establishment, Portsmouth (1948–1959); Admiralty Signal Establishment (1941–1948); Admiralty Experimental Department (1917–1941); Admiralty Gunnery Establishment, Teddington (AGE) (1943–1959); Admiralty Research Laboratory (ARL), Fire Control Group, Teddington (1921–1977); Admiralty Compass Observatory (1842–1971); Admiralty Marine Technology Establishment (1978–1984); Naval Construction Research Establishment (1946–1978); Admiralty Materials Laboratory (1947–1978); Admiralty Underwater Weapons Establishment (AUWE); Torpedo Experimental Establishment (TEE); Torpedo Experiment and Design Department; Underwater Countermeasures and Weapons Establishment (–1960); and the Underwater Detection Establishment (–1960).

[11] As well as the smaller organisations the Directorate General of Test and Evaluation (DGT&E), the Defence Operational Analysis Centre (DOAC), the Centre for Human Sciences (CHS), and the British Underwater Test

However in 1998 the Strategic Defence Review recommended a Public Private Partnership (PPP) to “[maximise] strategic value and operational cost-effectiveness of the United Kingdom's defence research capabilities”. The resulting 2001 privatisation “pulled apart” DERA, splitting it in two: a government body called the Defence Science and Technology Laboratory (DSTL), and a company “destined for privatisation” which became Qinetiq (a wholly government-owned PLC until its listing in 2006). Despite the great number and renown of the originator agencies of DERA and DRA, privatisation in 2001 therefore deprived the UK of a major state innovation-specific defence agency.

and Evaluation Centre (BUTEC). It began with four divisions: CBDE, DRA, the Centre for Defence Analysis (CDA), and the Defence Test and Evaluation Organisation (DTEO).

3. Innovation at the End of History: short-termism in the privatisation era

The era of Qinetiq has coincided with growing concerns in the UK of a crisis of 'short-termism' within shareholder-owned corporates especially. Shareholders, seeking dividends and often measuring performance on a quarterly basis, are said to drive down the long-term investment needed to maintain market position and firm growth, harming economic growth in the round. This can be understood with reference to Qinetiq itself and through evidence on the UK in general, helping clarify the potential benefits from structural improvements to technology investment, especially in defence.

The National Audit Office report of November 2007 into the Qinetiq privatisation stated: "Our assessment of the outcome in terms of value for money is mixed… privatisation [allowed] QinetiQ to expand its business into the US and other civil markets", but it adds that: 'In the long term, the value for money of the privatisation to the taxpayer will depend on a range of factors, such as… continued availability of independent advice, as well as the proceeds received." (NAO, 2007).

Indeed, a report by RUSI found that the "mainspring of the privatisation of DERA was the realisation that the huge cuts in the research budget after the collapse of Communism – by a much greater percentage than the cut in the defence budget as a whole – meant that [the] investment needed to maintain [government research establishments] could not be provided. If the UK had done what the US did in the early 1990s and had cut the defence budget, *but had retained the level of spending on research,* the need for privatisation would not have been so obvious" (Kincaid, 2007) [our italics].

RUSI also found that privatisation meant the "loss of many outstanding research facilities… deemed to be commercially unproductive [and] uncertainty over the continued availability of independent advice across [research] with the exception of those elements that were retained in DSTL". This "woeful" under-funding of research undermined "the whole future of R&D in this country".

