How Geopolitics is Changing the Economics of Innovation

Aaron K. Chatterji *   Fiona Murray†

April 2025

Abstract

This paper argues that the significant geopolitical shifts of the last decade require a new approach to studying the economics of innovation. We document that national governments increasingly seek to control critical technologies rather than encouraging diffusion globally. This dynamic is reshaping the direction of, participation in, and scale of innovation around the world. To enable greater control, nations are creating new institutions to shape the innovation ecosystem, guided by the logic of economic security as opposed to only the traditional metrics of efficiency and cost. We demonstrate the impact of this shift on the development of three technologies: quantum computers, advanced semiconductors and fusion energy systems. We provide several implications for economists studying innovation as they develop new research questions and seek to explain the rate and direction of innovation in this new paradigm.

*Duke University Fuqua School of Business and NBER
†MIT Sloan and NBER

1 Introduction

Over the last 40 years, economists have developed extensive evidence to support the crucial role that innovation plays in driving economic growth. Accordingly, there has been increasing scholarly interest in the rate and direction of technological progress that facilitates that economic growth. But most of this research has been undertaken in a relatively stable geopolitical context. In the post-World War II era, economic growth occurred across many parts of the world, but always in the shadow of the uneasy stability of the Cold War. The fall of the Soviet Union ushered in a new era also characterized by a new version of predictability, with the United States as the sole superpower shaping geopolitics and driving the global innovation economy. Even as Japan rose as an economic competitor in the latter half of the 20th century, this ascension never created serious geopolitical tensions, in part because Japan lacked a formidable military and did not have superpower ambitions. After the dawn of the 21st century, the national security challenges of the post-9/11 era mostly presented asymmetric threats such as Al-Qaeda, which could inflict significant harm, but ultimately did not establish technologically sophisticated alternatives in the form of weapons or other parts of the innovation economy, such as advanced computing.

In this broad global context, and prior to the rise of China as a military and economic power, the economics of innovation traditionally focused on how, in a globalized and largely unipolar world, government policies could be deployed to accelerate the discovery of new ideas and enhance the speed at which commercialization could be accomplished - not only by incumbents but also by new entrants whose response to competitive opportunities ensured that waves of new innovations would be scaled into products serving large swaths of consumers and businesses. Along the continuum from idea generation to commercialization, scale-up and growth, certain geographies might be favored for R&D or production due their endowments of human capital or natural resources but the positioning of such advantages and the supply chains that connected them were typically dictated by efficiency and cost. Against this backdrop, specialization and comparative advantage have served as the key principles guiding "who" does "what" and "where", with respect to global innovation.

Academic research on the economics of innovation historically focused on central questions that aligned with this relatively stable geopolitical context that facilitated the globalization of innovation; What is the geographic distribution of technological expertise? What are the underlying drivers of this expertise? To what extent do policy interventions shape this distribution through the institutional context for technology development and commercialization? How does the organization of scientific inquiry - in terms not only of levels of public and private funding but also of policies for intellectual property - shape innovation? And how do market structures and competition policies shape these outcomes?

The innovation topics that have been most studied by economists also emphasized the so-called 'high tech' industries that formed around advances in (1) biotechnology - where the United States developed a formidable early advantage with the spin-out and formation of firms such as Genentech, Biogen, and Genzyme, - and (2) information and communication technologies (ICT) - largely dominated by Western firms today known as FAANG (Meta, Apple, Amazon, Netflix and Google) and Microsoft. These American companies have clearly built on the significant investments in R&D by the U.S. government, and have been enabled by a predictable set of rules and regulations, albeit with a range of antitrust challenges over the past several decades. The era of predictable geopolitics preceded the seminal work edited by Nelson (1962) on the rate and direction of technological advance and held for nearly five decades up to a follow-up volume that revisited Nelson's ideas (Lerner & Stern, 2012). This stability provided innovation economists the luxury of holding key variables fixed, to the point that politics and geopolitical dynamics often faded into the background.

That predictability is now giving way to tremendous uncertainty. The rise of China as an economic and military superpower has created a new paradigm in geopolitics. We now live in an era that will be shaped by superpower competition between the U.S. and China, which has been widely documented by economists, political scientists and media commentators (Nye, 2023). Further, against this backdrop there have been increased tensions and complexity in the relationship between the U.S. and its traditional allies in Europe and in the Pacific (e.g. Japan and South Korea). For scholars studying innovation, it is essential to examine how this new era of geopolitics will redefine the core questions that must be addressed in order to support effective innovation policy and strategy in high-tech industries. We argue that because geopolitics is radically changing, so must the economics of innovation.

