From the Telegraph to the Cloud

Policy Exchange

Geopolitics, Technology and Sovereignty

Harry Halem and Marcus Solarz Hendriks

Foreword by The Lord Harris of Haringey

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Foreword

The Lord Harris of Haringey

The United Kingdom faces a new strategic situation with a new government. Threats abound internationally, from Russia's war on Ukraine and attempts to redraw the European map to a long-range competition with China, and the potential for Middle Eastern instability to explode into war.

In this context, the Government has understandably set growth as its objective. Without a dynamic economy that ensures British vitality and prosperity, it will be near-impossible for the UK to secure its interests and counter the threats its faces.

Equally relevant, technology is changing the foundations of our society. As this paper articulates, a number of advanced technologies – ranging from Artificial Intelligence and advanced telecommunications to engineering biology and quantum computing – are becoming increasingly integrated into the way we live, work, and interact with each other. This promises attendant economic benefits, as the British economy adapts once again to a technological transition. Harnessing these technologies is central to long-term, sustainable growth.

In turn, new technologies create new vulnerabilities. This includes the prospect of attack, sabotage, and disruption against critical infrastructure, as we have seen on display in Ukraine since Russia's full-scale invasion. It also includes the prospect that powers departing radically from the UK's values and interests might gain a dominant developmental position in certain technological streams, compelling the UK and its allies to submit to their wishes. The following paper demonstrates the need not to balance security concerns with growth, but to consider them as inseparable: sustainable growth is impossible without a simultaneous focus on building resilience into British society and the British economy. Preparedness is a choice, one that must be made long in advance of the crisis a country will confront.

Any technology policy must be long-term. The technologies considered here, in particular, will take decades to reach fruition, often providing compounding benefits as they develop and mature. The result, per the paper's recommendations, is a carefully-constructed policy that combines investment and regulation to sustain growth well beyond this government's tenure. Politics and policy generate many demands on a prime minister and cabinet's attention, from the mundane tasks of day-to-day governance to intense national and international crisis. A successful growth policy cannot be mortgaged to political exigencies, particularly when that growth policy rests upon technological investment and a long-term resilience approach.

The government must, therefore, take the recommendations articulated in this report seriously, and use them as a coherent starting point to craft a technologically-focussed resilience and growth policy for the long-term. If it fails, delivering a sustainable, resilient future for the UK will become increasingly difficult to envision over time, especially as Britain's major allies pursue their own paths towards technological development.

The Lord Harris of Haringey is the Chair of the National Preparedness Commission.

Executive Summary

A new period of transnational political rivalry demands that the UK view technology policy geopolitically. The UK and its allies will face a series of rivals in a long-range strategic competition. This proposition has obvious cross-partisan consensus, expressed both in the *Integrated Review Refresh* and the major foreign and defence policy pronouncements from the new government. It is critical to identify the nature of this competition, since a medium-sized power like the UK cannot afford to misunderstand the nature of the current geopolitical environment, for the sheer amount of time and money this competition demands will make early mistakes extraordinarily costly.

History demonstrates the baseline relevance of technological development and critical capabilities in long-range political competition. The Cold War provides a useful parallel. The UK benefited in the extreme from its partnership with the US, not simply for tangible security reasons, but also because it allowed the UK to derive immense benefits from American research investment that would have simply been impossible independently. The Cold War is not an exact parallel: the capabilities considered today have a different funding model, different effects, and different deployment mechanisms. But its broader lessons on the nature of long-range competition should be integrated into British strategic framing today.

There are six critical capabilities that will determine the future of both economic development and technological competition more generally: AI, Quantum, Engineering Biology, Advanced Telecommunications, Semiconductors, and Space-Based Capabilities. These six capabilities all align directly with the UK's Science and Technology Framework, and with the exception of space, are all specifically identified within it. Moreover, the role of non-ministerial, non-partisan individuals in developing both current science and technology policy and its antecedents creates the obvious potential for strategic continuity irrespective of the Government over the next 10 years, creating the conditions for long-range capabilities planning. The UK, US, China, and European powers are all investing in these capabilities to varying degrees. Not only do these capabilities have independent implications for long-term economic development. They also overlap, meaning advances in one area are in some manner dependent upon, and typically catalyse, advances in the other areas.

Advanced Telecommunications have the ability to increase data access and connectivity and, if combined with a quantum

communications system, to create a highly secure network. An effective delivery environment is crucial for telecommunications development, which demands an enormous amount of fixed investment year-on-year. Quantifying results can be difficult, but even in the early 2010s, a £200 million investment in British telecommunications was estimated to generate £430 million in direct growth.[1] Moreover, the UK has the potential to serve as an initial deployment market, but has yet to create the right market incentives for actual advanced telecommunications deployment.

Quantum Technology is the most cutting-edge capability, and also the most difficult to get out of the lab and into the marketplace. The UK's early leadership in quantum, and £214 million of research since 2014, speak to its long-term strategic relevance in the British context. The EU has taken few to no steps to accelerate AI deployment despite a vibrant research ecosystem. The US, because of its private-public funding model, has the ability to race towards quantum computing deployment. China has recognised that it remains behind the US on AI, and actively seeks to close the gap with a robust investment programme. The UK, meanwhile, has a coherent quantum strategy – the only question is long-term commitment.

Artificial Intelligence is the most publicly apparent critical capability. The UK has already articulated a new AI regulatory policy, and has made AI central to its long-term planning. Europe struggles to translate AI investment into actual deployable capabilities, and has instead made a major bet on regulation, which intuitively indicates a long-term stagnation in European AI development. The US has a vibrant AI ecosystem, but there is an obvious gap between the private sector and explicit government applications, especially in a defence context. Chinese AI investment is enormous, while China has clearly created a strategically minded AI policy. The UK has a number of structural advantages in AI development, but must ensure continued private sector investment to compensate for constrained public funds.

Spacepower has emerged as a defining 21st century capability, but it is too nascent for most actors to have grasped how to cultivate it. The UK space industry has also expanded over the past year, growing by 5.1%, indicating its economic and strategic potential.[2] European efforts centre upon duplication of extant capabilities, which may play well as an industrial policy, but also risk leaving Europe well behind other actors once technology accelerates. The US and China both have an obvious strategic focus on spacepower, and have largely understood its role in major competition. The UK, despite its lack of wholly national space-sector capabilities, has obvious potential for leverage due to its specialist space capacities, research system, and links to ESA.

Semiconductors have exploded in geopolitical importance over the past two years, and will remain at the forefront of the critical capabilities debate for the coming decades. The UK has been confronted with semiconductor questions far more frequently over the past two years, resulting in a new semiconductor strategy, but there remain obvious

1. Deloitte, *'The Impacts of Mobile Broadband and 5G',* (June 2018), p.11, link
2. UK Space Agency, *'Size & Health of the UK Space Industry 2022'*, (31 March 2023), accessed via: link

long-term gaps for implementation and policymaking, particularly in the international context. Nearly every actor, with the partial exception of the US, has treated the semiconductor issue as an industrial policy problem. This misses the overlap between advanced microprocessors and AI that should actually govern most policy towards the issue. Europe's industrial policy efforts are likely to fall well short of the EU's long-term goals. China and the US certainly understand the higher-end considerations at play, but are largely focussed on traditional industrial policy. In this context, the UK has a major opportunity to leverage its research system for strategic benefit.

Engineering Biology has the obvious potential to impact nearly every major industry, but there are significant questions about scaling its processes. Governmental estimates indicate that every pound invested in engineering biology returns £63 to the economy down the line.[3] The European engineering biological landscape, much like Europe's broader biotech ecosystem, remains heavily integrated with the UK's, providing a potential leverage point for British policy. The US has the market size to enable engineering biological deployment, but it lacks a sufficiently granular funding framework to discriminate between different types of biotechnology, hurting engineering biology in the long-term. China has made little progress in engineering biological deployment despite enormous funding. Ironically, although the UK lacks major public funding, its well-designed research system points to potentially explosive development if linkages can be built with the private sector.

It is clear that, despite specific well-conceived policies, all major actors struggle with individual capability lines, let alone integrating them and directing their development in a strategic manner. Long-range competition requires a new strategic framework for each capability set, an integrated approach to capability development, and most critically, a coherent linkage between technology policy and resilience.

Major power competitions are also extremely expensive, and require immense amounts of strategic effort, technological focus, and international coordination for one side to succeed. This creates the need for *market investment* in critical capabilities during contemporary competition. It also demands a coherent set of policies that channel investment towards strategically productive ends – the goal must be to harness private sector innovation through proper framing and a handful of prudent market interventions. Without this public-private partnership model, the UK will not acquire the technological capabilities needed to complete in the coming geopolitical landscape.

The most important choices in a long-range competition are often made in decadal or multi-decadal intervals, reinforcing the need for prudent, carefully-considered action today. This generates the need not just for high-level strategic documentation – which can lapse into analytical paralysis – but more specifically, for a comprehensive reevaluation of the place that British capabilities policy has in *diplomacy* and *resilience*.

The critical capability sets discussed are all relevant for manipulation

3. Council for Science and Technology, *'Report on engineering biology: opportunities for the UK economy and national goals'*, (19 May 2023), accessed via: link

below the threshold of active conflict. All the capabilities considered have obvious military relevance. But they also allow for disruption in other societies prior to and independent of major conflict, whether by locking firms out of a market, undermining critical infrastructure, or otherwise enabling societal disruption.

The Ukrainian experience demonstrates the necessity of in-build infrastructural and technological resilience in the current environment. Ukraine has survived in no small part because of more effective than expected critical national infrastructure and critical capabilities. By in-building resilience and redundancy and viewing critical national capabilities as an intrinsic element of strategic policy, the UK can harden itself against future disruption.

Winning a long-range technological competition demands the embrace of a cost-imposition approach. Any actor's resources are finite – even a Sino-Russian *entente*'s. A smart power can employ well-timed technological deployments and a robust critical capabilities system to reduce the strategic vulnerabilities that an adversary's critical capability developments can impose. This entails communications security developments, or a more robust AI ecosystem that increases cyber defence, among other possibilities.

The UK's International Technology Strategy is a good starting point, but requires expansion and clarification. The strategy itself is ambitious, and is an attempt that goes beyond any comparable document in other policy contexts. However, it requires more specificity, granularity, and a better strategic framing to have real long-term impact.

The UK's allies have not demonstrated, apart from in a handful of instances, the strategic and political nous to operationalise a cost imposition framework. The industrial policy framing that guides European and American responses to Chinese technological development is in some ways correct, but more fundamentally misses the heart of the issue. China has grasped the need to impose costs on the US, Europe, and the UK – pouring cash into the creation of extraordinarily expensive capacities will simply siphon off resources for social tasks and broader sustainment of a competition.

The UK's unique market size, technological characteristics, and research base allow it to play a central role in the broader creation of an integrated, transnational critical capabilities policy. If the UK can see farther, and act more coherently and nimbly, than its allies *and* rivals, then it can actually shape the policy of much larger, wealthier powers, while accruing the benefits of transnational technological investment and development.

1.0: Introduction

The UK has entered a geopolitical era of open rivalry. This demands a truly synthetic grand strategy, in other words, a policy that integrates all factors, and all levers of national power, applying them towards the goal of British security and prosperity. Hence technology policy must be considered geopolitically.

This paper sets out the case that a fundamental element of modern political competition is technological development, and the deployment of what can be termed "**Critical National Capabilities**", which blend elements of *critical national infrastructure* and *advanced technology*, even if the technologies currently employed to deliver that capability, like the telecommunications network, are comprised of legacy systems.

Viewing technological advancement geopolitically harkens back to the First Cold War. However, the difference today is the financing model. Historically speaking, *critical national capabilities* were overwhelmingly publicly financed, given either the degree of *basic research needed* to generate these capabilities, like nuclear technology, or the degree of *public oversight and structural regulation* needed, like the UK telecommunications system. Yet today, advanced technologies are often so costly that it is impossible for any national government to finance solely their research, development, and deployment – the private sector thus has a crucial role as a *strategic partner*. Moreover, because Critical National Capabilities often require large-scale deployment across existing infrastructure, the financial model for those companies that actually produce and sustain large-scale infrastructure matters. Generating demand for technological development is an additional matter, one of crucial importance in the long run – but generating the technology itself is also central.

We are at a tipping point in technological investment and maturity in a number of critical contexts – investments today, and coherently-crafted strategy today, is central to ensuring long-range British security, prosperity, and competitiveness. The Government has made steps towards this objective, but a truly comprehensive, synthetic approach is still demanded.

2.0: Transnational Competition and Technology: History and Modern Reality

2.1: Introduction

The reality of transnational competition demands a geopolitical lends for technological development. Just as in the 20th century, the UK today – as a middle power – requires robust international partnerships to ensure its strategic success and develop the critical national capabilities needed to compete strategically. This section provides a historical backdrop to contemporary decisions, ensuring we understand the necessity of long-range policy development during major competition.

2.2: From Economics to Geostrategy

Two factors combined to result in the transnationalisation of political-military competition: the development of the Eurasian trade system and the Second Industrial Revolution.[4] Eurasia, the landmass containing Europe, the Middle East, and Asia is the focal point of human development.[5] Human trade began with the Euro-Asian Silk Road and Indian Ocean maritime route, and intensified as transcontinental empires developed the ability to project power in the 15th to 18th centuries.[6]

In the 18th and 19th centuries several new technologies – the railroad, machine tools, advanced metals production, fossil fuels, other petrochemicals, and ultimately electrification and the internal combustion engine – triggered and accelerated the Industrial Revolution.[7] These technologies enabled the growth of the state, which gained the bureaucratic means to monitor and control territory and the ideological concept of national identity.[8] But as technology diffused, power did as well, with the European empires facing non-European challengers, ultimately resulting in the World Wars.[9]

Window Box: The Transcontinental Empires

The rise of transcontinental colonial Empires was the logical result of the Eurasian theme. Throughout the 18th and 19th centuries, European politics was defined by a struggle for continental mastery, typically between France and a number of European principalities and kingdoms at wish to remain autonomous from French rule.[10]

4. Joel Mokyr and Hans-Joachim Voth, *'Understanding growth in Europe, 1700–1870: theory and evidence'*. In Stephen Broadberry and Kevin H O'Rourke (eds), *'The Cambridge History of Early Modern Europe, Volume 1: 1700-1870'*, Cambridge: Cambridge University Press, (2010), pp. 36-40.
5. Tal Tovy, *'The Changing Nature of Geostrategy, 1900-2000: The Evolution of a New Paradigm'*, Air University Press, (2015), pp. 11-20.
6. Xinru Liu, *'The Silk Road in World History'*, Oxford: Oxford University Press, (2010), pp. 65-70; James B Collins, *'State Building in Early-Modern Europe: The Case of France'*, Modern Asian Studies, 31:3 (July 1997), pp. 603-633.
7. Jose Ortega y Gasset, *'The Revolt of the Masses'*, New York: WW Norton, (1932), pp. 117-123.
8. David Bell, *'Recent Works on Early Modern French National Identity'*, The Journal of Modern History, 68:1 (March 1996), pp. 84-96; Charles Issawi, *'The Struggle for Linguistic Hegemony, 1780-1980'*, The American Scholar, 50:3 (Summer 1981), pp. 382-387.
9. Aaron Friedberg, *'The Weary Titan: Britain and the Experience of Relative Decline, 1895-1905'*, Princeton: Princeton University Press, (1988), pp. 135-150; Henry Kissinger, *'Diplomacy'*, New York: Simon and Schuster, (1994), pp. 201-217; Alfred Thayer Mahan, *'The Problem of Asia: and Its Effect upon International Policies'*, Boston: Little Brown, (1900), pp. 47-52; Gail Honda, *'Differential Structure, Differential Health: Industrialization in Japan, 1868-1940'*. In Richard H Steckel and Roderick Floud (eds), *'Health and Welfare During Industrialisation'* Chicago: University of Chicago Press, (1997), pp. 251-270; Philip Zelikow, *'Why Did America Cross the Pacific? Reconstructing the U.S. Decision to Take the Philippines, 1898-99'*, *Texas National Security Review*, 1:1 (November 2017), pp. 36-67; David C Evans and Mark R Peattie, *'Kaigun: Strategy, Tactics, and Technology in the Imperial Japanese Navy, 1887-1941'*, Annapolis: Naval Institute Press, (1997), pp. 32-50; Friedberg, *'The Weary Titan'*, (1988), p. 153; Paul M Kennedy, *'The Rise and Fall of British Naval Mastery'*, London: Allen Lane, (1976), pp. 205-238; Nick Lloyd, *'The Western Front'*, Penguin, (2021); Richard W Stewart, *'American Military History, Volume II: The United States Army in a Global Era, 1917-2008'*, Center for Military History, (2010), pp. 7-51.
10. Naomi J. Andrews and Jennifer E. Sessions, *'The Politics of Empire in Post-Revolutionary France'*, French Politics, Culture & Society, 33:1 (Spring 2015), pp. 1-10.