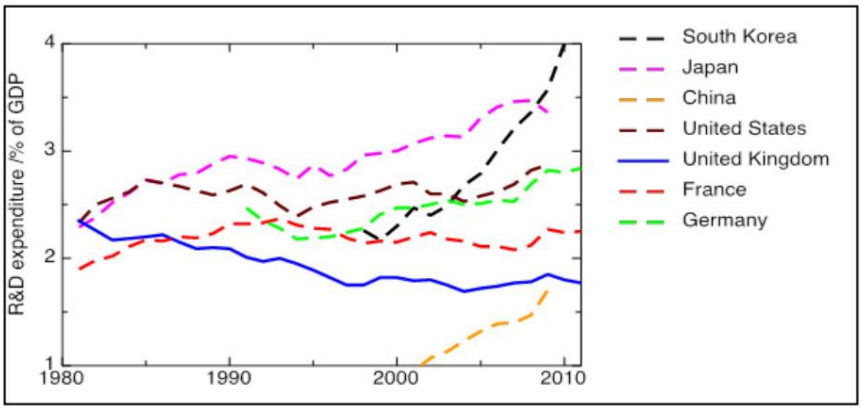
However, an increase to the defence research spend alone is unlikely to solve the problem of investment short-termism that privatisation appears to have compounded. In listed firms, much evidence shows directors under pressure from shareholders for dividends, at the expense of long-term value including via R&D. This is outlined below to demonstrate the crisis of R&D spending in the UK generally, and the need for improved long-term structures.

In 2015, Bank of England Chief Economist Andy Haldane argued that strong shareholder power causes slower growth in the wider economy and worsens short-termism. That year, the McKinsey Global Institute also released the Corporate Horizon Index – measuring the economic impact of short-termism – and found that publicly listed companies with a "long-term mindset" grew on average 47% more than others, spending nearly 50 per cent more on R&D over the previous 15 years. But in one study, a group of managers admitted they would avoid a highly profitable long-term project if it meant falling short of the current quarter's expected earnings (Graham et al, 2005). Meanwhile, Kraft et al's experiment (2017) showed how more-frequent financial reporting prompted managers to cut long-term investments for short-term performance.

Financial markets' orientation has also changed, becoming more dominated by short-term trading: in the 1950s, the average holding was 6 years; now it is 6 months (Haldane, 2015). Companies held predominantly by 'transient' investors appear more likely to cut R&D (Pozen, 2014); and financial analyst coverage may harm R&D efforts: US firms covered by more analysts generate fewer and worse patents (He and Tian, 2013).

While the UK's R&D spend per unit of GDP is now lower than the US, France, Germany, Japan, Korea, or China, business-funded R&D has fallen especially severely (Jones, 2013). Yet our major traditional competitors' have maintained or increased spending, and China and South Korea have increased it strongly. Patenting is generally accepted to be a good indicator of R&D (Griliches, 1986), and the UK possesses fewer graphene patents than Samsung alone, despite the material being invented in a British university (Cambridge IP 2014 figures). In 2007, the US filed 330,000 patents, Japan 240,000, and the UK, the creator of the modern patent system, filed 17,000 (Dyson, 2010). The UK now lacks a single firm in the global top 20 R&D spenders.[12]

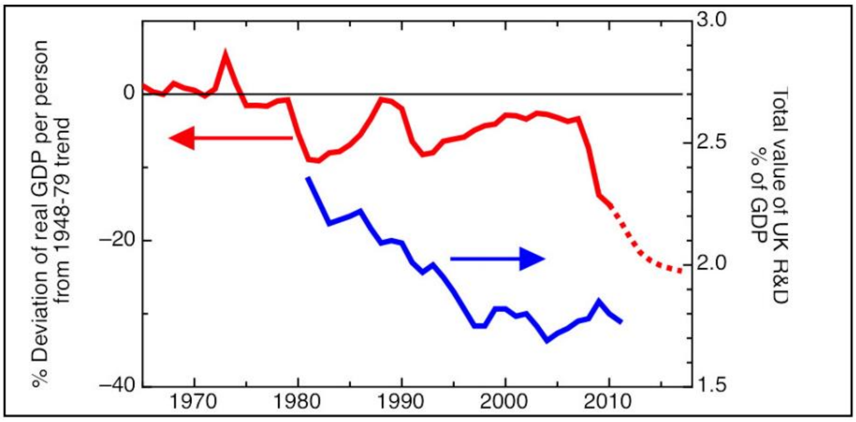
<u>Figure 3: R&D intensity as Gross Expenditure on R&D as a fraction of GDP (1980-2011)</u>



(Source: Eurostat; SPERI; Jones, 2013)

[12] Critics argue that defence R&D 'crowds-out' R&D spending, but Buck et al (1993) found that a 10% cut in UK defence equipment expenditure reduces employment levels by 6%, with no negative causal relationship between public defence and civil R&D expenditure.