National security concerns are beginning to play a larger role in economic policy and business decisions around the world. This shift in priorities introduces new externalities to economic models and questions traditional assumptions underpinning how economists understand the innovation process. In particular, these externalities focus on shaping and controlling the direction of the innovation process towards specific goals and towards specific geographic locations. Notions of technological sovereignty - i.e. the ability of a nation to control the entire innovation process that links inventive activity to the production of a technological capability - have become increasingly salient in debates over innovation policy. Indeed, many nations are now seeking to control the rate and direction of innovation so as to build innovative new technological capabilities and develop national expertise that limits reliance on others. Rather than assuming that comparative advantage lies in having narrow areas of expertise and specialization (e.g., at the early stages of innovation while allowing other nations to host production and supply chains), nations now increasingly seek to control innovation from idea through to deployment at scale in a wide range of technological domains. Where this "full stack" approach is not feasible nations seek control within narrowly constrained partnerships and alliances. Once relevant only with respect to nuclear technologies (and a handful of other specialized arenas such as cryptography), discussions of sovereign control over innovation are now expansive and growing. For economists to understand how this new technological landscape will be developed and by whom, and how innovation policy will shape this terrain, we will need to consider rising concerns about national security and its downstream effects on economic policy, human capital flows and private sector incentives.

At the same time as the geopolitical landscape is shifting, there is another, simultaneous shift in terms of what kind of technology lies at the core of the most important and economically relevant innovations. The technologies that are being pioneered today that are essential to solve a range of national and global challenges are distinct from the earlier era in which the economics of innovation was pioneered. Unlike the Internet, software-as-a-service (SaaS), and social media, the technologies of this new era are dependent on hardware as well as software. They are based on research at the frontier of knowledge across a wide range of scientific disciplines. This set of technologies continues to include the life sciences to solve medical challenges but has expanded to the landscape of so-called "deep tech" solutions in energy systems, communications systems, and defense (from the seabed through to space) to solve the challenges of the modern world. These technologies build on the foundations of chemical, material and physical sciences, not only computer science. As a result, nations are seeking to assert control over direction of, participation in, and scale in an array of priority technologies ranging from quantum computing, nuclear fusion, semiconductors and general artificial intelligence.

In this new technological and geopolitical context, as the deep technology revolution unfolds alongside a geopolitical paradigm shift, innovation economists must refresh our intellectual agenda. In the subsequent sections, we develop this argument further by explaining the increased coupling of geopolitics and technological innovation (often referred to as the rise of "economic security" (Friedberg, 2019)). We then outline three dimensions along which the economics of innovation has shifted with the return of geopolitics and rise of deep technology: the direction of innovation (i.e. the focus on specific technologies and trajectories), the participation in innovation (i.e. which people and organizations are empowered or limited in participation), and the scale of innovation (i.e. the shift towards producing ideas at scale not simply inventions). We next explore how government departments are adapting to shape innovation policies to intervene in these three dimensions. Lastly, we provide case studies of three important technologies as examples for how innovation will develop differently under this new paradigm.

2 The Rise of Economic Security

In the traditional model of the innovation economy, the assumptions generated by the Arrow-Nelson formulation emphasized the role of R&D as a fundamental input into innovation (Arrow, 1962). The core argument for government involvement in R&D, and innovation more broadly, was grounded in the importance of unexpected spillovers from R&D that might generate significant economic benefit. As a result of these hard-to-predict outcomes, private actors (mainly large corporations and start-ups) under invest in R&D. As a result, governments have traditionally intervened to increase R&D spending in hopes that this will boost spillovers and amplify important economic outcomes and the long-term prosperity that follows. Historically, it is only for a very narrow set of technologies and capabilities - such as those necessary for national security and defense - that government R&D (especially directed towards classified and unclassified research in national labs) has been justified less on the potential for spillovers and more as a means to overcome market failure in unique capabilities where traditional markets are unlikely to produce the desired result.

Building on this framework, the economics of innovation research hasemphasized analysis of the levels of R&D spending and their impact on productivity and growth. Scholars have also examined the ways that such spending is allocated (i.e. through grants, prize competitions, etc.) and the resulting impact on research outcomes — including levels and quality (see Murray, Stern, Campbell, & MacCormack, 2012, as one example of this robust literature). More recently, various research streams have examined the outcomes arising from changes in incentives for R&D targeted at amplifying the impact of increased investment, including changes to patenting and licensing rules, procurement processes, and capital gains taxes. Taken together, these research papers all emphasize economic outcomes, with the relationship between the R&D production function on the one hand and productivity and economic prosperity on the other.