A power that could control the entirety of the European continent, and marshal its resources and population, would likely be able to subjugate those competitors scattered around Europe's fringes – namely, Russia and the United Kingdom, neither of which are wholly European powers.[11] But the political difficulties of such a conquest are self-evidently immense. Napoleon came the closest, yet even his attempt fell short because of the natural difficulties of administering an empire of such immense size and the natural political disagreements between that empire's French core and its German and eastern European peripheries, particularly given the persistence of pre-Napoleonic elites in those societies.[12]

Rather than attempting to subjugate Europe, it was self-evidently more efficient to expand elsewhere, for extra-European expansion was less likely to trigger and immense backlash against the expanding power.[13] Hence the rise of the British colonial empire was the natural result of the pressures of European competition.

With this colonial empire in hand, however, the United Kingdom found itself virtual master of the world. Controlling the resources of India along with all critical trade routes around the Eurasian rimland, and facing no challenger that was capable of disrupting that sea control beyond Europe, the UK was entirely safe and capable of removing itself from an active role in European politics. In turn, the safety and stability of the Pax Britannica enabled even greater trade across your Asia, looking in the logic of a multi regional, and multi-continental, trade system.

Moreover, despite the interwar attempt to legalise differences in power between major actors, and to convert Europe from a system of empires to that of nation-states, the Second World War followed the First.[14]

2.3: Critical Capabilities and Transnational Political-Military Rivalry

The Second World War's end marked the transition to fully transnational rivalry between the US and USSR, with some parallels to the current situation.

The First and Second World Wars were enormous undertakings, making it hard for small powers to resist major powers absent a coalition.[15] Equally critically, technical advancements themselves also intensified the need for transnational political military integration. Nuclear and precision weapons provide relevant examples.

The United States expended $2.2 billion on the Manhattan Project, which employed 130,000 personnel over a half decade period, to produce only two operational weapons.[16] The US and Soviets rapidly expanded their arsenals, both at immense cost.

11. Jorgen Moller, *'Why Europe Avoided Hegemony: A Historical Perspective on the Balance of Power'*, International Studies Quarterly, 58:4 (December 2014), pp. 660-670.
12. Tim Blanning, *'The Pursuit of Glory, Europe 1648-1815'*, London: Penguin, (2008), pp. 611-630ff.
13. Robert Massie, *'Dreadnought: Britain, Germany, and the Coming of the Great War'*, Vintage, (2007)
14. John Jordan, *'Warships After Washington: The Development of the Five Major Fleets 1922-1930'*, Pen and Sword, (2011); Raymond Aron, *'The Dawn of Universal History: Selected Essays from a Witness of the Twentieth Century'*, translated by Barbara Bray (New York: Basic Books, 2002), pp. 16-21; Brian Vick, *'The Origins of the German Volk: Cultural Purity and National Identity in Nineteenth-Century Germany'*, German Studies Review, 26:2 (May 2003), pp. 241-256; Clive Whitehead, *'Education in British Colonial Dependencies, 1919-39: A Re-Appraisal'*, Comparative Education, 17:1 (March 1981), pp. 71-80; Vatro Murvar, *'Messianism in Russia: Religious and Revolutionary'*, Journal for the Scientific Study of Religion, 10:4 (Winter 1971), pp. 277-338; Piotr Wandycz, *'The Little Entente: Sixty Years Later'*, Slavonic and Eastern European Review, 59:4 (October 1981), pp. 548-564; Graham E Fuller, *'The Emergence of Central Asia'*, Foreign Policy, 78 (Spring 1990), pp. 49-67; Salvatore J Freni, *'The Soviet Nationality Policy in Central Asia'*, Inquiries, 5:3 (2013), accessed via: link
15. Michael Howard, *'Men Against Fire: The Doctrine of the Offensive in 1914'*. In Peter Paret (ed), *'Makers of Modern Strategy: From Machiavelli to the Nuclear Age'* (Princeton: Princeton University Press, 1986), pp. 510-526; David Glantz and Jonathan House, *'When Titans Clashed: How the Red Army Stopped Hitler'* (Lawrence: University Press of Kansas), pp. 160-176ff; Aron, *'The Dawn of Universal History'*, p. 59; Alexandre Kojeve, *'Outline of a Doctrine of French Policy'*, Hoover Institution, 1 August 2004, accessed via: link
16. US Department of Energy Office of Legacy Managemen, *'Manhattan Project Background Information and Preservation Work'*, (2017), accessed via: link

The Nuclear Parallel

The British and French nuclear programmes both demonstrate the difficulties of middle-power technological development. Both nuclear programs stemmed from a fundamental conviction that nuclear weapons, independently wielded, would confer upon their developer great power status. Britain developed its nuclear arsenal in the early years of the Cold War, relying on the UK's extensive experience with atomic research, and first tested nuclear weapons in 1952.[17] France took slightly longer. Although the scarring experience of the Suez Crisis allegedly convinced the French political establishment that it must obtain nuclear capabilities, France began a dual use nuclear program immediately after the Second World War.[18]

Small nuclear arsenals – both the British and French arsenals were and remain relatively small compared to those of the major powers – did have a psychological point, particularly in domestic contexts. However, it rapidly became apparent that nuclear weapons independently maintained and targeted were extraordinarily expensive. The UK avoided some of these issues through a robust partnership with the US: after 1958, the UK resurrected its joint nuclear cooperation with the US, thereby giving it access to a variety of American developed delivery devices.[19] Moreover, RAF and USAF interoperability, cultivated throughout the Second World War and maintained under NATO, meant that the UK retained access to American technology and intelligence products that made the British nuclear deterrent more effective. Nevertheless, even with these cost reduction measures, the UK's independent nuclear deterrent was not truly independent, but rather an independent contribution to a broader NATO deterrent.[20]

Despite its destructive power, a single nuclear device did not guarantee security.[21] Only leading powers could maintain an arsenal capable of generating a stable nuclear balance, let alone a conventional one. Throughout the Cold War, France spent slightly upwards of half its military budget on nuclear weapons.[22] Even today, France spends a notable percentage more of its defence budget on nuclear weapons than the UK.[23]The scale scale of transnational military competition made strategy a task of economic-technological maximisation to accrue long-term advantage.[24] The central issue was how to manage joint capabilities, and whether to emphasise ownership, collaboration, or access. In the event, the US ultimately led in fixed investment, while its allies developed ways to collaborate developmentally or, most commonly, gain access to US assets.

The First Ownership Debate

The French deemed ownership paramount when it came to nuclear forces. This decision had several apparent benefits.

17. Matthew Jones, *'The Official History of the UK Strategic Deterrent, Volume 1: From the Bomber Era to the Arrival of Polaris, 1945-1964'*, London: Routledge, (2017), pp. 1-60.
18. For a contemporaneous discussion, see Wolf Mendl, *'The Background of French Nuclear Policy'*, International Affairs, 41:1 (January 1965), pp. 22-36.
19. The Cabinet Papers, *'Skybolt and Polaris missiles'*, (2014), accessed via: link
20. Ministry of Defence, *'UK underlines commitment to NATO Nuclear Deterrence'*, (28 April 2023), accessed via: link. See also Lawrence Freedman, *'The Evolution of Nuclear Strategy'*, 3rd Edition, London: Palgrave MacMillan, (2003), pp. 292-297.
21. Albert Wohlstetter, *'The Delicate Balance of Terror'*, Foreign Affairs, Vol. 37, No. 2, (Jan, 1989), pp. 211-234
22. Pascal Boniface, *'French Nuclear Weapons Policy After the Cold War'*, The Atlantic Council, (1998), accessed via: link
23. Claire Mills, *'The French Nuclear Deterrent'*, House of Commons Library, (7 October 2020), accessed via: link
24. Eliot Cohen, *'Net Assessment: An Amerian Approach'*, INSS, (April 1990), accessed via: link

> It gave France the prestige of being the only Western power beyond NATO's nuclear umbrella.[25]
>
> A strategically self-sufficient France therefore retained its stature as a legal great power with a seat on the UNSC. Yet France's military, on the whole, was incapable of actually securing its European interests beyond the context of the Atlantic Alliance, and France's nuclear deterrent was quite likely incapable of accomplishing its stated mission, since it remains entirely unclear whether French weapons would have actually hit the relevant targets on Soviet territory during wartime.[26] The UK pursued and approach that was more heavily weighted towards collaboration and access. The British nuclear deterrent was independent, insofar as the UK did develop its own hydrogen bomb, have its own testing facilities in Australia, and could independently target and deliver nuclear weapons against the Soviets.[27] Yet the UK thoroughly benefited from its technology transfers with the United States: it had no need to develop its own nuclear delivery mechanisms after the early 1950s with the exception of strategic bombers and submarine designs.[28] In fact, the contemporary British nuclear deterrent remains American-derived – the UK's Trident missiles are American. The UK did gain from this arrangement politically as well, given the central role of the US within the Atlantic Alliance.

A similar dynamic governed the development of precision capabilities, under which long range communications and exceptionally accurate weapons could be delivered against specific targets in small numbers, which would replicate and perhaps outclass the impact of long range yet inaccurate weapons that had dominated military affairs previously.[29]Only the US and USSR could develop precision weapons at scale.[30]

But while the USSR used a centralised model, the United States and Europe had thriving industries that produced the fundamental components needed the precision revolution. Of course, the United States fielded the lion's share of these weapons. However, the rest of NATO also benefited from these advancements. The British, German, and other NATO militaries received direct equipment transfers from the US. Moreover, major British military producers, along with their cousins on the European continent, were able to replicate and develop their own precision weapons and long-range communications designs. Underpinning this all was the U.S satellite communications and navigation system.

Different Precision Models

Military capabilities development was inextricably linked with economic and technological development from the 1960s onwards. It is obvious that the UK and the rest of NATO benefited overwhelmingly from its association with the United States and their ability to both collaborate on technological developments and access to capabilities that American industry had developed.

25. Liviu Horovitz and Lydia Wachs, *'France's Nuclear Weapons and Europe: Options for a better coordinated deterrence policy'*, SWP Berlin (March 2023), accessed via: link
26. Albert Wohlstetter, *'Nuclear Sharing: Nato and the N+1 Country'*, Foreign Affairs (April 1961), accessed via: link
27. Lorna Arnold, *'Britain and the H-Bomb'*, Palgrave MacMillan, (2021), pp. 71-84ff.
28. Clare Mills, *'Replacing the UK's nuclear deterrent: the long awaited warhead decision'*, House of Commons Library, Briefing Paper Number 8941, (2 March 2021).
29. Thomas G Mahnekin, *'Weapons: The Growth & Spread of the Precision-Strike Regime'*, Daedalus, 140:3 (Summer 2011), pp. 45-57.
30. Eliot A Cohen, *'A Revolution in Warfare'*, Foreign Affairs (March-April 1996), pp. 37-54; Massimiliano Gaetano Onorato, Kenneth Scheve, and David Stasavage, *'Technology and the Era of the Mass Army'*, Journal of Economic History, 74:2 (June 2014), pp. 448-481.

The Soviets, by contrast, did not have a political economic model capable of keeping up with the Western system once the West decided to invest a significant proportion of its GDP in the production of conventional armaments. By the mid 1980s, the West had wiped out most Soviet advances in military technology and numbers, thereby putting the USSR in an increasingly adverse military position. One should note that the groundwork for this situation was laid over the proceeding 20 years, when Western governments, in particular the US government, undertook a number of long-range planning exercises and leveraging their scientific talent identified the technologies and capabilities that would drive economic development and innovation in the near future.

2.4: Conclusion

The above analysis has demonstrated the defining role of technological advancement in long-term strategic competition. The greatest specific difference between pre and post early 20th century competition is the way in which the major powers can gain a long-range advantage through technological investment, and in turn, the growing gap between those powers and their second or third rate rivals and allies.

The next section will review the specific technologies that will have a strategic impact upon contemporary transnational geopolitical competition.

3.0: Critical Capability Sets

3.1: Introduction

Major transitions in power rest upon technologically dependent economic transformations, which require the right infrastructure, regulatory, and support context.

The below explicates *six distinct technological areas* that will have an outsized impact upon economic life and international politics: Advanced Telecommunications, Quantum Technology, Artificial Intelligence, Space-Based Capabilities, Semiconductors, and Engineering Biology. These are partly derived from the Office of Science and Technology's innovation framework, which despite the potential for revision, has remained relatively durable.[31] Other technologies are obviously relevant, including advanced nuclear technology and robotics, but these advances have greater potential for underlying transformation and have established bureaucratic heft.

These technologies are at distinct developmental stages. However, there are enough overlaps between each technological area in technical *and* political terms to necessitate a comprehensive strategy, as the Government's International Technology Strategy recognises.[32] Moreover, DSIT's Research Areas of Interest link directly with these technologies.[33] Given advances up to this point in the 2020s, many of these technologies are accelerating towards inflection points, either in development or deployment. Investment and policy development *today* is therefore crucial. This is true, moreover, even if different technologies have different degrees of accessibility to the UK.

3.2: Advanced Telecommunications

Modern telecommunications is a bedrock capability for economic and social development. Increased network speed, coverage, and connectivity greatly amplifies the data that can be generated from a given population. In turn, the increased volume of data that a 6G network can transport compared to a 5G network actually enables automation at scale – beyond Internet of Things, a 6G city can include significant daily automated processes, including self-driving cars and fully robotic, independent production lines.

However, one can understand a telecommunications network's role most readily with reference to a major outage. In November 2023, Australia's second-largest wireless carrie, Optus, experienced a near-total network outage, which ground the Melbourne metropolitan rail network

31. Department for Science, Innovation and Technology, *'The UK Science and Technology Framework'*, (March 2023), accessed via: link
32. Department for Science, innovation, and Technology, *'The UK's International Technology Strategy'*, (22 March 2023), accessed via: link
33. Department for Science, Innovation and Technology, *'DSIT Areas of Research Interest 2024'*, (26 February 2024), accessed via: link

to a halt, along with cellular and internet connectivity and emergency services.[34] In July 2022, Rogers Communications, one of Canada's two leading telecommunications providers, also experienced a large-scale outage, which removed a quarter of Canadian internet connectivity.[35] These incidents, alongside the 2008 and 2011 submarine cable disruptions, demonstrate the *physical nature* of a telecommunications system.[36] This physical reality creates opportunities for hostile disruption.

There are thus two considerations, the need to *balance* advances in telecommunications technology with a networked designed for security and resilience. For now, cloud computing amplifies the power of the cyber defence – cloud computing can concentrate far more compute than an offensive cyber attacker can usually muster. But this balance will shift over time, while the "surface area" of a 6G network is far greater than a 5G network, creating more opportunities for offensive cyber disruption. Quantum communications technology is the natural evolution of telecommunications. However, there is an enormous gap between quantum telecommunications development and current network design, which requires a carefully-considered infrastructure policy to bridge. Moreover, telecommunications is extraordinarily capital-intensive. Project Gigabit, the UK's £5 billion plan to deliver gigabit broadband to 85% of households by 2025 and 95% by 2030, is a commendable long-term ambition.[37] However, basic network upgrades are largely fronted by the providers themselves: BT, one of the UK's largest telecoms players and its key fibre-optic provider, has invested £12 billion in upgrades since 2020, but still requires another round of internal investment this year.[38] Absent stable revenues, this investment stream is unsustainable – and the Cost of Living crisis has already disrupted some telecommunications profit stability.[39]Hence it is equally important, alongside innovation in itself, for resilience purposes, to ensure that the large fixed investments in network upgrades crucial for telecommunications networks can occur, which requires stable cashflow.

3.2.1: Europe

Europe's fundamental telecommunications developmental difficulty is uneven market distribution. Certain markets, like France and Spain, have provided fibre-optic access to the vast majority of the population. By contrast, Germany in particular has struggled with high fixed costs.[40] 5G penetration and market capitalisation is similarly uneven.[41] The EU has yet to generate a framework for sustainable long-term telecommunications investment, generating is a near-200-billion-Euro gap.[42] Germany, France, Italy, and in part Spain have surged ahead in Quantum telecommunications investment, while Finland's Nokia still holds a dominant telecommunications market position more broadly.[43]Rhetorically speaking, the EU seems to have grasped the resilience imperative behind quantum communications, which links with a broader push for technological sovereignty.[44] The difficulty seems to be translating multiple years of record investment into tangible deployments, given it will fall well short of its 2030 telecommunications

34. Josh Taylor, *'Optus reveals routine software upgrade the cause of 14-hour network outage'*, The Guardian, (13 November 2023), accessed via: link
35. Denette Wilford, *'Remembering the crippling Rogers outage of 2022'*, Toronto Sun, (7 July 2023), accessed via: link
36. Kim Zetter, *'Undersea Cables Cut; 14 Countries Lose Web – Updated'*, Wired, (19 December 2008), accessed via: link
37. Department for Science, Innovation & Technolgy, *'UK Wireless Infrastructure Strategy'*, (11 April 2023), accessed via: link
38. BT, *'The road to full fibre'* , accessed via: link
39. Tom Loozen and Adrian Baschnoga, *'Top 10 risks for telecommunications in 2023'*, EY, (30 November 2022), accessed via: link
40. David Abecassis and Shahan Osman, *'Full-fibre networks in Europe: state of play and future evolution'*, Analysis Mason, (3 May 2023), accessed via: link
41. Foo Yun Chee, *'EU's Breton cites telcos' investment gap for Big Tech network fee push'*, Reuters, (6 June 2023), accessed via: link
42. European Commission, *'Investment and funding needs for the Digital Decade connectivity targets'*, (12 July 2023), accessed via: link
43. European Commission, *'Technological trends in the telecommunication industry'*, Sectoral Watch (July 2021), accessed via: link
44. Aureliano da Ponte, Gonzalo Leon, and Isabel Alvarez, *'Technological sovereignty of the EU in advanced 5G mobile communications: An empirical approach'*, Telecommunications Policy, 47:1 (February 2023), accessed via: link

targets.[45] Several EU-wide telecommunications and Quantum investment frameworks exist, including the European Quantum Communication Infrastructure Initiative (EuroQCI), but its aggressive timeline – a cross-border Quantum telecommunications network by 2027, is patently unfeasible.[46] EuroQCI has turned to a traditional large-actor consortium model, tapping Deutsche Telekom (DT) as the lead, alongside aerospace and defence providers Thales and AirBus and ESA, although it is unclear whether the space-based leg of the initiative can be scaled.[47] Hence in a telecommunications infrastructure *and* an advanced technology sense, the EU has significant roadblocks to clear

3.2.2: US

The US has clearly linked in an advanced telecommunications network with geopolitics, given its skittishness over Chinese telecommunications and consumer electronics penetration into American and allied markets.[48] The Biden administration has also engaged in a transnational development push, centring its efforts upon the G7, while private telecommunications and quantum telecommunications investment has been enormous – $2.35 billion in 2023, following over over $2 billion investment in 2021.[49]The issue is that American industrial policy is largely stovepiped, generating a situation in which American VCs pour cash into quantum technologies, but generally speaking, quantum telecommunications development lags behind.