Figure 4: The UK's R&D and growth crisis



(Red, left axis: the percentage deviation of real GDP per person from the 1948-1979 trend line, corresponding to 2.57% annual growth (solid line, source: 2012 National Accounts, SPERI; dotted line: March 2013 estimates from the Office for Budgetary Responsibility). Blue, right axis: total R&D intensity, all sectors, as percentage of GDP (source: Eurostat, SPERI, in Jones, 2013)).

The Conclusions discuss some of the solutions to this threat in the defence innovation sphere. First, we outline how the US government defence system has maintained core R&D institutions since the Cold War and incentivised the private sector towards long-term innovation investment.

4. The US Case: DARPA's VC ecosystem and why it works

The US shares some of the UK's corporate and financial short-termism problems (Pozen, 2014; He and Tian, 2013), but unlike the UK has an ecosystem for 'ventured' firms to compensate, behind which stands the US defence establishment. While DARPA sits within this ecosystem, it is only one part of it, and innovation success depends on the other parts.

This is why DARPA's purposes include catalysing the formation of new companies (with patent rights to publicly financed inventions) and establishing – and renewing – the infrastructure of the modern VC industry (*Ibid*). In other words, it succeeds only through a VC ecosystem.

DARPA's programme managers also have meaningful tranches of money and long-term incentives (under 200 programme managers divide $2.97bn). The UK has tried to achieve breadth by dividing finely, sometimes giving projects £50k funding.

Hybrid venture capital funds

The critical role of hybrid VC funds (or Government Venture Funds, GVFs) can be understood through the above problem of misaligned incentives for innovation finance, with shareholders' interest in maximising short-term profit (dividends) placing R&D investment under pressure, which can reduce long-term innovation success.

In the US, the venture capital sector provides more balance. But while the role of the state in this system is less commonly understood, it is essential to US VC, especially through hybrid GVFs (like DARPA itself, these provide different risk-sensitivity to long-term innovation investment).

Private finance can 'discipline' public sector investment and take products to market, but state investment often takes technology through the 'valley of death', granting a later guaranteed market through preferential procurement contracts. Thus portfolio firms see risk lowered to a level private VC can accept. VC is essential to growth; but state co-investment is essential to much VC:

- Studies such as Weiss (2014) show *most* US high-risk VC tech investment comes from hybrids;
- Despite the growth of private VC, from 1994 to 2002 at least 64% of seed/early-stage financing was from hybrid funds;
- 40% of all companies that went public in the US from 1974 to 2015 had VC funding; those companies make up 85% of R&D spending.[13]

[13] National Venture Capital Association (US) data (Weiss, 2014).

Google, Apple, FedEx, AOL, Sun Microsystems and many others had early-stage GVF funding, often for defence objectives. Intel received a $300,000 hybrid investment in 1969, with 218 employees and under $570,000 in revenue. In 1971 it produced the first single-chip microprocessor, leading to the PC.

Types of venture initiative by government agency

- **Direct equity positions.** The most important type of hybrid is the quasi-independent fund with direct equity positions, including **the CIA's In-Q-Tel** and **DoD's OnPoint Technologies**. Products meet defence/intelligence needs and add value for commercial customers. In-Q-Tel's network includes over 200 VC firms. It has seen invested over $150m in over 90 companies, delivering over 130 products and solutions. Keyhole, the company that designed the software that became Google Earth, was an In-Q-Tel portfolio company in 2003 (Weiss, 2014).

Success also depends on the right environment in two other respects especially.[14]

Small Business Investment Act

The US Small Business Investment Act 1953 (amended 1958) launched the Small Business Investment Companies (SBICs, under the Small Business Administration (SBA)). This was the period in which the Eisenhower Administration fundamentally began moving to prevent a Soviet innovation lead by taking an active role in VC.