Geopolitical competition between the U.S. and China has shifted the calculus for what the appropriate outcome measure should be when it comes to investments in innovation, introducing a new dimension to the traditional model. Sovereign control of key parts of the technology ecosystem are now an important consideration for public and private sector leaders. Indeed, the ability of a nation to exercise such control across a wide range of technologies is now seen as an essential aspect of national security - in much the same way that control over nuclear technology has always been a national imperative. As a result, policy interventions are being framed not simply by the degree to which they drive technology development and subsequent economic advancement, but also whether they enhance national security. Bringing these two dimensions together, the goal for today's investments in innovation is often to increase economic security - i.e. developing technological advantage for economic growth and controlling that advantage along the value chain for national security. This pivot is not without consequence. The traditional objective of economic policy is to raise standards of living of the population while national security policy prioritizes the physical safety of constituents. While developing and leveraging advanced technology is critical to both endeavors, these dual policy objectives might often be at odds.

The origins of this shift can be traced back to ∼2006 when China announced its state-led industrial policy aimed at making China a global leader in high-tech industries. The subsequent decade featured growing concerns over Chinese control of national infrastructure, especially the communications infrastructure of the U.S. and its allies (which led to a ban on Chinese telecom giant Huawei from U.S. networks over security concerns),highlighting the lack of a domestic alternative and the hollowing out of the telecoms sector in Europe. At the same time, the more wide-ranging "Investigation into China's Acts, Policies, and Practices Related to Technology Transfer, Intellectual Property, and Innovation" by the U.S. Trade Representative found numerous attempts to appropriate U.S. ideas, know-how and intellectual property alongside cyber attacks against confidential business information (Office of the United States Trade Representative, 2018). This work arose against the backdrop of clear policy statements from the Chinese Communist Party (CCP) regarding the ambitions to become a technological power with technological excellence at the core of geopolitical influence (State Council of the People's Republic of China, 2015). And it has illustrated the ways in which China, much like the U.S., increasingly sees technology not simply as a source of either economic prosperity or a source of military/security power, but as the core of both.

Importantly, in the Chinese context, these goals started to be implemented through what is referred to as "Military-Civil Fusion" (MCF) in which all aspects of the Chinese economy (public and private, military and civilian) were corralled by the CCP to serve technological ends that could be deployed for civilian and military outcomes. A case in point for MCF was highlighted by the 2016 Department of Justice indictment of China General Nuclear Power company for conspiracy to move nuclear materials out of the U.S. (Office of Public Affairs, 2016). Likewise, in the non-military domain, the launch of a quantum communication satellite by China in 2016, incorporating research from a range of leading laboratories around the world, including the U.S., emphasized the potential challenges of China's rising technological prowess as a vehicle for both geopolitical and economic ambitions (Wong, 2016).

China's clearly stated ambitions, alongside specific cases of technological appropriation from the U.S. to China, led to a shift in U.S. policies towards technological advantage, emphasizing sovereign advantage and control and tighter connections between economic prosperity and national security. These are first articulated in the 2017 National Security Strategy from the first Trump Presidency which lays out the importance of maintaining technological superiority as a critical element of national security noting that "economic security is national security" (Executive Office of the President, 2017). The strategy highlights three aspects of technological innovation: First, how technological innovation has transformed the nature of global competition, making it essential for the U.S. to outpace rivals in critical fields to safeguard national interests and security, thus putting national security considerations front and center. Second, the importance of securing supply chains and cybersecurity to protect American technological assets, and ensure that critical technologies and infrastructure remain under U.S. control. Third, the ways in which a country can use its technological advantage as a source of resilience against hostile economic decisions from adversaries which in turn provides a means to project power by denying others access to critical technologies (or their inputs). As a remedy, the strategy suggests: "We must defend . . . .the American network of knowledge, capabilities, and people—including academia, National Laboratories, and the private sector—that turns ideas into innovations, transforms discoveries into successful commercial products and companies, and protects and enhances the American way of life"(Executive Office of the President, 2017). Alongside this recognition came a call for action to protect and control innovation.

This fusion of economic and military strength became increasingly referred to as "economic security" and the deployment of this strength is referred to as "economic statecraft." These concepts, together with the emphasis on geopolitical competition in the technological realm have formed the basis of a new approach to policy making where national security concerns become as or more important (or more salient) factors in the economic policy calculus. This change is especially relevant to innovation policy as it expands the emphasis on direction and control and away from simply increasing the rate of innovation. And the widening scope of national security on innovation also increases the emphasis on economic statecraft to align trade policies, investment activities and supply chain access with national security goals all within the context of the innovation economy. Recent examples include export controls for semiconductor chips, sanctions from China on key components for drone companies such as Skydio in the light of the conflict in Ukraine, the increased salience of critical mineral processing technologies and supply chains, and import controls on capital.