3.2.3: China

China has grasped the strategic purpose of large-scale telecommunications deployment and a quantum telecommunications network and seeks to operationalise it as rapidly as possible. This stems from its Military-Civil Fusion (MCF) doctrine, under which civil capacities do not simply support military development, but are actively treated as identical to military capacities.

China has sponsored several national champions in telecommunications technology, creating a technological development to export pipeline with China Telecom, China Unicom, and Huawei, with an extensive presence in Africa, latin America, and Europe.[50] Moreover, following MCF, China has cultivated quantum expertise since the late 2000s, and crosses over quantum investments in multiple industries.[51] Space-based quantum is also a major focus. From 2016 to 2023, China conducted a series of quantum key decryption experiments, and in 2023 has committed to creating a small half-dozen satellite grouping for advanced QKD experimentation and early deployment.[52] This has an obvious global goal of creating a Quantum telecommunications satellite constellation that gives it a market stranglehold.

China's large, digitalised population and national telecommunications champions allow it to conduct enormous developmental projects, including the world's largest FTTP network by users.[53] Yet rhetoric does not translate into private investment. Only $434 million of private capital investment

45. European Telecommunications Network Operators' Association, *'State of Digital Communications 2023'*, (January 2023), p. 6
46. European Commission, *'The European Quantum Communication Infrastructure (EuroQCI) Initiative'*, (last updated 20 July 2023), accessed via: link
47. Yanitsa Boyadzhieva, *'News brief: Deutsche Telekom to lead EU's quantum comms network project'*, TelecomTV, (16 February 2023), accessed via: link
48. Chang Che, *'Huawei, Pummeled by U.S. Sanctions, Reports Plunge in Profit'*, New York Times, (31 March 2023), accessed via: link; Giorgio Leali, *'US bans Chinese telecom gear sales over national security fears'*, Politico, (26 November 2022), accessed via: link
49. The White House, *'FACT SHEET: President Biden and G7 Leaders Formally Launch the Partnership for Global Infrastructure and Investment'*, (26 June 2022), accessed via: link
50. Matthew Johnson, *'China's Grand Strategy for Global Data Dominance'*, Hoover Institution, (18 April 2023), accessed via: link
51. James Dargan, *'China: The Rising Star Of Quantum Communication'*, The Quantum Insider, (26 July 2022), accessed via: link
52. Andrew Jones, *'China is developing a quantum communications satellite network'*, Space News, (10 March 2023), accessed via: link
53. Paul Lee, *'China, by design: World-leading connectivity nurtures new digital business models'*, Deloitte Insights, (11 December 2018), accessed via: link

has been made in quantum telecommunications, overwhelmingly from Chinese firms.[54] There is additional public cash supporting development, but absent a major funding injection, China will struggle to deploy a quantum telecommunications system at scale.

3.2.4: UK

The British telecommunications market is unique compared to that of its allies and competitors primarily because of its historical structure. It is consolidated by necessity, considering the state-run character of the national telegraphy network until 1979. This explains why BT Group, formerly British Telecom, is the only telecommunications national champion in the Western world.[55] While mobile network operators have diversified, BT remains the company primarily responsible for the creation, maintenance, and improvement of UK telecommunications infrastructure, with various local market responsibilities as well. Moreover, the UK is the central node in the transatlantic telecommunications system, which stems from 19th century investment and British geography.[56] Although BT Group does not directly service undersea cables, unlike the now-private French telecommunications giant Orange, it frequently contracts with other UK companies to conduct cable laying and repair.[57] UK cables have come under pressure in the past two years, most notably with the Shetlands Cable Incident, likely conducted by a Russian spy ship.[58]There is a potential disconnect between the British approach to general telecommunications in quantum development in particular. The UK Quantum Communications Hub, funded through the NQTP, has excellent links with UKRI, but there is limited strategic focus on telecommunications.[59] The UK's Wireless Strategy mentions quantum telecommunications only once, a glaring gap given international competition.[60] Moreover, there is a gap between the way in which the UK considers telecommunications as a day-to-day capability and the developmental aspirations the UK holds. The UK telecommunications market is extraordinarily capital intensive, but Government has not recognised this and cultivated market stability for investment.[61]

3.3: Quantum Technology

Quantum technologies are legitimately transformational. The invention of the transistor in the late 1940s, and the subsequent popularisation of small radios, televisions, and ultimately computers small enough to enable personalisation can be considered the "first Quantum revolution", given the reliance of these technologies on Quantum concepts, even if Quantum research only exploded subsequently.[62] Quantum technology generally speaking refers to any development that relies upon Quantum mechanics, the concepts in physics that describe the behaviour of atomic and subatomic particles, and capture the unique characteristics of their behaviour as compared to larger entities.

54. Verdict, *'China Telecom to set up quantum technology unit with $434m'*, (1 June 2022), accessed via: link
55. BT Group, *'BT Annual Report 2023'*, (17 May 2023) accessed via: link
56. Rishi Sunak's work at Policy Exchange, accessed via: link; see also Policy Exchange's report: *'From space to seabed'*, (19 February 2024), accessed via: link
57. BT Newsroom, *'BT awards £26.9m subsea cabling contract to three firms'*, (22 December 2023), accessed via: link
58. BBC, *'Damaged cable leaves Shetland cut off from mainland'*, (20 October 2022), accessed via: link
59. Quantum Communications Hub, *'Quantum security at all distance scales'*, accessed via: link
60. Department for Science, Innovation and Technology, *'UK Wireless Infrastructure Strategy'*, (11 April 2023), accessed via: link
61. BT Newsroom, *'Results for the full year to 31 March 2023'*, (18 May 2023), accessed via: link
62. Daniel Garisto, *'The second quantum revolution'*, Symmetry: Dimensions of Particle Physics, (12 January 2022), accessed via: link

The Potential of Quantum Technology

It is not necessary to understand the technical characteristics of either Quantum mechanics or Quantum technologies *per se* to grasp their relevance, and to assess the policy framework around them in different national and transnational contexts. Rather, we may generally identify some applications for Quantum technology that have relevance for long-range strategic competition, economic growth, and societal resilience:

- Computing: Quantum computing uses quantum principles to greatly increase the processing power and speed of a device, thereby allowing it to solve problems beyond the capability of even the most advanced classical computers. Quantum computing has implications for every industry at least as profound as the initial digital revolution had for economics more generally. Estimated Quantum computing value-added reaches $850 billion over three decades – as if another Holland was added to the global economy.[63]
- Sensing: Quantum sensing has the most direct military application of any Quantum applications. Quantum technology provides three sensing benefits. First, it enables the rapid processing of images, either taken from space-based assets or aircraft, to detect extraordinarily small changes over time. This creates the potential for the detection of traditionally well-camouflaged assets. Second, it allows for the improvement of magnetic field sensors that can therefore detect stealth technologies, particularly submarines. As it stands, there are no anti-submarine continuous surveillance capabilities that are capable of aerial deployment – one must actually place a sonobuoy in the water or have a towed sonar array to detect subsurface assets. A quantum-enabled magnetometer would facilitate submarine detection, not making the oceans transparent, but nevertheless having profound implications for seabed infrastructure and undersea sensing.
- Simulation: Quantum simulators can be far more accurate than traditional simulation techniques because they capture with a great degree of granularity the conditions in which the simulated system exists.[64] This stems from the reality of Quantum technology – because it is more precise, it can be far more accurate. Quantum simulation promises benefits in a variety of scientific contexts, but as quantum technology proliferates, commercial applications are easy to envision, particularly for complex financial transactions and in the medical sector where large-scale modelling can greatly bolster efficiency.

Quantum demands a coherent public policy framework because of the time lag between deployment and economic returns. But there has been little thought given to the quantum integration period, and the challenges

63. James Hurley, *'Quantum computers 'to hit GDP before uplift'*, The Times, (24 July 2023), accessed via: link
64. Tomi H Johnson, Stephen R Clark, and Dieter Jaksch, *'What is a quantum simulator?'*, EPJ Quantum Technology, (1: 2014), accessed via: link

this will entail following severe market disruption.

3.3.1: Europe

The EU is in a structurally strong position for quantum deployment considering its ability to generate market size and direct long-term investment bureaucratically. There are some signs for optimism, considering increasing EU acceptance of the need for a quantum industrial base and pressure for a quantum industrial policy, along with initial structures for a quantum ecosystem through the Quantum Flagship and the QuantumSuperQPlus Project.[65] The difficulty is that, despite progress, investment rationalisation is difficult.[66] Despite progress under OpenSuperQPlus, the related AQTION programme, and the quantum sensing ASTERIQS initiative, there is still no real timeline for transitioning from ramp-up to commercialisation or way to measure progress.[67]This points to a potentially fundamental issue when it comes to EU technological development. Despite its flourishing academic and scientific community and potential market size, unless a single actor can draw together multiple bureaucratic actors, different lines of effort can degenerate into less than the sum of their parts. This provides the smaller, more nimble UK the ability to be a disruptor in advanced technologies and build leverage *vis-a-vis* Europe.

3.3.2: US

The US' quantum programme is strategically oriented given the threat Chinese Quantum development poses a threat to American economic growth and political-military power. The National Quantum Initiative (NQI) is the central touchpoint for American quantum development, with an initial £1 billion ($1.2 billion) pot of cash, with funding increased annually.[68] Cryptography and cybersecurity have been a major focus in light of Sino-American competition and cybersecurity incidents of the past two years.[69] The spate of hacks on American critical systems in the Pentagon and State Department, alongside attacks against critical infrastructure like the Colonial Pipeline Hack in 2021, demonstrate the US' vulnerability to cyber pressure and cyber-conducted espionage. The US has therefore emphasised cryptography and defensive cyber in its quantum development, as expressed through the Biden administration's rhetorical focus on cryptography and data security through quantum development.[70]

3.3.3: China

China's quantum policy is coloured by the New Cold War with the United States, both given the military potential of quantum technology and its benefits if combined with AI. This has driven an enormous public research budget. As of 2021, China had authorised some $10 billion (£8 billion) of research and development grants on quantum, outpacing the US.[71]Despite an avalanche of funding for Quantum research, Chinese quantum technology does lag behind American, even with more recent

65. European Commission, *'Digital Strategies: Quantum'*, last updated 13 June 2023, accessed via: link
66. James Dargan, *'New Report Shows Quantum Technologies Thriving In Europe'*, The Quantum Insider, (10 February 2023), accessed via: link
67. ASTERIOS, *'Advancing Science and Technology through diamond Quantum Sensing'*, accessed via: link
68. United States Government, *'National Quantum Initiative'*, accessed via: link; see also The White House, *'National Security Memorandum on Promoting United States Leadership in Quantum Computing While Mitigating Risks to Vulnerable Cryptographic Systems,'* (4 May 2022), accessed via: link
69. Michael Sugden, *'Congress Should Protect U.S. Leadership in Quantum Research,'* Foundation for Defense of Democracies, (16 June 2023), accessed via: link
70. Fredisha Snag, Andreas Wildner, *'Quantum Computing and the Financial Sector: World Economic Forum Lays Out Roadmap Towards Quantum Security,'* Cleary Gottlieb, (30 January 2024), accessed via: link
71. Mateusz Masiowski, Niko Mohr, Henning Soller, and Matija Zesko, *'Quantum computing funding remains strong, but talent gap raises concern,'* McKinsey Digital, (15 June 2022), accessed via: link; Martin Giles, *'President Trump has signed a $1.2 billion law to boost US quantum tech,'* MIT Technology Review, (22 December 2018), accessed via: link

breakthroughs.[72] IBM's 433-qubit computer dwarfs the processing power of any Chinese alternative, while Google created 50 and 70 qubit devices five years ago, an achievement it took China until the early 2020s to reach. Yet Chinese development is accelerating: China deployed a 66-qubit device rather rapidly, while classified developments are almost certainly more advanced.[73] China has also been integrating Russian quantum technology into its development pipeline, allowing Russia to make gains despite its international isolation.[74]

3.3.4: UK

British Quantum strategy is relatively coherent despite resource constraints. The National Quantum Strategy (NQS) pledges £2.5 billion in investment over a decade. Although this lags well behind Chinese funding, it is comparable to the US and Japan.[75] The UK has also maintained reasonably coherent strategic focus on Quantum development, and has fit its approach into UKRI's priorities more effectively that equivalent approaches in France, Germany, and Holland.[76] The UK's Quantum bet relies upon three factors: 1) aggressive commercialisation and adoption that leads to market growth; 2) international talent attraction; 3) the financial access to the City of London. The UK's quantum strategy thus offers a clearer path between government inception to capturing private investment than in the case of AI. As quantum remains a latent technology, however, it will be incumbent upon the government to continue fine-tuning this public-private roadmap, particularly with the advent of quantum capabilities viable for wide commercialisation.

3.4: Artificial Intelligence

Of the technologies identified in this study, AI is by far the most mature, particularly with rapid commercial rollout for LLMs in late 2022.[77] This is remarkable considering AI's uneven development timeline. Until the 1970s, the expectation was that an Artificial General Intelligence (AGI) – an intelligence capable of accomplishing any standard human task – would exist by the end of the 20th century, if not earlier.[78] The difficulties of AGI development prompted, from the 1990s onward, specific focus on discrete AI tasks. Investment into AI increased by half in the 2010s, while in the US alone, around £40 billion of investment is made in AI.[79]

The Potential of Artificial Intelligence

AI's effects can be broken into three streams – economic, political-societal, and strategic:

- *Economic*: AI will increase economic productivity through three channels. First, it will improve the productivity of the individual worker by creating workforce efficiencies, particularly by replacing low-value tasks in clerical and white-collar settings.