SBIC VC funds are independently owned and run, for-profit investment firms. Under the Act, the SBA invests in new VC funds, mandates repayment terms, then, crucially, **gives the fund operational autonomy**.

Backed at the highest level, SBIC funding is combined with the more recent Small Business Innovation Research funding (SBIR, 1982), constituting hybrids' main state funding source. SBIR has considerably reunited R&D and defence acquisition:

- SBIC has provided over $60bn to over 107,000 companies;
- In 2009, SBIR provided 60% of US high-risk VC tech investment (most private VC finances buyouts, marketing and late-stage expansion);
- All federal agencies with external R&D budgets over $100m must set aside a fixed percentage of their annual R&D budget to SBIR (2.5%);
- Of total SBIR funds, DoD accounts for 48%.[15]

---

[14] See Appendix *Small Business Investment Companies (SBICs) and Small Business Innovation Research (SBIR)*.
[15] Weiss (2014).

Patent reform

Next, two major patent reforms were the Bayh-Dole Act and Stevenson-Wydler Technology Innovation Act (both 1980). Bayh-Dole gave **funded SMEs the right to retain full ownership of government-funded innovations**. Stevenson-Wydler[16] created inducements for the National Laboratories to commercialise innovations beyond the major contractors: "a technical archipelago of immense value".[17]

- As a result, SBIR is now the largest single source of US patents, its recipient firms generating 50% more patents annually than the entire university sector (Weiss, 2014).

Table 1: Government-sponsored VC funds (US) (1950s-2010)

Those making direct investments are highlighted.

Sponsor	Name	Started	Funding source	Form
SBA (Small Business Administration)	**SBICs** (Small Business Investment Companies)	1953	Federal leverage 2:1-4:1 (public-private)	**Direct investments and financial risk underwriting**
State generally (97% of funding)	**SBIR** (Small Business Innovation Research programme)	1982	Levies on agencies' R&D budgets	**Direct investment**
DoE-Argonne	**ARCH Ventures**	1986	DoE/Chicago U	**Direct investment**
DoE-Sandia	**Technology Ventures Corp**[18]	1993	DoE and Lockheed Martin	Tech transfer; VC scouting for start-ups
CIA	**In-Q-Tel**[19]	1999	Largely CIA	**Direct investment**
DoD-Army	**OnPoint**[20]	2002	Army: levy on R&D budget	**Direct investment**
DoD-OFT (Office of Force Transformation)	**DeVenCI (latterly Army VCI)**	2002	-	Information/ collaboration

[16] Amended 1984, 1987, 1989, and 2007 (in the America COMPETES Act 2007).
[17] Los Alamos, Sandia, and Lawrence Livermore.
[18] Technology Ventures Corp closed in 2017, but created an estimated over 13,500 jobs, 121 new companies, and helped stimulate over $1.2bn of venture capital in New Mexico especially.
[19] Ironically, In-Q-Tel is named after the fictional Q Branch, of which "Q" is head, which provides Britain's secret service with R&D in the James Bond novels. The UK organisation is fictional, the US version real.
[20] Latterly run by Arsenal Venture Partners.

DoE[21]-Oak Ridge	**Battelle Ventures LP**	2003	Private and DoE	**Direct investment & tech transfer**
DoD/DoN-Navy	**VCs@Sea**; **NRAC VC Panel; Rapid Innovation Fund**	2004	-	Information/ collaboration
NASA	**Red Planet Capital**[22]	2004	NASA and private firms	**Direct investment**
DoE-Los Alamos	**Los Alamos National Security LLC Venture Acceleration Fund**	2006	Private and DoE	**Direct investment & tech transfer**

Other US reforms

The most important of the other US initiatives to **engage non-traditional stakeholders** are:

i. **Defense Innovation Board (DIB).** A 'change agent' chaired by former Google CEO Eric Schmidt, actively looking for procurement problems in defence;[23]

ii. **Defense Innovation Unit (DIU).** An agency embedded in Silicon Valley to make faster use of emerging technologies, tapping into projects still in the works to utilise others' R&D budgets. Mainly run by former military staff to understand military needs. DIU also links start-ups (Tanium, Quid, ShieldAI) with existing VCs (Andreessen Horowitz, Sequoia). It has fundamental similarities to some of the DREs the UK abolished.