In this new era of economic security and economic statecraft, an appropriately revised economics of innovation has yet to be developed. As a step toward a deeper theoretical grounding of the levers of innovation in today's geopolitical context, we explore the recent 'pivot to control' and its implications for the direction, participation and scale of innovation. We use this foundation as an opportunity to examine further the ways in which the government must reorganize to account for the different considerations for innovation policy.

3 The Pivot to Control

A growing number of policy documents on economic security and recent examples of government innovation policy create the basis for a set of principles to be incorporated into a "new economics of innovation." While the shape of the context is still emerging and likely subject to significant flux in the present Trump administration (2025-2029) and beyond, we propose that the shifting geopolitical environment can best be understood through the lens of control: in particular, nations seeking to exert control over new innovations as opposed to simply seeking to increase their overall levels of innovation. We examine this preference for more control and its implications for future research across three dimensions: i) the direction of innovative activity (i.e. what goals are targeted), ii) the participation in innovation (i.e. who can engage in innovation), and iii) the scale to which innovations are developed (i.e. how are associated production and supply chains organized).

First, nations like the U.S. and China are increasingly seeking to control the direction of innovation to align with their own national security priorities. Since many of the most important technologies of our time – including generative AI, vaccines and post-quantum encryption – are obviously directly relevant to and critical in national security, governments are taking a significantly more active role in shaping the direction of innovation to ensure and accelerate innovative solutions. For example, the Biden Administration discouraged the development of "open" models like Meta's Llama (where the parameter weights are publicly available) due to national security concerns. There remains an active debate today in the AI community as to the benefits of open vs. closed models. Moreover, the introduction of Chinese firm DeepSeek's R1 open model in 2025 further raised concerns about whether the U.S. should take broader steps to shape the technological trajectory of AI, given how DeepSeek built on U.S. investments but also emphasized reduced reliance on high-powered AI chips such as those from U.S. company Nvidia (which had been banned from exporting their next generation chips to China) (Milmo, Hawkins, Booth, & Kollewe, 2025). Likewise, in the post-Covid-19 era, governments have sought to shape investments in biotechnology towards rapid vaccine development and production instead of new vaccine design or rapid viral analysis. Nations also increased their emphasis on controlling over bio-manufacturing technologies given the vulnerabilities that otherwise arise from having essential medicine production (and design) controlled by adversaries. Similarly, efforts to build so-called post-quantum encryption, or encryption methods that are resistant to powerful quantum computers, have been pioneered by the government as a way to counter threats to national security and protect U.S. defense systems from future quantum-enabled cyber threats. This strategy operates through standard setting as well as investment in national labs and wider academic research.

Understanding this renewed emphasis in the U.S., and around the world, to direct innovation towards critical missions is a central feature of the emerging new economics of innovation. Gross and Sampat (2022) have used the term "crisis innovation" to illustrate the ways in which innovation happens at pace and in response to a sudden change - such as a pandemic, the nuclear arms race or a similar event. They illustrate shifts in effort characterized by urgent mobilization and novel organizational arrangements. Controlling the direction of innovation is not entirely new: the Critical Technologies List was created in 1987 to help the U.S. identify, protect, and promote technologies crucial to its national security (Office of the Under Secretary of Defense for Research and Engineering, 1986). At the time, however, the list was short and emphasized military and communications technology. And DARPA has long served as a mechanism to control the direction of innovation by spurring activities against national priorities (especially those with defense applications). However, this approach is increasingly widespread and thus worthy of additional analysis. The Biden Administration, for example, instituted the CHIPS and Science Act to fund the construction of semiconductor manufacturing facilities but also aimed to fund R&D facilities to spark American innovation towards a new generation of chips (U.S. Congress, 2022). The government also specifically earmarked funding for areas to which they hoped to direct innovation, such as advanced packaging and created research labs to serve as "digital twins" to advanced facilities.

Beyond directing attention to specific challenges (such as semiconductors), in 2018 the Critical Technologies List was significantly expanded as the U.S. sought to outline a set of priority technologies to focus investment and where aligned policymaking efforts were deemed essential (Bureau of Industry and Security, 2018). The list is now extensive and moves questions of directional control from a handful of specific crisis cases or military instances towards a wide landscape of innovation activities including AI, biotechnologies, quantum computing, advanced manufacturing etc. The publication of this list aligned with the wider national security context (outlined in the 2017 NSS noted above) with superiority in these various fields seen as key to future warfare, economic power, and cybersecurity.

The second dimension of control of innovation emphasizes who can participate in and access the fruits of the innovation process. The traditional economics of innovation has long been founded on the importance of spillovers to a range of parties and sought to consider how to balance control rights in the form of intellectual property, with the open flow of knowledge. Today, attention has shifted to control within geographic boundaries- sometimes referred to as sovereignty (i.e. the ability of a nation to deploy a particular effect or capability without dependence on another nation).