72. Berenice Baker, *'Chinese Quantum Startup Raises $148M'*, Enter Quantum, (1 August 2022), accessed via: link; Jeff Pao, *'China's fastest yet quantum computer still way behind US'*, Asia Times, (9 June 2023), accessed via: link.
73. Thomas Corbett and Peter W Singer, *'China May Have Just Taken the Lead in the Quantum Computing Race,'* Defense One, (14 April 2022), accessed via: link
74. Stephen Chen, *'Quantum entanglement: how US-led sanctions are turning Russia's genius scientists to China for collaboration'* South China Morning Post, (22 July 2023), accessed via: link
75. McKinsey Digital, *'Betting big on quantum,'* (13 September 2022), accessed via: link
76. UKRI, *'UK National Quantum Technologies Programme,'* accessed via: link
77. Accelex, *'ChatGPT and the LLM revolution: A private markets perspective,'* (26 April 2023), accessed via: link; Shymal Anadkat, *'The language revolution: How LLMs could transform the world,'* VentureBeat, (11 February 2023), accessed via: link; Bryan Smith, *et. al.*, *'Driving a Large Language Model Revolution in Customer Service and Support,'* DataBricks, (24 My 2023), accessed via: link
78. Ragnar Fjelland, *'Why general artificial intelligence will not be realized,'* Humanities and Social Sciences Communications, 7 (2020), accessed via: link
79. Daniel Pitchford, *'A Decade Of Advancements As We Enter A New Age Of AI,'* Forbes, (31 December 2019), accessed via: link

Second, AI will be able to take over a number of front-end tasks that involve dealing with individual clients, allowing for significant cost savings and improving efficiency. Third, AI *should* accelerate the pace of innovation in other sectors as ML algorithms are applied to different, larger data sets. Moreover, depending upon the scale of AI application, an economy's resources can be allocated more efficiently through predictive algorithmic forecasting. This need not occur in a centrally planned context. Indeed, it is more likely to occur in a market one, as a variety of AI types and applications compete for cash and innovate more aggressively. This has the potential to revitalise Western manufacturing, given the degree to which AI could reduce labour costs and accelerate resource distribution.[80] However, a major question is whether AI's first mover advantages accrue at scale, or whether the technology is diffuse enough to enable smaller actors to capitalise on the same trends as larger ones. **The trend seems to be that scale actually does matter, particularly for developing cutting-edge algorithms, because of the immense datasets that they need, and the amount of information they must absorb.**

- *Political-Societal*: AI has a potential first-mover advantage insofar as the larger an algorithm becomes, the more data it requires, and in turn, the more information and information-gathering points it needs to accelerate development.[81] Politically, there are obvious potential benefits for AI deployment in government contexts. Meaningful civil service reform might become possible, a truly digitally enabled government could be far more nimble than otherwise, and as the Ukraine War demonstrates the migration of government data onto a secure cloud platform with AI-enabled cyber defences can ensure resilience *even* in the event of strategic catastrophe. AI, however, also has the potential to have a corrosive impact upon political discourse, particularly with the accelerating quality of deepfake videos and images that can authentically simulate events. Social media penetration into society has creqated the potential for nefarious actors to deploy obvious misinformation at scale, thereby disrupting political cohesion.
- *Strategic*: In military contexts, AI is the most effective enabling capability that has ever emerged.[82] It has three probable impacts upon battlefield outcomes. First, AI facilitates the distributed employment of autonomous systems in a swarming manner, thereby creating a flexible, dispersed force that is far more resilient to enemy electronic and kinetic disruption. Second, AI reduces what has been termed the "kill chain", the cycle of

80. Jörg Gnamm, Thomas Frost, Frank Lesmeister, and Christian Ruehl, *'Factory of the Future: How Industry 4.0 and AI Can Transform Manufacturing,'* Bain, (10 July 2023), accessed via: link; Katie Rapp, *'Artificial Intelligence in Manufacturing: Real World Success Stories and Lessons Learned,'* National Institute of Standards and Technology, (7 January 2022), accessed via: link
81. Thor Benson, *'This Disinformation Is Just for You,'* Wired, (1 August 2023), accessed via: link
82. Forrest E Morgan, et. al., '*Military Applications of Artificial Intelligence: Ethical Concerns in an Uncertain World,'* RAND, (2020), pp. 8-24.

events in combat between identification, engagement, and post-engagement assessment. An AI-enabled force will therefore fight far faster than a non-AI-enabled one. Third, AI could conceivably generate insights into enemy capabilities and combat development far more rapidly than traditional human-led military learning efforts, meaning an AI enabled force will improve faster than a traditional one.

While AI products are varied, the underlying research in all three contexts is extraordinarily similar; the difference between these AI tools is small enough to allow for *research* cross-applicability. Hence the necessity of an integrated AI policy that has synergistic effects in all fields.

3.4.1: Europe

European AI development is EU directed given European lag compared to China, the US, South Korea, and the UK, especially in research.[83] The EU, however, does have two clear strengths: an increasingly structured regulatory environment and private sector adoption.[84] Nevertheless, the EU needs to translate an AI framework into tangible innovation and economic growth, especially considering disparities within Europe. There are well-funded European AI startups, particularly in Germany and France. But there are no EU-based AI unicorns – the UK now has three – while there are few major international firms with the desire to purchase major AI-related ventures in the EU, or to locate their cutting-edge AI development within the EU.[85]EU AI policy has emphasised cross-bloc regulation through the AI Act and GDPR. Indeed, the EU's strategic approach makes regulation central, with the idea that GDPR standards and well-crafted AI legislation can turn Europe into a model for AI development.[86] The focus on regulation is even more stark when one considers the EU's fragmented funding system is considered.[87]There are two issues that arise from the EU's approach for British consideration. First, Europe does have AI partners that the UK can access, but the EU's regulatory system may be problematic if the UK wishes to engage with European firms more closely. Second – and more critically – the EU's regulatory malaise, combined with EU-US data protection and AI regulation negotiations, must be monitored carefully, for the UK risks being placed in an odd position beyond the European bloc, but still subject to a restrictive regulatory framework. This would put the UK in the worst of both worlds: locked out of intra-union S&T collaboration and investment schemes; and stifled by a hands-on regulatory environment it has no role in formulating.

3.4.2: US

American AI developments remain world-leading in every category. Indeed, the US is still the "reference power" when it comes to AI research, development, and deployment. There are three major lines of effort that should be recognised – and in turn, three considerations for British policy.

83. European Commission, *'A European approach to artificial intelligence,'* last updated 19 June 2023, accessed via: link
84. Serena Cesareo and Joseph White, *'The Global AI Index,'* Tortoise Media, updated 2023, accessed via: link
85. *Ibid*.
86. Gian Volpicelli, *'ChatGPT broke the EU plan to regulate AI,'* Politico, (3 March 2023), accessed via: link; European Commission, *'Regulatory framework proposal on artificial intelligence,'* last updated 20 June 2023, accessed via: link; see also *'The AI Act,'* accessed via: link.
87. David Matthews, Thomas Brent and Goda Naujokaitytė, *'Here's what the first two years of Horizon Europe look like in numbers,'* Science Business, (31 January 2023), accessed via: link; European Commission, *'Horizon Europe: Performance,'* accWessed via: link

First, the sheer amount of funding the US can direct towards AI development is its greatest, most insurmountable, and structurally-continuous strength. As of FY2021, private US investment in AI reached $73.40 billion (£57 billion), more than three times that of China, and six times that of the UK and Europe combined, while financial sector access ensures a steady stream of long-term funding. Second, US Federal funding is overwhelmingly defence focussed, with only limited exceptions.[88]This approach has strengths, but also several weaknesses. First, current AI Contracting is concentrated with small firms, but as larger traditional defence primes and government services companies catch up, there is a risk that the lower end of the American AI ecosystem will be swallowed up. This is a risk because, second, the US lags behind when it comes to the human talent base it needs for AI development.[89] Third, and most critically, there is a gap between the perceptions of the US Government and that of the broader US technology ecosystem as to AI's strategic purpose, manifested in the distance between Google and the Pentagon.[90] This is illustrative for the UK, because it demonstrates that human capital and clear strategy is as relevant as corporate entities and funding levels.

3.4.3: China

MCF is most apparent in Chinese AI development because the PRC views AI as a strategic golden ticket to global power status. This stems from the Chinese view that an AI-enabled military will be capable of dominating a non-AI force because of its ability to process information and respond to enemy actions at insurmountable speed. Chinese AI investment also dovetails with the demands of the Chinese security state, demonstrating the obvious strategic pressures upon Chinese AI development. AI is dependent upon data, since without vast quantities of information, it is difficult to develop and refine and algorithm. China has the world's largest security state both relatively and in absolute terms. It employs AI for a number of analytical and monitoring tasks. Most notably, the Chinese security state uses facial recognition technology to improve its population monitoring and increase the granularity of its social control, particularly in Xinjiang.

China's AI industry is projected to reach around $60 billion (£47 billion) by the middle of the decade.[91] Chinese AI policy implementation and AI market growth, meanwhile, stem from a systematic research and investment approach guided by China's AI Five-Year Plans. China's AI ecosystem of academics, large corporations, and start-ups has enabled the PRC to accelerate AI deployment, particularly when it comes to smart home, facial recognition, and drone control technologies. Additionally, while China has the world's largest captive data market, China also attracts international data by hosting a number of data storage centres, particularly for Chinese-developed applications like TikTok. China's data storage ambitions extend far beyond specific apps. In 2022, China unveiled a massive data storage development plan. By developing 10 major data storage hubs throughout China, Beijing hopes – at least nominally – to enable the flow of information between the country's east and west,

88. AI.Gov, *'National Artificial Intelligence Initiative,'* accessed via: link; see also NSCAI, *'Final Report: National Security Commission on Artificial Intelligence,'* (March 2021), pp. 43-58; Gregory S. Dawson, Kevin C. Desouza, and James S. Denford, *'Understanding artificial intelligence spending by the U.S. federal government,'* Brookings, (22 September 2022), accessed via: link
89. Gregory S. Dawson and Kevin C. Desouza, *'How the U.S. can dominate in the race to national AI supremacy,'* Brookings, (3 February 2022), accessed via: link
90. Daisuke Wakabayashi and Kate Conger, *'Google Wants to Work With the Pentagon Again, Despite Employee Concerns,'* New York Times, (3 November 2021), accessed via: link
91. Alexander Chipman Katy, *'Artificial Intelligence in China: Shenzhen Releases First Local Regulations,'* China Briefing, (29 July 2021), accessed via: link

thereby more evenly distributing compute and reducing local energy stresses.[92] Yet it is highly probable that such a data storage system will be offered to international actors, thereby increasing Chinese access to overseas data.

3.4.4: UK

The UK's AI ecosystem has two advantages, a high-quality research base and significant commercial deployment opportunities, but two disadvantages, a lack of a large-scale data pool, and limited inbound investment.

The UK has a robust AI research base. The British research environment ranks only ten points behind that of China on international assessment metrics, primarily because the UK has a number of cutting-edge academic departments that have AI specialities, which the Government's £54 million UKRI grant will bolster.[93] Moreover, the UK also provides AI startups with excellent commercial opportunities for scaling and capital access.[94] Additionally, alongside this startup ecosystem stands several broad applied AI companies, particularly in cybersecurity, equally relevant for AI sector growth.[95] Structurally, however, there may be limits to British AI development. The UK's population is a fraction of the size of the US and China, while Singapore, which edged out the UK from the third spot on international leaderboards because of an aggressive inbound investment strategy, is somewhat of an outlier. Because AI depends upon data, a captive market of hundreds of millions to billions of people is extraordinarily relevant for algorithmic development. Moreover, the UK's AI ecosystem has limited inbound investment.[96] The US and China have a respective share of 82% and 87% of domestically-originating AI investment. Only the UK, Israel, and Singapore have below 50% domestic AI investment and remain global AI leaders.

Cognisant of these developmental and financial limitations, the Government hopes to place itself at the spearhead of global AI regulation.[97] But aside from the feverishly politicised nature of AI development and regulation, the UK's wider lack of clarity and progress in this emergent technological field hampers its capacity to position itself as a global leader. This shows how critical technologies as a holistic strategic challenge require coordination across all spokes of the wheel.

The lesson here is that the UK must consider strongly how it ensures long-term inbound investment, or whether it shifts to another model, and the mechanism through which the UK sustains a domestic AI industry absent a large-scale data network.

3.5: Space-based Capabilities

Modern satellite technology is unmistakably dual-use. Almost any space-based asset, whether an imaging, communications, or PNT satellite, is capable of being applied in a military purpose. The Ukraine War has demonstrated the versatility and critical nature of space-based infrastructure, despite its obvious cost.

There are two major technical developments in space-based capabilities

92. Arendse Huld, *'"Eastern Data, Western Computing" – China's Big Plan to Boost Data Center Computing Power Across Regions,'* China Briefing, (30 March 2022), accessed via: link
93. Innovation News Network, *'Government invests £54m into developing secure and trustworthy AI research,'* (14 June 2023), accessed via: link
94. Marc Cooper, *'Rise Of The AI Investment Bankers,'* Forbes, (20 April 2023), accessed via: link
95. National Cyber Security Centre, *'Ecosystem; NCSC Annual Review 2023,'* accessed via: link
96. Serena Cesareo & Joseph White, *'The Global AI Index,'* Tortoise Media, (2024), accessed via: link
97. Joseph Bambridge, *'Blow for Sunak's AI summit as leaked document shows UK scaling back research plans,'* Politico, (26 October 2023), accessed via: link

worth emphasising. First, the proliferation of satellite constellations at different orbits – whether Low, Medium, or Geostationary – diversifies satellite tasks. Second, the proliferation of microsatellites that have extremely effective sensors or communications systems allows for a far greater expansion of space-based infrastructure, particularly in the LEO area.

The expense of space-based infrastructure makes it an excellent case for the assessment of critical capabilities policy, primarily because private actors *and* states are incentivised to collaborate.

3.5.1: Europe

The EU has recognised space as a strategic capacity, particularly in light of the Ukraine War.[98] There are typical multilateral industrial issues, but the EU is solidly a top-tier spacepower with consistent strategic focus.[99] Nevertheless, there are three obvious impediments to European space ambitions. First, the EU remains dependent upon US space capabilities, generating an ownership-collaboration-access problem the EU's bureaucratic structure struggles to address.[100] Second, the indirect relationship between the ESA and the EU creates an odd regulatory and strategic framework that reduces the EU's ability to grow space power, while allowing the UK to integrate into ESA.[101] Third, despite the EU's captive European market, expansion remains difficult because of national interest divergences.[102] In typical fashion, the EU has identified a direct industrial policy for space as a probable goal in the next decade, with a flagship programme, IRIS2.[103] This effort will be extraordinarily expensive, and may well provide a product that lags technologically by the time it is delivered.[104]

3.5.2: US

The US has always been at the cutting edge of spacepower development, which gives it a distinct structural advantage in deploying high-tech assets.[105] The creation of the Space Force, the first large-scale state organisation tasked with space defence, in 2019 is a sign of the seriousness with which the US has now taken spacepower.[106] There is now a push to recognise space as critical national infrastructure, reinforcing the relevance of space-based assets to the American economy and society.[107] Moreover, initially quantified economic returns demonstrate that space has accounted directly for 0.6% of US GDP, a large proportion considering the small American space workforce.[108] The US' long-term issue is transitioning from the current public-investment model to a private approach when 60% of global state-led space investment is American, and declining private capital.[109]

3.5.3: China

China has grossly increased its space presence, with the explicit objective of leapfrogging the US, but a major funding gap remains.[110] There is some evidence of Chinese *industrial* production that may outpace that of the US

98. European Commission, *'EU Space Strategy for Security and Defence,'* (March 2023), accessed via: link
99. Rafael Loss and Silvia Samore, *'Multilateral space: A European space oddity,'* European Council on Foreign Relations, (28 April 2023), accessed via: link
100. Marian-Jean Marinescu and Andre Loesekrug-Pietri, *'Can Europe remain a space power?'* Tech EU, (26 March 2023), accessed via: link
101. European Space Agency, *'ESA and the EU,'* accessed via: link
102. European Space Policy Institute, *'European Space Strategy in a Global Context,'* 75, (November 2020), pp. 5-8.
103. Alessandro de Concini and Jaroslav Toth, *'The future of the European space sector: How to leverage Europe's technological leadership and boost investments for space ventures,'* European Investment Bank, (2019), pp. 59-63; European Commission, *'IRIS²: the new EU Secure Satellite Constellation,'* accessed via: link
104. Joe Barnes, *'Elon Musk 'refuses to turn on Starlink' for Crimea drone attack,'* The Telegraph, (31 July 2023), accessed via: link; Eric Berger, *'Europe's major satellite players line up to build Starlink competitor,'* Ars Technica, (3 May 2023), accessed via: link
105. Johnny Wood, *'The countries with the most satellites in space,'* World Economic Forum, (4 March 2019), accessed via: link
106. US Space Force, *'Space Capstone Publication: Spacepower – Doctrine for Space Forces,'* (June 2020), accessed via: link
107. Frank J. Cilluffo and Mark Montgomery, *'Time to designate space systems as critical infrastructure,'* Space News, (14 April 2023), accessed via: link; Stew Magnuson, *'Acknowledging Space Systems as 'Critical Infrastructure'',* National Defense, (10 May 2022), accessed via: link
108. Tina Highfill and Chris Surfield, *'New and Revised Statistics for the U.S. Space Economy, 2012–2021,'* Survey of Current Business: US Bureau of Economic Analysis, (27 June 2023), accessed via: link
109. Landry Signé and Hanna Dooley, *'How space exploration is fueling the Fourth Industrial Revolution,'* Brookings, (28 March 2023), accessed via: link
110. Ramin Skibba, *'China Is Now a Major Space Power,'* Wired, (4 November 2022), accessed via: link

by the mid 2030s, while Sino-Russian collaboration, especially on PNT, is also concerning.[111] Indeed, the fundamental reality of spacepower is interdependence. China is weaponising that interdependence with Russia and reducing its links with the West in search of strategic advantage.[112] What remains grossly unclear at this stage is whether major disruptions in space will have severely deleterious knock-on effects in the long-term, particularly those that include disruptions to satellites.

3.5.4: UK

The UK has initiated a strategic effort to conceptualise spacepower, including a formal spacepower doctrine, but progress still lags behind even that of Italy.[113] Solving British spacepower demands a clear-eyed evaluation of both the UK's reliance on European and American partners, which is particularly prudent in light of the DCPR's emphasis on Allied By Design.[114] The UK's involvement in the ESA provides an obvious leverage point. The prevailing strategic challenge will therefore lie in identifying where to allocate resources to developing national programmes and capabilities, and where to plug into pre-existing multilateral frameworks. As the UK continues to grapple with financial obstacles in the overall critical technology landscape, whether it can design a successful funding structure for the immensely expensive space domain will prove a canary in the mine for wider technological success.