iii. **National Security Innovation Network (NSIN)**, **Special Operations Forces Works (SOFWERX)** and **Air Force Works (AFWERX)**. Agencies bringing military challenges to a civilian audience. NSIN is a public-private partnership giving access to DoD assets (e.g. Hacking4Defense, Makerlabs). SOFWERX seeks mature tech for rapid military expansion; AFWERX does so for the US Air Force.[24]

These are overseen by the Deputy Assistant Secretary of Defence (Industrial Base).

[21] DoE contributes intellectual property, giving Battelle unique access to the federally funded technologies of six DoE national laboratories, which provide the catalyst for its investment activities.
[22] Red Planet Capital was controversially abolished by the Administration of George W. Bush.
[23] See the airborne tanker refuelling problem in Budden and Murray (2019).
[24] Budden and Murray (2019).

5. The UK situation and necessary reforms

Attempts to replicate the innovation success of the DARPA nexus outside the US have generally failed, because only some elements have been adopted (Duggan and Gabriel, 2013).[25] For a UK version to bear fruit (and new procurement providers to emerge) requires a genuine VC ecosystem for future firms. UK reforms have been relatively limited however and remain un-strategic.

For the UK, this ecosystem has become more important, not less. Outside hybrid funding, in both the UK and US it has become "more difficult to enlist companies in [the] private-sector to work on security-related projects". In the UK, government R&D has shifted dramatically from defence to health (36% in 1995 to 15% in 2017 (Jones, 2019)). While the US will clearly remain dominant in defence innovation, the UK has urgent untapped potential.

Only a very small number of countries have launched a comprehensive suite of reforms, including Israel's Yozma model.

- Israel created the Yozma Fund (a $100m fund of funds) in 1993, its chief scientist investing in ten VC funds. By 2000, Israel had the largest VC sector per capita and second largest in the world in absolute terms;

Singapore used Israel's Yozma Fund as a hybrid model to attract foreign VCs. Its Technopreneurship Investment Fund launched in 1999 with $1bn under management, a fund of funds for leading VC firms to establish in Singapore (Budden and Murray, 2019).

Non-hybrid bodies

Since 2016 the Defence Innovation Unit (DIU, led by a civil servant, the Director of Defence Innovation) has coordinated most core UK agencies:

- **Defence Science and Technology Laboratory (DSTL).** The primary defence R&D agency. It funds mainly late-stage, assured technology;
- **Defence and Security Accelerator (DASA).** Run by DSTL at its Porton Down HQ. It appears to have spread £57.7m between 402 projects (March 2019 figures);
- **Defence Innovation Fund (DIF).** Not independently managed; claims to seek "as broad a scope of innovation as possible", which is liable to prevent focused funding;
- **jHub (Joint Forces Command Innovation Hub).** Funds mature private-sector tech across a broad portfolio, only up to £1.6m; further finance requires being passed to and approved by the JFC Innovation Board (i.e. limited follow-through).

[25] See Budden and Murray (2019) for a thorough discussion of these systems.

The other main agencies are:

- The British Business Bank's (BBB) **Managed Funds Programme.** This has increased institutional investors' commitment to VC (but without hybrid fund coordination or technological specialism);
- **Defence Cyber Innovation Fund** (latterly CIF). Wrapped into the BBB **National Security Strategy Investment Fund**. Spreads investment widely, with some data security emphasis;
- **Industrial Strategy Challenge Fund** under UK Research and Innovation (UKRI), also spreads investments widely.

UK Government Venture Funds (GVFs)

The UK has some hybrid fund vehicles, but these have limited capacity to address core problems:

- **Enterprise Capital Funds (ECFs)**. At least one-third private VC contribution, but many ECFs are generalist, not technology "challenge-based" (e.g. focused on e-commerce or food instead of specific outcomes). Has a £2m maximum single firm initial investment,[26] and "difficulties accessing follow-on financing rounds" (Owen et al, 2019). Portfolio firms are not linked to preferential procurement.