In the past, a core feature of the economics of innovation was that countries were largely agnostic to who was generating innovative outcomes, but rather sought to generate their own specific expertise as a complement to the comparative advantages of others. Similarly, at the individual level, the war for talent emphasized the ability of one country, region or organization to attract and deploy more talent than another. Networks of collaboration, especially those that crossed international borders to tap into different complementary talent sources or as a source of soft power, were regarded as central to R&D productivity. Specifically, immigration policy has been a key driver of innovation and economists generally agree that high-skilled immigration has been a boon for innovation and entrepreneurship - whether this is in the context of the dislocation of war (e.g. Moser, Voena, and Waldinger (2014) on the movement of refugee scientists from Germany to the U.S.), large-scale migration (e.g. Borjas and Doran (2012) on the opening up of Russian mathematics to the world) or explicit programs (e.g. Fry (2022) on the role of African scientists who engaged in specific U.S. research programs).

In today's geopolitical environment, there is growing concern over the geographic boundaries of innovation because of an underlying perspective that intellectual property (as well as tacit knowledge) may flow through human networks to adversaries through relocation, collaboration or via information rights (garnered from investment participation). Exemplified by the rising interest in research security at U.S. federal agencies and universities, and recent high-profile prosecution of espionage cases, this approach to control of participation in innovation is significantly at odds with the traditional model of open science or of open agglomeration of talent in ecosystems such as Silicon Valley or Boston and presents a new set of policies for consideration by economists of innovation, and empirical questions about how changing norms of collaboration have shaped knowledge networks and spillovers. For example, economic models assume the free flow of people, and yet restrictions on innovative labor could be a real constraint going forward. Policies that aim to control the scope of participation are a growing aspect of the new economics of innovation, as manifested by recent U.S. policies.

The U.S. is not alone in this focus on separation and control: after the AlphaGo demonstration by DeepMind in 2015, China's leadership became more acutely aware of the vulnerabilities created by relying on foreign technologies, particularly in areas such as AI and quantum computing (Mozur, 2017). As a result, policies aimed at self-sufficiency and control have dominated China's approach to innovation including the creation of research institutes like the Chinese Academy of Sciences' National Laboratory of Quantum Information (Giles, 2018).

Beyond questions of control of innovation undertaken at the earliest stages of research and development by academic scientists, issues of control are also increasingly manifest in the ways in which capital flows into innovation project are subject to limits and strictures. While the policy apparatus is quite distinctive, questions of Control Foreign Investment into the U.S. (CFIUS) are now matters of innovation policy as they shape the degree to which funding (especially venture capital) can flow into the early stage startups commercializing ideas that are considered to be based on priority technologies. Largely unexplored by economists of innovation, this is a new domain and set of levers for controlling participation in innovation, specifically via controlling the information rights that come with investment (and often Board membership). Beyond simply learning by listening, ownership can lead to changing intellectual property flows into adversarial nations if companies find themselves in trouble or at risk of running out of funding; a situation exemplified by battery company A123 (Hals & Klayman, 2013).

Nations aiming to control the scaling of innovation - both production and supply chains - provide the third dimension of control of innovation. In other words, as the shift in innovation policy moves away from economic prosperity and global comparative advantage towards economic security, leaders would be rational to assume it is not enough to simply operate in the market for ideas. While economic prosperity has traditionally come from having ideas and contracting for production from global supply chains, national security increasingly relies upon control of ideas at scale. Traditionally, such scaled production was only considered to be essential for a narrow range of items such as defense technologies (e.g. F35s), satellites and space launch, and nuclear technology. Today, this has expanded across the growing list of priority technologies. As a result, nations wish to control entire supply chains so that they can develop and deploy, and thus control, technological innovation at scale.

Such a desire to scale is grounded in the positive economic benefits of being able to deploy sovereign capabilities in a self-reliant fashion (with the potential jobs that may arise etc.). But in the contemporary narrative it is based on the ability to use technological innovation as a tool of economic statecraft to deter or damage adversaries - a mechanism that has been highlighted in recent months by the decisions by China to limit the sale of key drone components to innovative companies such as Skydio who are building drones in support of the war in the Ukraine. Combined with recent sanctions placed on essential critical minerals and materials (CMMs) by China - (including in response to U.S. sanctions) - this highlights supply chain vulnerabilities and has provoked a shift in innovation policy towards considering the entirety of innovative effort from idea through to impact at scale (Bradsher, 2025).