3.6: Semiconductors

Semiconductors are the most obviously geopolitical of the technologies considered because of the linkage between semiconductor supply chains and global strategic hotspots. It is reasonable to link them with the other technologies discussed above because of their obvious relevance not only to general economic productivity, but specifically to communications, AI, and quantum. The semiconductor supply chain is concentrated in East Asia, with Taiwan, South Korea, Japan, China, and to a degree Singapore leading the pack, along with US fabrication. The most advanced facilities, however – the only facilities capable of creating advanced semiconductors required for modern high-end computing – are in Taiwan, the US, and to a degree South Korea. This has obvious implications for any technology policy. First, geopolitical rivalry that accelerates into an actual confrontation in East Asia will not only derail the global semiconductor supply chain: it will also fracture it for the long-term, with knock-on effects for nearly every modern technological process, and particularly for consumer electronics. If the above technologies are actually going to be transformative, they require a society that is extraordinarily digitally connected, simply to ensure that the amount of data needed to leverage advanced AI actually exists. Hence the destruction of a plentiful consumer electronics industry, one of the defining industries of the early 21st century, would be calamitous to British and allied quality of life.

The reality is, the UK cannot create a large semiconductor industry from scratch. Nor can it break into an already well-structured market. The

111. J Olson, et. al., *'State of the Space Industrial Base 2022'* Defense Innovation Unit, (August 2022), pp. 8-15ff; Alexander Bowe, *'China's Pursuit of Space Power Status and Implications for the United States,'* US-China Economic and Security Review Commission, (11 April 2019), pp. 5-7; see also Kevin Pollpeter, et. al., *'China-Russia Space Cooperation: The Strategic, Military, Diplomatic, and Economic Implications of a Growing Relationship,'* China Aerospace Studies Institute, (May 2023), pp. 41-44.

112. John Sheldon, *'Britain and the Geopolitics of Space Technology: Safeguarding long-term UK space interests in an era of great power competition,'* (Policy Exchange, December 2021).

113. Ministry of Defence, *'Joint Doctrine Publication 0-40: UK Space Power,'* (September 2022), accessed via: link

114. Ministry of Defence, *'Defence Command Paper 2023: Defence's response to a more contested and volatile world,'* (July 2023), pp. 10-11, pp. 40-42.

strategic question is to judge whether the UK can leverage any specific competitive advantages to shape the semiconductor supply chain in the long-term, and ensure that it has a place within it, thereby providing it access to any long-term developments in allied capitals more capable of large-scale technological and industrial programmes.

3.6.1: Europe

Although the European Chips Act meant to build European market share from 10% today to 20% by 2030, the initiative's 43 billion Euro financing injection is distributed across multiple programmes, in contrast to the US' $53 billion direct spending, making its goal unrealistic.[115] Nor is the EU committed to evolving its industrial approach to semiconductors.[116] There are a number of local and national political questions that must be addressed if Europe's semiconductor strategy is to work, ranging from permitting issues to environmental questions – all the while, the US and China accelerate their strategies. An enormous amount of infrastructure within the EU simply needs to be fabricated from scratch, while private capital lags behind, and environmental questions complicate production.[117] Hence the EU's semiconductor approach, which trends heavily towards industrial strategy, risks being both too late and simply not properly structured enough to be implemented.

3.6.2: US

The US' semiconductor strategy includes two components: an industrial policy to create a semiconductor industrial base and export controls on high-end chip development critical for advanced AI. The former element includes enormous cash investment, $53 billion of subsidies and $24 billion of tax credits, to reduce reliance on east Asian semiconductor manufacturing.[118] Export controls complement this by kneecapping Chinese AI and critical technology development.[119] The difficulty with US policy is twofold. First, despite the cash being poured into semiconductor development, the US semiconductor industry still lags behind: American chip production is still double the price of comparable Asian chip costs, while taking 25% longer.[120] Overregulation compounds the issue, including a ballooning set of environmental regulations that create a year-and-a-half gap between permit filing and the permission to break ground on a facility, as does a labour shortage.[121] Hence there will be *some* return on the investment that the CHIPS Act has made, but it is entirely unclear whether the US will be able to create a globally competitive semiconductor industry despite the amount of money it has poured into the effort.

3.6.3: China

China's two greatest vulnerabilities remain its import-dependence on food and on chips. Both being cut off or disrupted for any serious length of time would create extreme domestic pressures. Hence China's goal is to accelerate its domestic manufacturing of both capacities over the next decade. Chinese fabs can produce low-end chips, but still struggles at the

115. European Commission, *'European Chips Act,'* accessed via link; European Commission, *'Commission welcomes political agreement on the European Chips Act,'* accessed via: link

116. Pieter Haeck, *'Europe's chips strategy staggers past the starting line,'* Politico, (19 April 2023), accessed via: link

117. Jillian Cota, *'The European Chips Act: A Strategy to Expand Semiconductor Production Resiliency,'* CSIS, March 2022, accessed via: link

118. McKinsey, 'The CHIPS and Science Act: Here's what's in it,' (4 October 2022), accessed via: link; The White House, 'FACT SHEET: CHIPS and Science Act Will Lower Costs, Create Jobs, Strengthen Supply Chains, and Counter China,' (9 August 2022), accessed via: link

119. Matthew Reynolds, *'Assessing the New Semiconductor Export Controls,'* CSIS, (3 November 2022), accessed via: link; see also BIS' Fact Sheet on the Export Controls, accessed via: link

120. John VerWey, *'No Permits, No Fabs: The Importance of Regulatory Reform for Semiconductor Manufacturing,'* Center for Security and Emerging Technology (October 2021), pp. 22-24ff; Antonio Varas, *et. al.*, *'Strengthening the Global Semiconductor Supply Chain in an Uncertain Era,'* Semiconductor Industry Association, (April 2021), p. 4.

121. Bloomberg, *'$52 Billion Chipmaking Plan Is Racing Toward Failure,'* (28 March 2023), accessed via: link

higher end of the production chain, while US export controls have damaged Chinese advances.[122] Additional cash will not solve a technological issue, which China has struggled to work around despite its experience with illicit technology transfers.[123]

3.6.4: UK

The UK's semiconductor strategy, released earlier this year, does recognise the UK's fundamental weaknesses in the sector.[124] Semiconductor development and production is already so mature as to make even a robust industrial policy unlikely to grow British market share, while British semiconductor fabrication faces power generation issues. However, the UK retains strengths in chip design.[125] British policy to support the semiconductor industry with around £1 billion of investment over the next decade will likely be fruitful – the question will be whether the UK has the strategic good sense to ensure that its semiconductor investments become geopolitically relevant as well.

3.7: Engineering Biology

Defining Engineering Biology is slightly more difficult than the other technological lines of effort in this study, simply because cutting-edge biological research is multi-disciplinary and defines strict categorisation. Generally speaking, we might understand engineering biology as a branch of synthetic biology, as the set of techniques employed to modify organisms for scientifically, medically, and commercially useful applications. Engineering biology has obvious overlap with other advanced biological applications, including genomics and aspects of modern biochemistry. There are specific technical differences between engineering biology and genomics – the latter typically edits smaller sequences of a genome, while the former weaves different genomes together – but the general approach is similar, as are the technologies and methodologies required for both.

The Potential of Engineering Biology

Engineering biology has innumerable applications that can improve human life and economic activity. Several are listed below as illustrative applications of the approach:

- Synthesised Blood: Synthetic blood can alleviate any potential blood shortages that place stress upon public health systems. However, it also allows for far more specific triage and long-term treatment for specific blood-related diseases. Moreover, it can provide individuals who are deficient in a variety of essential chemicals and vitamins, or inserting additional enzymes into the bloodstream.
- SimCells: Cell modification has been a common technique in biological research for decades, particularly as GMO crops have

122. Sheila Chang, *'China's top chipmaker will 'struggle' to make cutting-edge chips competitively,' CNBC*, (28 April 2023), accessed via: link
123. Gregory C Allen, *'China's New Strategy for Waging the Microchip Tech War,'* CSIS, (3 May 2023), accessed via: link
124. Department for Science, Innovation and Technology, *'National semiconductor strategy,'* (19 May 2023), accessed via: link
125. Tech UK, *'A UK Plan for Chips,'* (25 January 2023), accessed via: link; Shelia Chang, *'Don't underestimate China's ability to build its own advanced chips despite U.S. curbs, tech analysts say,'* CNBC, last updated 6 June 2023, accessed via: link

proliferated in the global food supply. However, modified organic cells retain a fair amount of their original biological "programming", leading to long-term difficulties when one attempts to develop a synthetic product, since the organic direction of the cell can reassert itself. SimCells, by contrast, are "empty", insofar as they lack DNA programming, and can have various components inserted into them. This makes for a much more controllable product, allowing engineering biologists to develop outputs with much greater complexity, with applications across the medical industry.

- Synthetic Flavourings: Synthetic flavourings have been commercially available for decades. However, the synthesising process can have a variety of poor impacts upon the final product that generate adverse health outcomes over the long-term, while a synthetic flavouring also fails common "naturality" tests that regulators apply in the EU and elsewhere. Engineering biological alternatives to traditional synthetic flavourings avoid both pitfalls, enabling immediate commercialisation.
- Biofuels: Over the past 40 years, the private sector has experiment with the biological creation of fuel from various waste products, both for environmental reasons and for simple cost-savings motivations. The issue, however, is scale – the facilities needed to create fuel precursors in this manner are extremely expensive. Recent breakthroughs in engineering biology have decreased the fixed cost of synthetic methods, creating the potential for a cheap, clean, recycled fuel precursor industry.

Engineering biology is a particularly fruitful investment line because of the sheer amount of research conducted in major medical institutions and academic departments internationally. Universities and large research hospitals are routinely on the cutting edge of medical development and biological research. These often generate insights that could be commercialised with relative ease if there were the right vehicles to package, articulate, and apply engineering biological techniques to wider industry purposes.

3.7.1: Europe

Europe has a solid base for potential research into engineering biology, with world-class academic institutions and a leading research ecosystem.[126] There is a EU-wide push for expanded engineering biology research through the European Synthetic Biology Society (EUSynBioS), but European research still relies upon UK programmes.[127] The EU also has a nascent biotech industrial base, with 4,500 EU-based companies in the biotech space, and a growing European VC focus.[128] However, there are obvious lag areas. The UK still retains more members of major bio-innovation organisations like the Global Biofoundries Alliance – four in the EU versus five in the

126. Stefano Donati, *et. al.*, *"Synthetic biology in Europe: current community landscape and future perspectives"*, Biotechnology Notes (3, 2022), pp. 54-61.

127. EUSynBioS, *"EUSynBioMap"*, accessed via: link

128. Matthias Evers, et. al., *"Europe's Bio Revolution: Biological innovations for complex problems"*, McKinsey, (10 January 2023), accessed via: link

UK.[129] There are three specific gaps. First, while there is an increase in VC funding, and there are a handful of governmental programmes that provide funding to engineering biological research, there is no systematic funding framework for the EU's engineering biological development, nor is there, at this point, any sign that a systematic framework is under consideration. Second, there is no physical cluster of engineering biological development. EUSynBioS registered labs are illustrative. The UK has seven labs – three in London (UCL and Imperial College), one at University of Warwick, one at University of Nottingham, one at Oxford University, and one at University of Edinburgh. Barring Edinburgh, which is in relative terms not particularly far away, the four non-London labs are relatively close to London, enabling researchers to travel relatively efficiently. The same cannot be said of Europe's infrastructure, where labs are scattered across the western EU. Third, there is no clear framework for translating academic research into commercially deployable products despite Europe's broader biotech and biopharmaceutical industry.

3.7.2: US

The US private sector has identified the potential applicability and revolutionary nature of engineering biology for several decades. Food production and pharmaceuticals/broader biotech are the primary research lines. There has been similar policy recognition, but not direct translation into an innovation framework, let alone a national strategy.[130] The US has a large market for accelerated deployment, intensifying private investment – American VCs spend $15-20 billion annually on biotech – although the majority of research is not in engineering biology.[131] The US' greatest long-term issue is a lack of a coherent regulatory and strategic authority. There is a push for the creation of some centralised authority, especially from private sector research.[132] Yet there is insufficient granularity in biotech investment for an engineering biology focus, while the US Federal government has avoided more specific policy frameworks.[133]

3.7.3: China

China has an obvious incentive to invest in engineering biological capabilities, given Chinese dependence upon food imports, which will only intensify as climate effects compound.[134] Chinese biotechnology funding is enormous[135], reaching around $220 billion over eight years, some 30% more than average US funding until 2019.[136] Moreover, China's synthetic biology investments, and general biotech investments, obviously follow Military-Civil Fusion. China has prioritised linkages with universities and state-funding research organisations,[137] which still pose a security risk in the UK.[138] The difficulty in Chinese policy is translating cash investment into results, despite a five-year biotech plan.[139] Because the government is the central actor, and therefore moves slowly, rapid deployment is near-impossible. Combined with the obvious biosecurity issues that the COVID-19 Pandemic has raised in China, and it becomes clear that, despite the importance of engineering biology to Beijing, there

129. Stefano Donati, et. al., *"Synthetic biology in Europe: current community landscape and future perspectives,"* (2022)
130. US Governmnet Accountability Office, *"Science & Tech Spotlight: Synthetic Biology"*, (17 April 2023), accessed via: link
131. Christopher A Voight, *"Synthetic biology 2020–2030: six commercially-available products that are changing our world"*, Nature Communications (11: 2020), accessed via: link
132. Schmidt Futures, '*The US Bioeconomy: Charting a Course for a Resilient and Competitive Future – A Bioeconomy Strategy*', (April 2022), pp. 43-50.
133. Todd Kuiken, *"Synthetic/Engineering Biology: Issues for Congress"*, Congressional Research Service (30 September 2022), accessed via: link
134. Genevieve Donnellon-May, *"China's food dilemma"*, The Interpreter, (29 March 2023), accessed via: link
135. Tom Connors, *"How China May Soon Lead the Bio-Revolution"*, Bloomberg, (29 March 2022), accessed via: link
136. Bloomberg, *"China's $220 Billion Biotech Initiative Is Struggling to Take Off"*, (15 May 2023), accessed via: link
137. BBC, *"Universities get Synthetic Biology China Partnering Award grants"*, (15 October 2023), accessed via: link
138. Daniel Martin, *"How Beijing made its way into the heart of British academia"*, The Telegraph, (13 July 2023), accessed via: link
139. Xu Zhang, *et. al.*, *"The roadmap of bioeconomy in China"*, Engineering Biology, 6:4 (December 2022), pp. 71-81; see also Li Tang, *et. al.*, *"Synthetic biology and governance research in China: a 40-year evolution"*, Scientometrics (2023), accessed via: link

are serious obstacles in its development.[140]

3.7.4: UK

The British engineering biology landscape is robust, as its role in the EU's general biotech ecosystem demonstrates. The baseline issue is a lack of investment to translate a vibrant research system into a broader tangible production line. UKRI's engineering biology policies provide a clear roadmap for development, facilitating a biotech boom that international research links have assisted.[141] The difficulty is one of funding. There has been an enormous post-COVID bump in biotech funding generally, increasing public and private financing in 2021 by 60%.[142] Yet this pales in comparison to European, American, and Chinese funding, even with the difficulties of all three development ecosystems, and may not be sustainable. Without a long-term investment approach that ensures consistent financial expenditures on biotech and engineering biology, it will be difficult to create the incentives for commercialisation.

3.8: Conclusion

Each of the capability areas discussed above have their unique characteristics. However, the areas of overlap are also unmistakable. On the one hand, there is *thematic* overlap, and in a manner, a fundamental dependence between technologies. Quantum computing runs together with AI development and the production of more advanced semiconductors, while a quantum-enabled communications network links with space-based capabilities. The UK will not support all of these technologies equally. Not only is this a financially impossible task – it also would compel the UK to make strategically unsound investments in sectors where others have already pulled ahead quite rapidly. Yet considering these six technological streams in tandem still provides strategic benefit given their overlaps.

More broadly, grouping technologies like this together enables for a long-term assessment of allied and competitor strengths. It is no accident that each actor assessed – the US, the EU, China, and the UK – all have policies for each of these technology areas, even if these policies vary depending upon national context, and are of uneven quality.

Moreover, the harmonisation between long-term technological investment and the cultivation of a realistic deployment mechanism. Developing critical national capabilities requires a society and strategic system that can actually absorb them. This makes fixed capability investments, various forms of critical national infrastructure, a baseline necessity. The most relevant of these investments is almost certainly telecommunications to ensure that the network upon which new technologies are deployed is hardened against disruption.

Additionally, considering the scale and scope of investment in the US, Europe, and China in each technology area, critical national capabilities are hurtling towards major leaps in deployment capacity. This makes contemporary investment crucial to ensure coherent policy.

140. Bob Kaldec, Bob Foster, and 117th GOP HELP Committee Staff, "*Muddy Waters: The Origins of COVID-19 Report*", US Senate Committee on Health, Education, Labor, and Pensions, (17 April 2023), pp. 143-199.