- **British Patient Capital (BPC)**. A 'booster' to existing patient capital funds and very diverse.

- **UK Innovation Investment Fund (UKIIF).** UKIIF operates two funds of funds launched with c.£150m UK government contribution and private VC contribution (the UK Future Technology Fund, which has stopped making new investments, and the Hermes Environmental Innovation Fund). UKIIF is broad, lacking departmental coordination (green energy, recycling, advanced manufacturing, life sciences and digital). Its portfolio firms are generally relatively mature.

i. Possible reforms for UK GVFs

Broadly, UK GVFs increase the *volume* of VC funding, much less the quality and innovation impact.

1. The UK instead may require large, private-sector-led, high-profile **hybrid funds** (or GVFs), with government setting repayment terms. These would improve scale; defence would be central, but the model could apply to other sectors. These GVFs should:

[26] Or 10% total fund value; £5m or 15% if follow-on funded.

- Be **sector-specific and connected to single departments**. UK GVFs often have insufficient scale to reach Markowitz's (1952) optimal portfolio size (Baldock, 2016). For example, from 2000 to 2012, the Department for Business, Innovation and Skills (BIS) placed £600m in 34 VC funds, financing over 1000 businesses (CfEL, 2013);
- End the widespread salami-slicing of funding within funds;
- Include a defence focus, e.g. an MoD-linked hybrid like In-Q-Tel (or Mossad's Libertad Ventures);
- Be able to address the Rowlands gap (in over five-year R&D financing).

2. **GVFs need technological specialism** for better resource-concentration. Funds should follow a **strategically-led challenge focus**, with portfolios assembled for practical goals, and need **strong links with university spin-out funds**.

3. GVFs should routinely provide **assured procurement preference** for portfolio SMEs: with no procurement guarantees, they often cannot secure second-round funding. Governments typically spend much more on procurement than they do on R&D, so this 'functional procurement' is essential (Edquist et al, 2015);

4. **GVFs need follow-on investment for high-performing portfolio firms**. Firms backed by GVFs perform better than firms with only private VC funding, **but only if funded *past five years***.[27] US VCs are more likely to back firms over several rounds.

5. GVCs may also form separate **funds for departmental clusters**, branded separately and run externally. Because all major US departments must join an SBIR fund, in the UK a sensible clustering may include – most importantly – a **defence fund. Half of GVC funding may need to go to defence**: this is a feature of the US model and can help defence technology diffusion to the economy. **US SBIR defence projects create almost as much non-defence as defence commercialisation.**

The Small Business Research Initiative (SBRI)

The Small Business Research Initiative (SBRI, launched 2001), a portal for departments to advertise R&D contracts, was designed as a UK version of SBIR. However, SBRI has much smaller contract values than the US; fewer are commercialised or lead to procurement due to insufficient institutional awareness

- UK funding often does not reach government targets: US departmental SBIR budgets are set by law;

[27] Library House data on 800 firms (Reed, 2010).

- As a lead customer, SBRI should also help firms become 'VC ready' – guaranteeing Phase 3 funding (like In-Q-Tel).

Other possible UK reforms: Venture Capital Trusts (VCTs) and the Enterprise Investment Scheme (EIS)

Like GVFs, the VCTs and EIS insufficiently increase VC investment quality, generating instead a larger volume of funding. VCT tax relief should be extended beyond the current 30% to £200k, while EIS tax relief should be extended beyond 30% and to firms larger than 250 staff and assets of £15m.

6. Conclusions and summary of recommendations

The great Sir Solly Zuckerman wondered at the end of his life "that efficient financial management of R&D mattered far less than choosing the right projects on which to work and the right people to do the job."[28] Short-termist UK R&D faces what could be called the 'Zuckerman Quandary': has financial management become so efficient that nothing gets spent?