In recent years, for example, we have observed broad efforts in the United States to exert more control over supply chains and scale-up of innovative technologies, including over critical minerals and materials through the Department of Energy CMM Program (U.S. Department of Energy, 2021), energy infrastructure (Loan Porgrams Office, 2023)), biological drugs (U.S. Department of Health and Human Services, 2020), and computer chips (U.S. Congress, 2022). Localizing supply chains is not the only response relevant for the new economics of innovation: the emphasis on "friend-shoring" is also designed to reduce geopolitical risk even if they might increase the price of critical inputs and suggests the need for a different economic calculus in decisions on scaling innovation. Programs such as collaboration with Japan, South Korea (Shepardson, 2024) and, most recently, India (Office of the Spokesperson, 2024) on semiconductor production speak to the shift in approach from one of globalization of production to more strategic, geopolitical control of supply. Taken together, these policy shifts towards controlling (and supporting) innovation at scale suggest a new opportunity for the economics of innovation to (re)consider questions of the scale and scope of production, tacit knowledge, and the boundaries of the firm, and perhaps to examine questions that animated economic historians of technology who have long placed manufacturing and production more broadly at the core of their inquiry.

Considering these three dimensions of control; direction, participation and scale is not a new task for governments. Indeed, national security and geopolitical concerns have shaped innovation for decades. RADAR was first developed by the U.K. and then transferred to the U.S. in the hopes that this would allow for Allied control of scale and production, and to ensure that technological capabilities did not fall into the hands of Nazi Germany. The

Manhattan Project was also an initiative borne out of the desire to shape the direction of atomic weapons, control who had access to them and enabled their scalability for the United States alone. Likewise, economic history is also replete with examples of technological capabilities being subject to intellectual property theft, blockades or attempts at rapid crisis innovation. Nonetheless, during the Cold War, the era during which the seminal papers in the economics of innovation were authored, the geopolitical context of innovation played only a limited part in scholarship.

An important exception was the much more narrowly focused economics of military and nuclear technologies, with leading work such as the collection of essays "The Economics of Defence," edited by Hartley and Sandler (2001), which explored the economic implications of military spending, the cost-benefit analysis of defense expenditures, and how military spending interacted with economic growth. Herman Kahn's work was pivotal in analyzing the costs of nuclear deterrence and understanding how arms races and military strategy interacted with economic factors. And, he was one of the first to provide detailed cost estimates for maintaining nuclear arsenals and the resulting benefits of the military-industrial complex (Kahn, 1962). And, in the same vein, Higgs and later Dunne and Tian (2013) emphasized the economics of military spending and the impact of defense expenditure on economic growth. This research examines the relationship between military spending and economic performance, particularly in terms of its effects on capital accumulation, industrial output, and technological innovation - a topic more recently revived by Moretti, Steinwender, and Van Reenen (2019).

In the more traditional economics of innovation, Arrow and others cited defense technologies as a classic public good because it is non-excludable (everyone benefits from national defense, regardless of whether they contribute to its funding) and non-rivalrous (one person's enjoyment of defense services does not reduce its availability to others) arguing thus for greater public spending to make up for market failure. Much of this work remained in the spirit of the direction of innovation and its impact on economic growth and wider productivity. At the same time, issues of control were not far below the surface (in the policy context if not the scholarly one): the U.S. imposed stringent export controls on key military technologies (as noted above). And, the U.S. limited certain types of scientific exchanges with Soviet (and later Russian) scientists. For example, during the 1980s, when Soviet scientists sought to come to the U.S. for collaboration, they were subject to tight visa restrictions and bureaucratic hurdles (National Research Council, 2004). These restrictions were intended to ensure that individuals coming from the Soviet Union were not involved in sensitive defense projects or posed a threat to national security. Conversely, in areas such as defense and missile systems (but less so nuclear weapons), Russian scientists established close academic research partnerships as well as industrial relationships with Eastern Bloc nations especially prior to the collapse of the Soviet Union (in 1991).

Economists establishing the new economics of innovation can thus learn much from studying the Second World War and the Cold War era that followed and prior periods, as Mowery and Rosenberg (1998) and Gross and Sampat (2023) have illustrated. But the particular technologies at stake in this new era are broader in scope, have a mix of features that put them squarely in the realm of complex and costly 'deep tech' systems based on hardware and software (thus based on large scale production) and grounded in a range of disciplines from the life sciences and chemical sciences to material science and advanced physics. The renewed focus on controlling innovation, often through industrial policies, opens up new questions for scholars of innovation particularly as they relate to understanding the intersection between the public and private sectors. And, the renewed interest of policymakers in structuring and having leverage over supply chains opens up new opportunities to develop better measures of supply chain resilience and quantify the geopolitical risks in global value chains. Indeed, in a world where national security is paramount, governments might wish innovators to exert greater control over their supply chains and receive national subsidies to do so. When it comes to the location of a R&D facility, the markets where the "right" talent is located may ultimately not be the "right" place to build a new outpost if the geopolitics rewires international relations. All these are questions for scholars of the new economics of innovation. At the same time, they are subject to active policy making in the halls of government.