141. Alex Ralph, "Biotech is in Britain's DNA but still needs investment", *The Times*, 13 April 2023, accessed via: link; *UK Biotech Financing in 2021* (January 2022), accessed via: link

142. UK Biotech Financing in 2021.

4.0: Geopolitics, Infrastructure, and Technological Rivalry

4.1: Introduction

The contemporary geopolitical environment demands a focus on long-range competition, during with British allies will not always be aligned, but *coordination* nevertheless remains crucial. Identifying coordination mechanisms and objectives for the UK requires, first, a look at the character of Sino-American rivalry in Eurasia, second, a review of US-European friction, and then third, an assessment of the British role. While the UK's International Technology strategy makes a start towards answering these questions, and DSIT's Areas of Interest reinforce this, the below provide a more granular, and more strategically grounded, overview of the questions we face today.[143]

4.2: Great Power Rivalry

The Sino-American rivalry is the proper framing for British policy because it is the defining factor in Eurasian geopolitics. A First Cold War style bloc system may not come into existence, but all other Eurasian powers will orient themselves towards these two poles of rivalry simply because of their combined economic and technological heft.[144]

No coalition relationship is preordained.[145] In the Second Cold War, the UK and its allies will gain the upper hand *only* if they make themselves flexible and attractive enough to incentivise engagement.

The deployment and improvement of critical capabilities at scale, is a strategic question for the UK, US, European powers, and all their affiliated states, but are typically treated as issues of industrial policy. Meanwhile, China has accelerated development in three fields – AI, Microelectronic production and thereby basic semiconductors, and advanced telecommunications – to a degree that *could* provide it an unmistakable advantage by the end of the decade.[146]

143. GOV.UK, *"The UK's International Technology Strategy,"* (22 March 2023), accessed via: link

144. Thomas F. Lynch III and Frank Hoffman, *"Past Eras of Great Power Competition".* In Lynch III (ed), *"Strategic Assessment 2020: Into a New Era of Great Power Competition,"* Washington, DC: Institute for National Strategic Studies, (2020), pp. 17-43.

145. Henry Kissinger, *"Diplomacy,"* New York: Simon and Schuster, (1991), pp. 703-732.

146. *"Mid-Decade Challenges to National Competitiveness,"* Special Competitive Studies Project, (September 2022), p. 19.

Chinese Structural Issues

The PRC is investing in these technologies primarily because of structural changes in its population and economy. China's population almost certainly contracted in 2022. This stemmed in part from the COVID-19 Pandemic, but also from the structural controls that the CCP's One Child Policy imposed upon Chinese families. Declining birthrates are probable in the long-run, even with a brief rebound, primarily because of the age of China's population.[147] By 2040, between a third and two-fifths of Chinese will be over the retirement age of 60 – of those currently at the lower end of this bracket, females in the group have generally passed child-bearing age. By the end of the century, China's population may contract to around 600 million, well under half of its 1.4 billion peak.[148]

This trend in population decline is coupled with other economic signs of structural distress. China's income tax base is extremely small, with no more than a tenth of Chinese workers paying income tax.[149] OECD countries rely on income taxes for around a quarter of their overall tax yield, with the United States being a unique outlier in deriving around 40% of its tax revenues from income taxes.[150] The UK, a country relatively emblematic of OECD tax trends, derives almost exactly 25% of its tax yields from individual income tax.[151] Chinese public statistics claim that income tax provides the government with around a quarter of tax revenues as well, with the majority being derived from taxes on goods and services.[152] But the realities of systemic corruption and lax tax enforcement on the upper classes, the primary engine of tax revenues in any developed economy with a white-collar managerial class, means that China's tax take is almost certainly well below its reported figure.[153]

Moreover, China is sitting upon a debt time bomb. China's regions were encouraged to sell land to real estate developers, and they conduct development through a public-private partnership scheme that essentially used individual deposits to subsidise local government budgets.[154] The system was sustainable as long as private developers had an incentive to pay increasingly high prices to purchase land from Chinese provincial governments, but the Chinese property market has unravelled over the past two years.[155] Hence local financial institutions are asked to extend credit lines to local governments that have no means of repaying debts. The final bill-payer is the central government in Beijing, which must execute a careful balancing act to avoid a major economic contraction.

Chinese debt troubles are relevant because it demonstrates the degree to which much of China's economic growth over the past decade stemmed from practices unsustainable in the long-term. Overall Chinese debt is likely higher than that of Western countries, although not grossly so – estimates place it at around 30% higher than the US' debt-to-GDP percentage. However, China accumulated this debt over the past 15 years. Before 2008, China experienced explosive economic growth, a result of internal liberalisation, the relaxation of capital controls, and China's integration into the global economic system. After 2008, that growth seemed to taper off, but still remained at around 7-10% per annum.[156] The explosion of Chinese debt, however, implies that at least some of China's post-2008 growth was illusory, and actually stemmed from an enormous amount of essentially fake credit.[157]

147. Alexandra Stevenson and Zixu Wang, *"China's Population Falls, Heralding a Demographic Crisis"*, New York Times, (16 January 2023), accessed via: link; Yi Fuxian, *"China Is Dying Out"*, Project Syndicate, (14 February 2023), accessed via: link
148. Xiujian Peng, *"China's population is now inexorably shrinking, bringing forward the day the planet's population turns down"*, The Conversation, (19 January 2023), accessed via: link
149. Tom Hancock, *"China Needs More Tax Revenue, Risking Backlash From Middle Class"*, Bloomberg, (14 June 2023), accessed via: link.
150. Daniel Bunn and Cecilia Perez Weigel, *"Sources of U.S. Tax Revenue by Tax Type, 2023"*, Tax Foundation, (27 February 2023), accessed via: link
151. Matthew Keep, *"Tax statistics: an overview"*, House of Commons Library, (5 June 2023), pp. 6-8.
152. China's last released public statistics from 2018, accessed via: link
153. Tanya YH Tang, *"A review of tax avoidance in China"*, China Journal of Accounting Research, 13:4 (December 2020), pp. 327-338.
154. Samuel Shen and Tom Westbrook, *"Exclusive: China's Qingdao sets up firm to bail out its local government financing arms"*, Reuters, (13 July 2023), accessed via: link; Wei Zhou, *"Why LGFV Debt Is a Growing Risk for China's Economy"*, Bloomberg, last updated 4 July 2023, accessed via: link
155. Nicholas Gordon, *"Developer at the heart of China's ongoing property crisis lost $81bn in the past two years—more than Google or Microsoft's entire 2022 profit"*, Fortune, (18 July 2023), accessed via: link; Vahid Karaahmetovic, *"China's property market crisis deepens despite developer rally"*, FinBold, (12 June 2023), accessed via: link; Tom Hancock, *"China's Mysteriously Resilient Real Estate Prices—Explained"*, Bloomberg, (25 March 2023), accessed via: link
156. Data from World Bank, accessed via: link
157. Michael T. Owyang and Hannah Shell, *"China's Economic Data: An Accurate Reflection, or Just Smoke and Mirrors?"* Federal Reserve Bank of St Louis, (25 July 2017), accessed via: link; John Burn-Murdoch, *"China's GDP blackout isn't fooling anyone"*, Financial Times, (21 October 2022), accessed via: link; The Economist, *"How to measure China's true economic growth"*, (9 March 2023), accessed via: link

result of internal liberalisation, the relaxation of capital controls, and China's integration into the global economic system. After 2008, that growth seemed to taper off, but still remained at around 7-10% per annum.[156] The explosion of Chinese debt, however, implies that at least some of China's post-2008 growth was illusory, and actually stemmed from an enormous amount of essentially fake credit.[157]

China's natural structural impediments have prompted its investment in critical capabilities to reduce the need for human labour, amplify economic growth, and thus mitigate the drag of a shrinking workforce on an enormous country, while also enabling exports to gain leverage over third countries.[160] Chinese developments are outlined below:

- AI: Artificial Intelligence provides three benefits to the PRC. First, an AI-enabled automated manufacturing system would grossly decrease the relevance of China's population. In the short-term this would demand extreme economic adjustment, since China has some 17% of its population at least employed in manufacturing.[161] However, as the Chinese population shrinks, an AI system will become increasingly capable of taking the load off China's human workforce. Second, AI facilitates extremely granular economic, financial, and industrial intelligence collection. China's great advantage is the intentionality of state-led capitalism. This is meaningless *unless* the PRC can actually target market gaps and understand the leverage it builds – a task that would be infinitely easier with an AI collection mechanism. Third, advanced AI can become a potential Chinese export, particularly to authoritarian states that see Chinese tools as a means to control their population. Russia's Wagner Group is part of a broader system that provides a sort of dictator assistance service. China could compete with this through an AI surveillance system it exports or rents out to friendly powers.
- Semiconductors: The PRC remains a net semiconductor importer, which raises the costs of any Indo-Pacific militarised friction, since even absent a Taiwan contingency, the disruption to regional shipping would severely complicate China's digitalisation and consumer electronics manufacturing. Building market share in the semiconductors industry would allow China to increase international leverage *and* insulate itself from shocks, thereby providing it greater freedom of action.
- Advanced Telecommunications: An advanced telecommunications system allows China to build leverage abroad. However, its greatest benefits are likely long-term data integration. If Chinese telecommunications hardware is deployed at scale internationally, and if this can be linked to a central processing system enabled by AI and large-scale data storage in China, then the PRC's intelligence,

158.Data from World Bank, accessed via: link

159.Michael T. Owyang and Hannah Shell, *"China's Economic Data: An Accurate Reflection, or Just Smoke and Mirrors?"* Federal Reserve Bank of St Louis, (25 July 2017), accessed via: link; John Burn-Murdoch, *"China's GDP blackout isn't fooling anyone"*, Financial Times, (21 October 2022), accessed via: link; The Economist, *"How to measure China's true economic growth"*, (9 March 2023), accessed via: link

160.Diana Gehlhaus, *"China's AI Workforce Assessing Demand for AI Talent"*, Center for Security and Emerging Technologies, (November 2022), pp. 6-8; PWC, *"What will be the net impact of AI and related technologies on jobs in China?"* (September 2018), pp. 12-15; Data from World Bank, accessed via: link

161.Darrell M West and Christine Lansang, *"Global manufacturing scorecard: How the US compares to 18 other nations"*, Brookings, (10 July 2018), accessed via: link

> manipulation, and subversion techniques will become enormously more effective. This is combined with state support for national telecommunications champion Huawei, which has made solid inroads into European, African, Latin American, and until more recently British markets. As it stands, there are only limited Western alternatives to large-scale Chinese telecommunications providers, particularly for developing nations, providing China a potential structural advantage.

There has, as of yet, been no Western-wide coordinated response to Chinese activity. Indeed, any responses are cast either in the framework of industrial policy or of tit-for-tat trade-related retaliations. Both viewpoints misconstrue the issue.

The first salvo in Sino-American long-range competition came in 2018, with the Trump administration's tariffs on China. These largely failed to accomplish their objective before being wound down in 2020.

The First Trade War

Trump's major targets were heavy industry – the administration sought to reduce the Sino-American trade deficit and ensure American industry could isolate itself from Chinese competition.[162] The tariffs expanded, however, to include a variety of industries, including washing machines, solar panels, and eventually semiconductors. Advanced capabilities were considered in the context of the trade war, but only large-scale telecommunications projects had significant restrictions imposed upon them.

The issue with the US' Trump-era trade policy was one of strategic focus. The reflexive protectionism that the Trump administration's trade team had was perfectly timed politically given the US public's appetite for a more aggressive anti-China stance. Yet the objective of the trade policy was largely unclear. The US did not aim for a full decoupling, whether in the short or long-term, despite the aggressive rhetoric of the Trump administration.[163] But if there was a specific objective that the trade war sought, it was not obviously achieved. Putting aside the difficulty of measuring the actual economic impact of the trade war on the US – there are a number of conflicting studies that imply it both improved and disrupted the US economy to varying degrees – the reality is, beyond the Phase One agreement announcement ceremony in early 2020, there was very little obvious policy change on Beijing's part.[164] China continued the same practices that the US had accused it of conducting over the previous decades, including technology theft and various forms of market dumping. Moreover, China fell short of nearly every declared metric under the Phase One agreement, which was meant to ensure US exporters access to Chinese markets to correct the trade balance over time. Perhaps this would have changed absent the COVID-19 Pandemic, but generally speaking, there was little to no tangible policy movement on China's part.[165]

162. Yukon Huang, *"The U.S.-China Trade War Has Become a Cold War"*, Carnegie Endowment for International Peace, (16 September 2021), accessed via: link; Laurence Nardon and Mathilde Velliet, *"The US-China Trade WarWhat Is the Outcome after the Trump Presidency?"* (IFRI, November 2020), pp. 17-20.
163. On Trump's policy, see The White House, *"United States Strategic Approach to the People's Republic of China"*, accessed via: link
164. Phelim Kline, *"From 'momentous' to 'meh' – Trump's China trade deal letdown"*, Politico, (13 January 2022), accessed via: link
165. Chad P Brown, *"Anatomy of a flop: Why Trump's US-China phase one trade deal fell short"*, Peterson Institute for International Economics, (8 February 2021), accessed via: link; Eleanor Wragg, *"New data reveals failure of US-China phase one trade pact"*, Global Trade Review, (16 February 2022), accessed via: link

The Biden administration has taken a different tack by combining export controls and industrial policy. At the high end, the US has imposed a number of restrictions upon the Chinese semiconductor industry and build leverage over Asian semiconductor manufacturers Taiwan and South Korea.[166] On the low end, the US has instituted a broad industrial programme that bolsters American semiconductor and green technology development through the Inflation Reduction and CHIPS and Science Acts.[167] This has profound implications for the UK and Europe, given that neither can compete directly with a full-fledged American industrial policy.

American policy is reasonable in principle, but in practice, it misconceives of the competition the US and its allies face. The sheer amount of cash the US has allocated to expand its semiconductor industry, along with its broader investments in green technology, will show some results by virtue of mass. But there are no explicit carve-outs for American *allies*, the powers that will provide the US in a coalition with the aggregate innovative capacity and economic strength to survive a long-term competition, nor a linkages between semiconductor policy and other capabilities beyond specific AI development.[168] Over time, absent a coherent capabilities strategy, the US and its allies, including the UK, will simply lose traction, ceding crucial diplomatic leverage to Beijing.[169] Treating strategic competition as one of industrial production therefore misses the actual situation's granularity.

Equally relevant, current US policy is not geared to the generation of strategic alternatives for baseline large-scale infrastructure like telecommunications, nor a variety of cheap consumer electronics that will be necessary throughout the Western world and the Global South. The result is that, while Western producers may fill the gap domestically, with benefits to national resilience, there will be little concerted pushback against Chinese market penetration and fixed infrastructure investment abroad.

In turn, if a flashpoint escalates, critical national capabilities will be central to societal resilience. Ukraine's case has demonstrated this fact. Ukraine's implementation of digital governance in the 2010s allowed it to migrate the vast majority of its public data onto cloud servers and move it out of the country. Amazon Web Services had developed a device termed the "Snowball", a mobile, hardened cloud computing platform that could rapidly download data and be moved to a secure location.[170] Hardened satellite communications have also been crucial for military tasks, while cyber defences have been tested, most recently during Russia's cyberattack on the Kyivstar mobile network.[171] Hence accelerating critical capability development concurrently provides strategic insurance and long-term competitive benefits.

166. Sylwia A Lis, *et. al*., *"BIS Issues New Export Controls Targeting China's Advanced Computing and Semiconductor Sectors"*, Sanctions and Export Controls (Baker McKenzie), (24 October 2022), accessed via: link

167. Connor O'Brien, *"Is US industrial policy headed in the wrong direction?"* The Interpreter, (16 June 2023), accessed via: link; Scott Kennedy, *"China Is the Wrong Industrial Policy Model for the United States"*, CSIS, (9 August 2022), accessed via: link; Anshu Siripurapu and Noah Berman, *"Is Industrial Policy Making a Comeback?"* Council on Foreign Relations, last updated 18 November 2022, accessed via: link

168. Matt Hourihan, Mark Muro, and Melissa Roberts Chapman, *"The bold vision of the CHIPS and Science Act isn't getting the funding it needs"*, Brookings, (17 May 2023), accessed via: link

169. Jude Blanchette and Gerard DiPippo, *"Reunification with Taiwan through Force Would Be a Pyrrhic Victory for China"*, CSIS, (22 November 2022), accessed via: link; Samson Ellis, *"Here's What Could Happen If China Invaded Taiwan (Repeat)"*, Bloomberg, (7 October 2020), accessed via: link

170. Accessed via: link

171. Accessed via: link

4.3: The Concept of Cost-Imposition

In a competitive age, during which adversaries seek to use specific pressure points to disrupt the UK and its allies, it is necessary to recognise the role that the development of critical capabilities plays in *resilience* under the framework of *cost-imposition*.[172] Complex modern societies have a number of pressure points that nefarious actors can exploit, whether in data protection, critical infrastructure, or other contexts.[173] Moreover, while militarised confrontation is neither inevitable nor necessarily probable, the UK has recognised that, strategically, the odds of a major conflict have greatly increased over the past two years.[174]

The implication is that, during a long-term competition, a struggle between *systems* defines the rivalry. The point of strategy is to impose costs upon an adversary through continuous pressure or the accumulation of leverage points, and the compulsion to put resources into different lines of development that are ultimately extraordinarily expensive.[175] If both parties have finite albeit enormous resources, the objective of strategy is to induce the adversary to channel resources inefficiently.