Meanwhile, in Beijing, a government office is tasked specifically with pinpointing future asymmetric advantages. According to Michael Pillsbury, "[our] only chance to remain dominant will be to develop superior technology and countermeasures". This needs a funding system that deploys, not neglects, our economic advantages. The UK has often generated defence innovation at the cutting edge: this paper suggests ways to do so again.

As we return to a scenario with a new potential major adversary in defence technological capability, the UK once more needs the capacity to plan and invest in paradigm leap research, by creating new long-term incentives for innovation through private finance.

An ARPA-type agency will need in addition:

- An initially small ecosystem of large, focused, hybrid VC funds, including for defence, incentivising private finance towards long-term innovation risk;
- An equivalent to the US Small Business Investment Act, establishing independent hybrids for early-stage funding for SMEs, handing over operational autonomy;
- Patent reform in the manner of the US Bayh-Dole Act to give SMEs full ownership of government-funded IP;
- New reforms to Venture Capital Trusts (VCTs) and the Enterprise Investment Scheme (EIS); and
- Mandated preferential procurement for portfolio firms (another VC-attracting device).

[28] Bud and Gummett (1999).

Appendix

Small Business Investment Companies (SBIC) and Small Business Innovation Research (SBIR)

The hybrid system began with **SBICs**, VC funds licensed by the Small Business Administration that are independently owned and run, for-profit, specialise in early-stage financing and merge public and private resources. Government sets investment eligibility guidelines, repayment terms, and minimum private investment before government funding may be received.

SBICs depend in part on the **Small Business Innovation Research** programme (SBIR), which mandates all federal agencies with external R&D budgets over $100m set aside a fixed percentage of this budget. One scholar has called this “the world’s largest seed fund” (Weiss, 2014).

Bibliography

Agar, J. and Balmer, B. 'British Scientists and the Cold War: The Defence Research Policy Committee and Information Networks, 1947-1963'. *Historical Studies in the Physical and Biological Sciences*, 28(2) (1998), pp.209-252.

Baldock, R. 'An assessment of the business impacts of the UK's Enterprise Capital Funds.' *Environment and Planning C: Government and Policy*, 34:8 (2016), pp. 1556-1581

Baldock, R. Deakins, D. and Savic, M. (2015). *Finance pathways for innovative SMEs: the new UK finance escalator*. Paper to Institute of Small Business and Entrepreneurship conference.

Buck, D., Hartley, K. and Hooper, N. (1993). 'Defence research and development, crowding-out and the peace dividend'. *Defence Economics*, 4:2 (1993): The Restructuring of the UK and European Defence, pp. 161-178.

Bud, R. and Gummett, P.: *Cold War Hot Science: Applied Research in Britain's Defence Laboratories 1945-1990*. Amsterdam: Harwood Academic Publishers, 1999.

Budden, P. and Murray, F. (2019) *Defense Innovation Report: Applying MIT's Innovation Ecosystem & Stakeholder Approach to Innovation in Defense on a Country-by-Country Basis* (May 2019).

Chang, M. (2015). 'Weapons of the 21st Century', *China Military Science*, 30:1, 1995, pp.19-24. In: Pillsbury, 2015.

Crane, K. et al.: *Modernizing China's Military: Opportunities and Constraints*. Santa Monica, CA: RAND Corporation, 2005.

Dugan, R.E. and Gabriel, K.J. '"Special Forces" Innovation: How DARPA Attacks Problems.' *Harvard Business Review*, October 2013.

Dyson, J. (2010). *Ingenious Britain: Making Britain the Leading High-Tech Exporter in Europe*. London: Russell Group.

Edquist, C. 'Towards a holistic innovation policy: Can the Swedish National Innovation Council (NIC) be a role model?' *Research Policy* 48 (4). October 2018.

Edquist, C., Vonortas, N.S. and Zabala-Iturriagagoitia, J.M. (2015). *Public Procurement for Innovation*. Cheltenham: Edward Elgar Publishing.

Graham, J.R., Harvey, C.R. and Rajgopal, S. (2005). *The Economic Implications of Corporate Financial Reporting*. Working Paper W/73, January 11, 2005.