Leaders around the world have already started the process of building new institutions and reforming old ones to adapt to this new era. In the next section, we examine the institutions that are emerging to deploy policy responses to the new geopolitical context for innovation. We then turn to the implications of our control-oriented innovation framework for three critical technologies.

4 Infusing Economic Security into Innovation Institutions

The economics of innovation has long focused on how particular institutions shape the productivity of innovation and the ways in which expenditures on R&D can be allocated and organized to allow for maximum and efficient spillovers. From work in economic history (Mokyr, 2002) to the emphasis on institutions shaping open science (Dasgupta & David, 1987), this research has explored institutions ranging from intellectual property rules, the norms of open science and specific institutional arrangements such as biological resource centers (BRCs), genetic libraries (such as the Jackson Laboratories), and standard setting efforts. Another line of research has examined how the particular structure and incentives of R&D funding organizations have increased the rate of innovation. Most notably in the defense and security context, Azoulay, Fuchs, Goldstein, and Kearney (2019) explored how DARPA has been most effective in fostering innovation. Taking a more experimental approach, Azoulay and co-authors have also explored the precise ways in which NIH study groups and evaluation processes drive the quality of innovation (Azoulay, Graff Zivin, Li, & Sampat, 2019). Together this work provides a strong foundation upon which to appreciate the ways in which the new economics of innovation might challenge existing results or suggest novel avenues for analysis, given that new institutions are arising to control the direction of, participation in, and scaling of innovation.

Governments are adapting their innovation institutions around economic security and to ensure their ability to deploy economic statecraft with allies and adversaries. These newly transformed institutions are being designed explicitly to control the innovation process from end to end. This shift opens up the question of whether governments will be able to identify the strategic control points in each industry and execute on their intended strategy. It also raises questions about how such innovation policy goals might be effectively deployed. As a starting point for scholars interested in these developments, we highlight some notable government programs and units that are being designed (or re-imagined) to control the direction, participation and scale of innovation.

When it comes to matters of innovative direction and how that is organized and prioritized, there is a long tradition of control. DARPA is one such mechanism and inside the U.S. Department of Defense we see an expansion of these approaches from the Defense Innovation Unit to the Office of Strategic Capital. Likewise, InQTel and CIA Labs aim to control the direction of innovation by providing investment capital to startup ventures with innovative projects that are aligned with government priorities. For other departments such as the Department of Energy, direction has been increasingly set through the ARPA-E mechanism and its tech-to-market programs that provide essential financial support for ventures with technological solutions aligned to departmental road maps. And for NIH there is a shift in emphasis to focus increasing levels of funding on core goals rather than investigator-driven agendas including ARPA-H and other challenge-based mechanism for funding.

Recent years have also seen new institutions arise to control the direction of innovation: under the CHIPS and Science Act of 2022, approximately $2 billion of the funding was allocated for the Microelectronics Commons Programs, run by the Department of Defense (U.S. Congress, 2022). This program was explicitly designed to direct innovation in semiconductors towards military applications by funding research at multiple hubs across the nation. Likewise, in other nations such as the UK, entirely new funding agencies - the Advanced Research and Innovation Agency - have been established with new approaches to defining and funding research projects that align with national goals. Further, a new National Science and Technology Council was established to coordinate cross-government strategies around priority technologies to that contribute to the UK's economic and geopolitical position, sending a clear signal to the sector about the government's priorities in this area" (Cabinet Office, 2022).

The second dimension of control - namely participation in innovation presents more of a challenge for government systems traditionally designed around open participation on a global stage with a wide range of talented foreign-born individuals coming first to universities and then serving as the bedrock of the entrepreneurial economy. To control flows of talented individuals from particular nations presents a range of difficulties, especially since frontier R&D has long emphasized global collaboration, including through attracting international talented foreign-born Ph.Ds.

Traditional government approaches relied upon a small handful of laboratories with security clearances and strict participation controls. But as the frontier widens this is no longer an effective path forward and participation must be mediated in new ways with new structures. Attempts by government departments such as the FBI to engage NSF and academia more broadly have been met with challenges. More recent briefing papers seek to outline government concerns regarding 'foreign malign influence' at universities. Further, government departments providing research funding, including the NIH have started research security efforts to ensure their grantees are free from foreign influence. Similarly the DoE now requires disclosure of participation in so-called Foreign Government-Sponsored Talent Recruitment Programs and requires additional reporting in this context at the time of proposal as part of current and pending support. More recent activities include proposals to ban student visas for all Chinese scientists.