Critical capabilities fit into this approach in two respects – one of *positive cost imposition*, one of *defensive cost reduction*.[176]

By developing and deploying critical capabilities faster than the UK and its allies, China seeks to force two policy choices upon the West. First, if Beijing can gain an edge in any critical capability line, it can force the US and its allies to race to catch up, pouring billions of pounds of investment into technologies with little long-term strategic objective.[177] Second, if China can *commercialise* certain technologies more rapidly, it can distribute them, and thereby gain pressure points in an international supply chain that disrupt or isolate specific members of the Western camp. In a long-range competition, marginal advantages – like whether Chinese owned PNT satellites are used in a geography, or whether China helps deploy advanced telecommunications infrastructure – are critical.[178]

Conducting a cost imposition strategy requires a well-crafted technology policy and a comprehensive focus on that policy's integration into critical national infrastructure. Without a national infrastructure system that is robust enough to withstand attacks today *and* flexible enough to employ new technologies that increase downstream resilience, an adversary can gain a decisive advantage. Ukraine's case is illustrative: Kyiv has been able to pursue workarounds to a variety of vulnerabilities, but there remain structural constraints around the vulnerabilities that can be limited because of infrastructure design.

Europe's response to American actions demonstrates the degree to which the UK's two major allies have yet to grasp the nature of geopolitical competition *and* to understand the critical capability imperative. Indeed, the longer it takes for Europe and the US to coordinate policy, the more difficult it will become for the UK to develop critical capabilities, leading to long-term lags from current policy divergences.[179] There is, moreover, some risk that Europe and the US see each other, if not as direct rivals in strategic terms, then as economic and technological competitors, reducing

172. Kenneth P. Ekman, "*Winning the Peace Through Cost Imposition*," Brookings, (May 2014), pp. 38-43ff.

173. Department for Science, Innovation and Technology, "*Cyber security breaches survey 2023*", (19 April 2023), accessed via link

174. Paul Schwartz, *"A War of Attrition"*, CSIS, (31 July 2023), accessed via: link

175. Gabriel Elefteriu, "*A Question of Power: Towards Better UK Strategy Through Net Assessment*," Policy Exchange, (November 2018).

176. Thomas G Mahnekin, *"Cost-Imposing Strategies: A Brief Primer"*, Center for a New American Security (November 2014), pp. 5-8.

177. Bryan Clark, Dan Patt, and Timothy A. Walton, *"The Department of Defense Needs to Relearn the (Almost) Lost Art of Net Assessment"*, The Strategy Bridge, (19 November 2020), accessed via: link; Andrew F Krepinevich Jr, *"Measures of Power: On the Lasting Value of Net Assessment"*, Foreign Affairs, (19 April 2019), accessed via: link

178. John Bateman, "*US-China Technological "Decoupling" – A Strategy and Policy Framework*", Carnegie Endowment for International Peace, (2022), pp. 73-74; J. Stewart Black and Allen J. Morrison, *"The Strategic Challenges of Decoupling"*, Harvard Business Review, (May-June 2021), accessed via: link; See Jonny Hall and Hugh Sandeman, *"NATO's Resilience: The First and Last Line of Defence"*, LSE IDEAS (May 2022); *"Resilience, civil preparedness and Article 3"*, NATO, last updated 2 August 2023, accessed via: link; Anna Dowd and Cynthia Cook, *"Bolstering Collective Resilience in Europe"*, CSIS, (9 December 2022), accessed via: link; Ann E. Hammer, Trisha H. Miller, and Eva C. Uribe, "*Cyber Resilience as a Deterrence Strategy"* Sandina Report 9589, (2020), pp. 11-15.

179. Clare Roth, *"EU to launch its own communications satellite network"*, DW, (18 November 2022), accessed via: link

their ability to coordinate development and ensure long-range strategic capacity-building.

The European response to American capability development presents an obvious set of risks under this context. For one, the EU risks capability replication. The EU is pouring cash into initiatives like the European CHIPS Act or its IRIS2 satellite programme to build sovereign European capabilities and increase market share. The danger is that Europe may never actually be able to compete. Theoretically, a wholly integrated European research, development, deployment, and industrial system would be an international juggernaut. But Europe is betting on the development of capabilities that may be out of date by the time the programmes that create them are completed. Hence the EU risks simply replicating plentiful and, by the mid-2030s, relatively low end capabilities, rather than accelerating high-tech capabilities. For another, the EU risks compartmentalising capabilities. There are remarkably few instances of integrated capabilities development between technology lines within the EU. Individual nations have sought to harmonise capability development, but there is no sign of a Brussels-level initiative to bring together several technological strands, with the moderate exception of advanced telecommunications and space-based capabilities. Another illustrative example is semiconductor policy, which is not being linked as it should to chips' wider applicability to other critical technologies. The obvious compartmentalisation of research systems, along with the lack of any obvious research and development clustering, will continue to hobble the EU's ability to deploy capabilities rapidly.

4.4: British Options

British capabilities strategy must be guided by the realities of political competition and of allied investments and strategic mistakes. The UK has several advantages, including market size, an ability to leverage the market to create a robust funding and coordination system, and the capacity to use capabilities as a leverage point with allies. The art will be balancing capabilities and a desire to establish a leadership role with the UK's financial constraints.

Three capability areas are at long-term risk. Chinese baseline *telecommunications development* threatens to outcompete and capture crucial third markets essentially without a fight. Chinese *quantum development* is catching up to that of the West – when combined with its world-leading *advanced telecommunications* providers, there is serious risk in the next 10 years that China pushes ahead in large-scale quantum technological deployment. Second, the scale of Chinese investment in biotechnology, pharmaceutical production, and advanced engineering biology poses a structural risk to the UK and its allies, particularly in light of the COVID-19 Pandemic's lessons in biosecurity and the relevance of biological capabilities access.

The UK has three structural advantages – these advantages should be taken neither as unimpeachable nor fully actualised, given the current state of British policymaking and machinery of government:

- *Market Size and Early Deployment*: The British market is relatively small compared to that of its major allies, the US and the Europeans. It is also obviously smaller than that of China, Russia, and India. However, the UK's relative market size, combined with the high-tech and digitalised nature of its economy and society, provides it with a potential advantage. Larger powers may struggle to phase in certain advanced capabilities deployments, particularly when it comes to telecommunications, simply because they have a much greater fixed cost. The UK's market size allows for capabilities deployment at reasonable scale – for example, the integration of a new genomic technique into NHS care, the use of a handful of highly-accurate PNT satellites for communications and navigation, or the acceleration of a quantum communications network around London – in a test market that actually resembles other high-technology economies. The Procurement Bill, which has nearly passed through the House of Lords amendment stage, has paid prudent attention to the importance of opening access to SMEs across the various stages of government technology acquisition. With the implementation of the new Procurement Bill, measures such as making contract opportunities easier to find, and removing the requirement for all bidders to proffer audited annual accounts and insurance for not-yet-awarded projects, will go a long way to activating the SMEs providing crucial early-mid stage technological development.[180] In turn, this allows the UK to build its domestic industrial base, and then an export coalition around other smaller powers like Australia and Japan, and perhaps Canada as well.
- *Market Size and Supportable Actors*: Particularly in the context of telecommunications, the UK's market size does create the potential for actors that can be bolstered internationally through careful policy development and regulation. Given the natural monopolies that arise, this creates an incentive for highly diversified operations amongst major telecommunications operators.
- *Potential for Policy Responsiveness*: Because the British market is smaller than that of the major powers, the UK *could*, with a properly designed machinery of government, actually have coherent and responsive policy in a number of capability areas. There are signs that the UK policy community is moving in this direction through documents like the Integrated Review and its 2023 Refresh, along with the national technology strategies that have been published over the past 24-36 months. There is, of course, significant room for improvement, not least the need to coordinate these cross-sector developments at a single government cohering level, as will be discussed in the recommendations.
- *Research Base and Commercial Opportunities*: British financial capabilities and world-class universities allow for a direct pipeline between research and financing for commercial deployment *if* the UK can ensure a start-up ecosystem exists to translate a variety of

180. House of Commons Library, "*Procurement Bill 2022-2023*", (5 January 2023), *pp.* 71-72.

technologies into practice. This is vital, as it would empower investment banks, VCs and other private funders to catalyse the accelerated progression from research and development stage to commercialisation. As outlined above, this is the central task for building national resilience through avoiding technological monopolisation by adversarial competitors and ensuring that the UK has a say in emerging regulatory frameworks. For higher fixed cost technologies, a similar approach could be taken that ensures their direct funding by government-led schemes to ensure their deployment.

Delivering UK objectives demands four broader framing shifts in UK policy.

First, the UK must be willing to use technology policy and the development of critical capabilities as a leverage point for other issues. Linkage, the policy of connecting a variety of policy questions together to encourage progress on a broad front, is relatively foreign to modern diplomatic sensibilities, and uncommon for technology. But if the UK is to actualise its leverage that it can build through critical capabilities development, it must use capability incentives to ensure access to other markets. This need not sit uncomfortably with liberal pro-market sensibilities, for state encouragement of comparative advantage is a founding principle of classic political economy. In fact, in this way the UK can use access to its critical technologies and investment base as a means of encouraging allies to align with our wider grand strategy via market mechanisms.

Second, the UK must be capable of gathering consensus and momentum for broader discussion from actors beyond its large traditional allies, the US and the Europeans. The US and Europe may be the most relevant of the UK's allies, but there are others that could provide sufficient pressure to push the Atlantic powers towards a constructive consensus. They include the other Anglosphere powers, along with the other members of the G7 and South Korea. A concerted effort to work with the "second tier" of powers beyond the US and EU, along with a forum shift, could generate the gains needed to encourage a reasonable trans-Atlantic policy. The AUKUS agreement is the most obvious model for this techno-economic cooperation, which compels expedited progress on Pillar 2 tracks to prove the merit of pursuing similar multilateral frameworks with other states. Whether or not the UK, the US and Australia cut through the bureaucratic and cognitive obstacles impeding rapid technological sharing, in time to respond meaningfully to Chinese competition in the Indo-Pacific, will set the tone for future critical capability cooperation.

Third, the UK must be willing to, in a handful of circumstances, get out in front of its major allies on certain capability deployments for the first two policy benefits to exist. This demands a handful of big capability bets. The UK will not build leverage purely through a superior development ecosystem or research base. It needs to demonstrate results through a handful of cutting-edge technological breakthroughs that are rapidly translated into actual capabilities deployment in at least one technology stream.

Fourth, the UK must identify the opportunities that its market consolidation presents it. Specifically, the UK has a number of infrastructure providers that can be used to scale and implement new technologies for export. This is a model rather alien to the British system, not because of market instincts per se, but because of an unwillingness to understand the British economy as a set of leverage points that can be exploited for strategic gain.

A coherent British capabilities policy will only become more important as international supply chains and technological development bifurcate even further. This bifurcation has accelerated over the past two years, with examples on the high and low end of the development chain. On the high end, Russia and China have increasingly decoupled their space-based developments from the West, and are turning to each other to accelerate their capabilities deployment, particularly in PNT satellite deployment. Beijing is also busy restructuring Indo-Pacific undersea cable networks by laying new cables owned and controlled by Chinese entities. This may well bifurcate the regional and indeed global fibre-optic cable network, immunising China from any disruption caused to Western undersea systems by hostile interference.

On the low end, China's recent UAS export controls will make it extraordinarily difficult for British, American, and European firms to purchase Chinese small drones, which still dominate the global consumer market.(REF) Instances like this will only increase in number over the coming seven years, until portions of the Chinese and American supply chain become disjointed enough to enable fully independent and diverging capabilities. The UK must act now to begin to shift the strategic perspective of its allies, or risk the entire bloc becoming fragmented and, in a reasonably rapid timespan, falling well behind.

The UK's International Technology Strategy points towards these concepts. It is particularly strong in encouraging international collaboration, and leveraging UK leadership in organisations like the International Telecommunications Union to ensure British policy development globally.[181] Yet the diplomatic levers it outlines subsequently are underdeveloped, primarily because as a policy document, the International Technology Strategy is both ambitious and unique, with few international analogues.

181. Ben Jiang, *"China's drone industry crosses US$14-billion mark in annual output in 2022 amid local market expansion into low-altitude logistics,"* South China Morning Post, (5 June 2024), accessed via: link; Simone McCarthy, *"China curbs drone exports over 'national security concerns"*, CNN, last updated 1 August 2023, accessed via: link

182. Accessed via: link

5.0: Recommendations

The following recommendations are grouped into four streams: infrastructure and resilience, export controls, long-range forecasting, and international collaboration. When taken together, they provide a comprehensive foundation for the UK to ensure its strategic technological advancement. The below can be viewed as building off the launchpad that the International Technology Strategy provides.

5.1: Infrastructure and Resilience

1) The UK should accelerate its push for diversified suppliers for fixed infrastructure to reinforce resilience.

The UK has recognised the vulnerabilities that its current infrastructure system faces in the context of foreign suppliers, especially for telecommunications. However, a more aggressive effort is needed. This should involve an open dialogue with industry to identify the most relevant areas in need of redundancy, alongside a viable pathway with international partners to remedy these gaps.

2) Large-scale telecommunications investment should be incentivised, along with a recognition of the way in which UK market structures modify private incentives.

UK telecommunications policy as currently designed does not take account of the actual market structures at play. In any context, telecommunications is a capital-intensive industry. In the UK in particular, considering relatively compressed market scope along with geographical variation, British telecommunications providers must consistently feed in growing amounts of capital to sustain current infrastructure, let alone expand it. The UK should explore tax structures on telecommunications producers that reduce the burden on them insofar as possible.

3) The UK should revamp its resilience strategy in light of lessons from the past two years.

The Ukraine War demonstrates the need for a forward-looking, that is, insofar as possible future-proofed against potential threats. The UK's resilience framework, published in 2021, made a good start towards actually considering issues of risk to national infrastructure and the potential for societal disruption.[182] However, it is far too vague for actual actionable proposals. More critically, it was written before the events of 2022 and 2023 demonstrated the full range of threats that could present themselves against societal resilience. This means it also lacks any sort of retrospective assessment from the Ukraine War and Ukrainian experience, creating a massive lacuna of practical information that can be built into a redr5afted policy. Additionally, the strategy's implementation timeline is far too long, and should be advanced to at latest 2028.

4) The UK should craft a new export strategy that emphasises critical technology areas and national infrastructure.

The UK does now have a formal export strategy that dovetailed with the government's previous policies on AUKUS and other trade developments.[183] However, a revamped strategy, with a real understanding of export opportunities and focus on infrastructure and technological competition, would be immensely beneficial. The UK could highlight critical infrastructure export opportunities, seeking to build international leverage by supporting its national champions.

5.2: Export Controls

5) A new export control framework should be developed for critical capabilities, with the UK taking the lead.

A long-range strategic competition with technological development at its heart will demand a careful reappraisal of the UK's export control framework. Innovation and development is undeniably the more critical piece of the puzzle, since both sides in this competition are attempting to impose costs on each other through technological deployment. But export controls remain relevant, since the ability of British competitors to free-ride off UK innovation, in a period of strategic competition, is not simply an economic problem, but a potentially fatal political challenge.

The UK must reconceptualise its export controls, going beyond the traditional remit of military equipment and dual-use items. The UK should review all critical capability areas and craft a variety of restrictions upon information-sharing between its researchers and corporate actors and those in other countries, namely China and Russia. The current export control system is extremely leaky, hence Imperial College London academics unwittingly assisted Iranian engineers in improving the Shahed-136 loitering munitions currently used to bombard Ukrainian cities.[184]

Although the UK could develop an export control framework, it need not implement this framework immediately. Indeed, the UK's financial intelligence and export control system must be scaled up and prepared for a host of new private-sector questions. It must be targeted to ensure that British partners are exempt, per the following recommendation. And it must be deployed at the right time – not ahead of major allies, but in

183. Accessed via: link
184. Accessed via: link
185. Gabriella Swerling and Louisa Clarence-Smith, *"The 11 UK universities accused of helping to develop Iran's 'suicide drones'"*, The Telegraph, (8 June 2023), accessed via: link

concert with them, since a major export control system is not a step that the UK can take independently.

The National Security Investment Act (2021) could form the basis of this export control framework. It has already been used to scrutinise and block acquisitions in the semiconductor industry.[185] The new framework, however, is extremely vague as to its definition of national security concerns and has a poor reporting system. Moreover, the Government is considering certain sector-specific regulations for semiconductors and critical minerals, but there is no evidence as of yet for a broader technological regulatory regime.[186]

6) An export control framework is necessary for quantum technologies, particularly for quantum telecommunications, and engineering biology.

Historically speaking, the UK has had an aversion to any high technology export controls, particularly over quantum and engineering biology. The US is building an export control framework for quantum technologies, but its current system is extremely compartmentalised. The EU has no such framework. Moreover, despite the post-COVID-19 rhetorical focus on biosecurity, there is no apparent coherent framework for restrictions on engineering biological technology transfers.