Griliches, Z. (1986). 'Productivity, R&D, and Basic Research at the Firm Level in the 1970s'. *American Economic Review*, 76:1 (1986), pp. 141-154

Haldane, A.G. (2015). *Growing, fast and slow.* Speech at the University of East Anglia, 17th February, 2015.

Haldane, A.G. (2015). *Who owns a company?* Speech at the University of Edinburgh Corporate Finance Conference, 22nd May, 2015.

He, J. and Tian, X. (2013). *The Dark Side of Analyst Coverage: The Case of Innovation*. Working Paper, 2013.

Hennessy, P. and Jinks, J. (2015). *The Silent Deep: The Royal Navy Submarine Service since 1945*. London: Penguin.

James, A.D. *et al*. 'Testing the boundaries of public private partnership: the privatisation of the UK Defence Evaluation and Research Agency'. *Science and Public Policy*, 32:2, 2005, pp. 155-161.

Jones, R.A.L. (2013) *The UK's Innovation Deficit and How to Repair It* (Sheffield Political Economy Research Institute (SPERI) Paper No. 6).

Jones, R.A.L. (2019) *A Resurgence of the Regions: rebuilding innovation capacity across the whole UK* (Working Paper).

Kincaid, W. (2007). *The Privatization of QinetiQ*. Royal United Services Institute.

Kraft, A., Vashishtha, A. and Venkatachalam, M. (2017). *Frequent Financial Reporting and Managerial Myopia*. Working Paper, 2017.

Latham, S. and Brown, B. 'Does Short-termism Influence Firm Innovation? An Examination of S&P 500 Firms, 1990-2003'. *Journal of Managerial Issues*, 22:3 (Fall 2010), pp. 368-382.

Nahum, A.: 'The Royal Aircraft Establishment from 1945 to Concorde'. In: Bud, R. and Gummett, P.: *Cold War Hot Science: Applied Research in Britain's Defence Laboratories 1945-1990*. Amsterdam: Harwood Academic Publishers, 1999.

Nakashima, E. (2013). 'Confidential Report Lists US Weapons System Designs Compromised by Chinese Cyberspies.' *Washington Post*, 27 May 2013. In Pillsbury, M. *The Hundred-Year Marathon: China's Secret Strategy to Replace America as the Global Superpower*. New York: St. Martin's Griffin, 2015.

National Audit Office (2007). *The privatisation of QinetiQ*. London: NAO.

Office for National Statistics (ONS). (2019). *Gross domestic expenditure on research and development, UK: 2017*.

Owen, R., North, D., and Mac an Bhaird, C. (2019). 'The role of government venture capital funds: recent lessons from the UK experience.' *Briefings in Entrepreneurial Finance*, January 2019, 28:1, pp. 69-82.

Pillsbury, M. *The Hundred-Year Marathon: China's Secret Strategy to Replace America as the Global Superpower*. New York: St. Martin's Griffin, 2015.

Pozen, R. (2014). *Curbing Short-Termism in Corporate America: Focus on Executive Compensation*. Governance Studies at Brookings, May 2014.

Reed, H (2010). *Reinventing Venture Capital: Towards A New Economic Settlement*. Demos.

Smith, R. A. (10 April 1956). 'Physics at the Radar Research Establishment, Malvern'. Proceedings of the Royal Society of London, Series A. 235 (1200): 1–10.).

Spinardi, G. 'Civil Spinoff from the Defence Research Establishments'. In: Bud and Gummett, *Ibid*.

UK Intellectual Property Office (2017). *Building the evidence base on the performance of the UK patent system*. UKIPO 2017/04.

Uttley, M. 'Rotary-Wing Aircraft'. In: Bud and Gummett, *Ibid*.

Weiss, L. (2014) *America Inc.? Innovation and Enterprise in the National Security State*. Cornell University Press.

Wright, T. 'Aircraft Carriers and Submarines: Naval R&D in Britain in the Mid-Cold War'. In: Bud and Gummett, *Ibid*.