UK leadership on the framing for export controls in both capability sets would position it to drive American and European policy. Both actors have considered some sort of system, but have not yet found a proper place to start. This system must, however, include carve-outs for partners, particularly in the G7, as will be discussed in the final recommendations section.

5.3: Long-Range Forecasting and Strategic Planning

7) The Cabinet Office should stand up an office of long-range technological and economic forecasting.

The UK has begun to adopt the North American net assessment technique, an invaluable strategic planning tool for long-range political competition. The Secretary's Office of Net Assessment and Challenge (SONAC) has begun to make headway in the Ministry of Defence, including through its oversight of the Defence Command Paper Refresh. Although many bureaucratically-produced analytical documents have limited policy value, a Net Assessment function is immensely important.

The Net Assessment methodology centres upon analysis of long-range technological, political, and strategic trends to shape defence policy over the course of decades, well beyond the viewpoint of a standard policymaker whose considerations are governed by annual and half-decadal budgetary documents. It is a synthetic approach that goes beyond the technical and physical, placing questions of doctrine, force employment, and command

186. Accessed via: link
187. Accessed via: link

at the heart of its research.

There has yet to be a serious attempt to apply Net Assessment beyond relatively strictly defined military questions. However, the US DOD's Office of Net Assessment routinely conducts studies on questions well beyond that of traditional military power, to include both technological trends and economic issues. Indeed, the foundation of much modern understanding of advanced military technology stems from a series of now-declassified research undertaken in the immediate aftermath of the First Gulf War.

Critical capabilities development, as an aspect of long-range technology policy, would overwhelmingly benefit from a Net Assessment methodology. Indeed, much of this report is an attempt to outline how Net Assessment might provide intellectual benefits to the creation of technology policy that go well beyond the invaluable but incomplete technical economic and scientific assessments that traditionally govern technology policy.

There have been attempts to stand up a sort of scientific forecasting organisation within the British government, most recently the Futures, Foresight, and Emerging Technologies programme (FFET).[187] However, there are a number of obvious drawbacks for the purposes of geopolitics.

First, the FFET system's scientific focus is concurrently too narrow and too broad for actionable long-range policy planning. Current advisory practices borrow very heavily from management sciences methodologies to some benefit, but generally speaking the way they cast "horizon scanning" is not subject-specific, but rather a highly generic way of assessing technological change.[188] The examples used to justify the methodology demonstrate a preference towards analysis *qua* analysis, rather than substantive information that feeds into long-range policy planning. Similarly, the system's narrowness *only* focusses on scientific processes when conducted in the British government, which makes it improper for a period of legitimate, robust geopolitical rivalry.

Second, FFET's methodology is based on a synthetic theory of "horizon-scanning", rather than a particularly practical or tangible set of processes for actual forecasting. The literature on Futures Studies is extraordinarily opaque, primarily because Futurism, the basis for the Office of Science's methodology, has lacked a significant amount of rigour since the 1980s. This is not to discount the potential role of futurism in long-range policymaking and forecasting. Rather, there is a gap that must be filled *alongside* the current Futurist bent in Government.

Third, FFET's general support model, and the Government Office for Science is neither institutionalised nor structured enough to match forecasting to strategic policy. Put simply, it is not clear whether the Office for Science, and FFET in particular, has anywhere near the degree of administrative and bureaucratic independence to assert itself institutionally and conduct the long-range assessments of British policy required for the Foresight system to work. This is unsurprising. The UK's SONAC has not been used properly, and is generally focussed upon day-to-day or medium-term policymaking, rather than the real substantive intellectual work behind strategic development. Yet there is

188. This is a non-standard acronym, but abbreviation is necessary within this section.

189. Government Office for Science, *'Trend Deck,'* (Spring 2021), emphasis pp. 114-124; see also the extraordinarily generic assessment of forecasting mechanisms in '*Features of effective systemic foresight in governments around the world,'* School of International Futures, (April 2021), pp. 72-78, a report commissioned by the Government Office for Science.

simply no understanding within the UK's science policy system of the benefits that a more assertive analytical body might provide because there are no obvious analogues to it.

Fourth, FFET is far too public to function as it should. Much of the information in a properly-designed geopolitically relevant technology forecasting programme would be classified. An office envisioned as such would require access to the UK's intelligence and diplomatic services, and in turn, push them to broaden their focus technologically. As it stands, FFET and the Office for Science are public-facing bodies that largely seem to operate in the open-source. An enormous aspect of any geopolitical technology policy is assessment of the actions of other actors, particularly those that may wish to do the UK harm down the line. As it stands, there is no organisation equipped to conduct such assessments within the British government.

None of this is to say that the Government Office for Science or the FFET programme should be eliminated. Both must be continued. They serve invaluable strategic and, of equal relevance, *cultural* roles in tilting the British policy establishment towards a new scientific-technological footing. Subject-matter literacy is a crucial factor in developing a coherent technology policy, which both efforts help cultivate.t would be prudent to establish an exploratory Net Assessment-style cell within either the Department for Science, Innovation and Technology, or the Cabinet Office itself. This small initial team would be tasked with presenting a handful of analytical products on critical capabilities, through the framing of geopolitical contestation and the resilience imperative. A Net Assessment technological-capabilities function would begin the work of reorienting British policymaking around long-term questions without thoroughly disrupting the current machinery of government until there is demonstrated value to facilitate interdepartmental buy-in. It would also require only a limited initial financial cost, a few million pounds over a three-year period, to enable the solicitation of studies on critical capabilities questions.

8) The UK should create national early warning system that includes an AI-enabling component.

Comprehensive critical capabilities policy with an eye towards resilience is an immense undertaking, not simply because of the potential costs it would demand, but rather because it requires the British government to synthesise a tremendous amount of data. Even from the point of view of consistent strategic monitoring for threat response, critical capabilities development demands a more effective strategic early warning system.

A properly constructed National Early Warning System would focus not only, and in some respects not particularly, on immediate conflicts and moments of volatility. Indeed, the UK's current intelligence system – as the run-up to the Ukraine War demonstrated – is actually remarkably effective, a testament to the UK's world-class foreign service and intelligence professionals.

What is needed, rather, is a focus that connects the day-to-day to an understanding of longer-range volatility and disruption. A National Early Warning System that leveraged data from various critical capabilities, particularly an advanced telecommunications network and AI, would be capable of identifying patterns in a complex threat environment more accurately than human analysts.

5.4: International Collaboration and Focus Areas

9) The UK's strategic objective in its diplomatic interactions on critical capabilities should be using its capabilities to enable its role as a convening power.

Recent strategic documentation has indicated the UK's ambition to serve as a convening power, a state that is capable of drawing in more powerful international actors to structure long-term collaboration and policy harmonisation. This explains the UK's focus in the 2021 *Integrated Review* on science and technology, and in turn, the emphasis in the 2023 *Integrated Review Refresh* on shaping the international environment.

The UK did implement an active convening strategy for around six months, strictly in diplomatic contexts. This included significant successes – the Trilateral Polish-Ukrainian-UK pact that enabled military aid to Ukraine during the first weeks of Russia's full-scale invasion, the donation of major military equipment prior to this, and then-prime minister Boris Johnson's visit to Kyiv in April 2023. All these steps laid the foundation for a comprehensive transatlantic policy towards Ukraine at a crucial juncture, when several Western European powers, and voices in Washington, showed signs of *de facto* capitulation in the face of Russian military aggression.

Well over a year into the Ukraine War, other events and strategic drivers have taken centre-stage, in part because the UK was incapable of maintaining a robust international role in light of a variety of economic and domestic-political challenges. The specific set of policies that enabled British strategic leadership cannot be resurrected because the political and military circumstances that the UK faces have shifted since that point.

However, the general model of British policy as pursued between November 2021 and April 2022 remains sound as a basis for long-range British strategy. Specifically, the UK *cultivated multiple leverage points* with major allies and smaller powers, *deployed its tangible capabilities only sparingly* to amplify the rhetorical, diplomatic, and political steps it took, and *integrated these activities* into a coherent policy whole that demonstrated a consistent grand strategy.

The UK should locate its capabilities policy within a broader grand strategy that seeks to position it *between the US and Europe*, while leveraging connections to the *G7 and other smaller powers, including those in the Anglosphere*.

As the subsequent recommendations articulate, the UK should link its technology policy to its foreign policy more broadly, thereby ensuring that it can translate leverage in one area to strategic results in other areas. Acting as a convening power should generate benefits across the entire British foreign policy portfolio, and allow the UK to shape allied policy in the long-term.

10) Achieving the objective of becoming a convening power requires a leading data security system through a quantum-secure telecommunications network.

The difficulty of quantum technological development actually speaks for quantum technology as a commercial strategic focus for the UK. If the British government can craft the right quantum policy that accelerates quantum technological deployment, particularly by generating a quantum-encrypted telecommunications network, then the UK would gain a dominant initial position in the advanced telecommunications market for export *and* attract any corporate actor that sought data security in a well-developed financial market. In turn, a quantum telecommunications network would thereby accelerate information-sharing across other capability areas given its improved security.

11) The UK should establish domestic biomanufacturing as a strategic focus.

The UK's research base and the fundamental reliance that Europe still has upon British research centres and academic institutions for engineering biology and biotechnology more broadly, means that a biomanufacturing industry in the UK would provide broader geopolitical gains. Moreover, British market size also ensures that innovations could be translated and deployed in a smaller population more rapidly than in larger countries like the US. Additionally, the UK remains immensely reliant upon inbound medical imports. A biomanufacturing system would have the benefit of ensuring that British medical supplies are somewhat domestically sourced.

The UK has explored some transnational biomanufacturing initiatives in the past, including the recent British-Canadian advanced therapies grant competition.[189] However, funding remains relatively limited and diffuse across specific scientific and technological initiatives. A coherent commitment to biomanufacturing that includes tax incentives for British and foreign firms, and research grants tied to commercialisation incentives, would leverage the UK's engineering biological expertise to ensure a vibrant ecosystem.

12) The UK should establish as a policy goal the objective of hosting as much international research on relevant capability lines as possible on UK servers.

190.GOV.UK, *'Canada-UK: Biomanufacturing of Biologics and Advanced Therapies,'* (26 June 2023), accessed via: link

A quantum network as outlined above would make the UK the natural location for allied critical capabilities research and development. In turn, the UK's strategic focus on engineering biology and quantum technologies would enable two initial data pooling lines: one on biotechnology, one on quantum development. The UK could host a US-UK-European bionetwork, and a quantum research network, as the lynchpin convening power in both cases. Nominating itself as the intellectual hub of these emerging technologies would exert a gravitational effect on subsequent research and development initiatives and, crucially and subsequently, on investment flows. As has been reiterated throughout this paper, the long timelines involved in new-age technology affords great advantages to early movers in the first stages of development which, if navigated artfully, can offset wider structural disadvantages pertaining to market size and financial resources.

13) The G7 should be the UK's primary effort line for transnational technology policy. There should be a handful of additions, particularly in light of below recommendations.

A strategic focus on the G7 for critical capabilities development provides the UK with two strategic advantages. First, the G7 includes the world's most financially capable and innovative economies, placing the US and several Western European powers alongside Japan and Canada. This bloc in and of itself can form the foundation of a new international system, one that transcends historical structures that include a significant amount of strategic detritus. Emphasising capabilities development across the G7 would allow the UK to link broader diplomatic and strategic efforts to its technological strengths. This has a reasonable chance for success particularly because of the combined wealth that the G7 powers can bring to the table, ensuring a legitimately pooled investment scheme for certain capabilities. All G7 members, moreover, are vulnerable to the sorts of pressure that a robust critical capabilities suite would mitigate.

Second, the G7 nature as a forum of *individual powers* is useful to the UK in the short-term, and reinforces the UK's ability to make itself indispensable to the European research and development ecosystem. The EU is, of course, an informal G7 member, but the bloc's major actors are all national governments. This enables the UK to attenuate the portions of its research system that are actively integrated into, in particular, the French and German economy. The goal is not to replace the UK-EU relationship with a number of bilateral relationships, but rather to build leverage in bilateral relationships that redounds to a broader, more beneficial UK-EU partnership. This is particularly important when it comes to engineering biology considering Europe's long-range developmental difficulties.

14) The US should be the UK's primary engineering biology partner.

The US has the biotechnology funding to ensure that British innovations can actually be brought to market, and has an obvious and growing interest in the operationalisation of biotechnology. The UK is the Euro-Atlantic area's engineering biology research hub, and can thereby provide a bridge between the US and Europe. This strategic approach reinforces the above recommendations to focus on engineering biological development and build leverage within the EU.

15) The UK should look to middle powers for initial deployment of advanced telecommunications, particularly Australia and Canada.

As previously discussed, the difficulty of quantum technology in general is deployment – getting developments out of the lab and into the commercial sphere takes time, money, and policy focus. The EU's struggles with quantum telecommunications in particular stem from these deployment difficulties, and in turn, the scale and complexity of a cross-border network. The UK should partner with smaller Anglosphere powers, Australia and Canada, because they share similar enough market characteristics to the UK to ensure that all three states could deploy this system before larger powers, thereby serving as reasonable test-beds. Partnerships with smaller powers also builds leverage beyond the US and EU, ensuring greater coherence in broader policy.

16) The AUKUS agreement's Pillar 2 is the litmus test of such techno-economic partnerships, and so greater focus is needed on progressing this track quickly

Pillar 2 comprises mutual capability enhancement and market exposure in seven identified 'advanced capabilities', including AI and quantum. As the agreement enters its third year, it is therefore incumbent upon the UK to work with its allies to prove the strategic, technological and economic merit of such multilateral frameworks, in order to promote similar endeavours in the future.

17) The UK should advocate for a joint financing mechanism to accelerate technological deployment for all critical capabilities.

Critical capabilities are extremely expensive and demand concrete national governmental commitments even if the private sector provides most of the financing. Only a transnational framework for development and deployment can ensure that the technologies needed for resilience and growth can be placed in broader circulation.

The UK should therefore lead the way in developing a number of transnational financing mechanisms for each critical capability area. This would begin to break down the industrial policy mindset that currently governs the development of European and American critical capabilities by placing the need for a collective research ecosystem and market at the centre of policymaking concerns. Bolstering cross-border investment to the necessary extent is therefore dependent on a strategic recalibration as states must acknowledge that, whilst their national capabilities are important, so too is the technological strength and resilience of their allies. The UK must lead the way in this cognitive shift to discredit the false binary – as is currently illustrated by the US and EU's divergent policies towards semiconductors – between developing national resilience and mutual capability enhancement in sensitive technologies

6.0: Conclusion – Geopolitics and Technology Policy

A geopolitical technology policy remains foreign to the UK, even if, as we have now understood, it has been crucial to the UK's survival and sovereignty for some time. The question now confronts us: what occurs if the UK does *not* adopt a geopolitical technology policy, and instead neglects and sort of coherent framework for critical capabilities investment, and refuses to bolster the security, resilience, and sophistication of UK national infrastructure?

The dangers are threefold.

First, there is the obvious possibility that the UK and all its allies simply fall behind. In this future, China makes a series of breakthroughs in at least three capability areas, and thereby gain leverage over a number of non-Western countries. This enables market penetration into Europe and North America. Commercial funding lines shift decidedly eastward, until the UK and European powers are faced with the choice between potential impoverishment or cooperation with a technological system led from Beijing. Over time, the Special Relationship deteriorates, either as the US becomes increasingly wary of any international technological and economic contacts, or as the US is locked out of foreign markets. Regardless, the trans-Atlantic economic and security structure that has sustained the UK since the early 20th century will slowly dissolve. Unable to decisively determine its future, the UK's fate will be determined not in Europe, but by the Asian powers.

Second, there is the possibility of bloc fragmentation. Europe and the US pursue industrial policies that are bound to be in tension by virtue of their mutual objectives and long-range preferences. These policies will, over time, separate European and North American technological development, creating entirely distinct ecosystems, and forcing the UK to choose in the long-term between one or the other. The UK gains different benefits from its American and European relationships, but they are fundamentally complementary for British policy. Removing one threatens the other. Hence even if Western transnational technological development continues, and critical capabilities are deployed beyond the UK, there remains a serious risk that the UK simply falls through the cracks and is left behind in the long-term, unable to shape European or American policy or advocate for its interests.

Third, there is the possibility of European or American breakthroughs that lead to a nefarious sort of dependence. The US and Europe are obviously advantaged by their larger market size and financial capacity. But if one or both of them simply surges ahead with capabilities development and begins to export this development absent British leverage over the project, the UK risks becoming hostage to one or the other camp. Even worse, the UK may become a technology battleground between multiple powers, undermining its relationship with all players involved.

Critical national capabilities take decades to develop, while implementing them in a societal context requires a well-cultivated delivery environment. The most important choice in the 2030s were made in the late 2010s. The central choice of the late 2030s and early 2040s are thus being made today. Absent a coherent, geopolitically minded technology policy that encourages the development of critical capabilities in a strategically sound manner, the UK actively accepts the possibility of disruption, and the probability of political marginalisation.

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