Lastly, we examine how innovation is controlled at scale, with an emphasis on how the U.S. government is developing its innovation institutions to try and ensure that ideas are generated but also scaled within the U.S. This objective remains a challenge but a few departments have sought to support scaling of ideas by U.S. corporations within the country, most notably the DoE, whose so-called tech-to-market and "First of a Kind" (FOAK) programs emphasize funding and other support for meeting milestones that demonstrate the scaling up of ideas well beyond the lab bench or even the small pilot facility. Increasingly the DoD is considering scale and supply chains when it comes to its work with startup ventures. New entities within the DoD such as the Office of Strategic Capital have approximately $1 billion in capital to invest in 2025, seeking to scale innovations at a level that has been lacking from previous DoD efforts. Increasingly focus on funding the defense industrial base so as to ensure domestic production in the face of supply-chain vulnerabilities. Even the NSF has a new Directorate of Technology, Innovation and Partnerships, which is similarly designed to commercialize and scale innovation emphasizing scaled production and manufacturing. As a case in point, the CHIPS and Science Act allocated $11 billion to R&D, some of which could be used to create a venture-style fund to seed and scale new chip innovations.

It is too soon to say whether these institutional changes will be long-lasting, especially given the considerable flux in the 'machinery of government' underway at the time of writing. To the extent that the new economics of innovation is a strong and durable theme driven by geopolitical tailwinds, we suggest that economists who study the organization of innovation (and especially the ways in which funding is allocated) familiarize themselves with the new institutions that have been built in government to exert greater control over the direction of, participation in, and scaling of innovation, not simply to accelerate the rate at which innovative outcomes are produced. These institutions have the potential to shape the trajectory of innovation for years to come, not just in the U.S. and China but around the world.

5 How Geopolitics is Shaping Three Critical Technologies

We next seek to draw out the implications of our argument through three cases of priority technologies that are evolving under this new geopolitical paradigm, with the shifting economics of innovation it implies. Through our discussion of quantum computing, semiconductors and nuclear fusion we demonstrate how geopolitical shifts are leading nations to exert more control over the technologies being developed at the frontier of knowledge and commercialized and scaled up as "deep tech."

5.1 Quantum Computing

Quantum computing - a domain within computer science adapting quantum mechanics to develop new technologies, has experienced a surge of popular and investor interest in the past several decades. Rather than simply produce new and more powerful classical computers, quantum computers promise to solve impossibly complex problems in new ways. In prior decades, building such a hardware system was largely a theoretical pursuit focused on elaborating the potential for such machines to break previously unbreakable codes. But with the mathematics and fundamental physics of quantum computers increasingly understood, international collaboration turned towards building quantum devices including designing the sophisticated and complex quantum chips that would actually form the core of such machines.

Given the timing of the explosion of quantum computing research, this field has proven to be one of the first areas of technology initiated at a time when China had its own technological prowess (rather than necessarily playing catch-up). And, especially since 2016 when China announced plans to develop quantum computers independently from international partners, other nations have also undertaken several steps to control the direction, participation and scale of innovation in quantum technologies within their own national boundaries.

The rationale for a shift to sovereign control is that quantum computing, though still years away from full-scale deployment, is a strategic technology for defense and national security (not simply for economic prosperity). This potential for economic security comes in part because of quantum's potential to crack encryption algorithms that today protect our most sensitive national security data. Quantum also has the potential to solve other extremely challenging problems. Adding to the desire to be autonomous in quantum expertise are growing concerns that the global diffusion of knowledge has undermined national security goals. A 2019 report by Strider's Global Intelligence Unit, for example, entitled The Quantum Dragon, documented how the Chinese government has exploited the open orientation of the quantum innovation system to leverage technologies for their military (Strider Global Intelligence Team, 2019). Over a ten-year period, the Chinese government executed a strategic plan to acquire knowledge from returning scientists who had worked in American research institutes to become a quantum leader. This report and similar data from sources like ASPI's Critical Technology Tracker (Australian Strategic Policy Institute, 2025) sparked concerns in the West about losing their edge on using quantum for military applications.

Against this backdrop a race for quantum "supremacy" has been ignited with many nations recently releasing quantum computing strategies and investment funds with an aim of exerting more control over the direction of, participation in and scale of quantum. France, for example, has long had significant research expertise in quantum physics and other foundational fields for quantum computing. To shape the direction of quantum more purposely, President Macron announced a $1.9 billion program in 2021 that has since supported over 80 projects (Le Monde with AFP, 2021). The French government has aimed to foster close ties between its domestic academic institutions and entrepreneurial community to shape the direction of research. Notably, these efforts to shape the direction of quantum research have increasingly leaned toward military applications. The defense procurement arm of the French government awarded over $500 million to 5 startup companies in 2024 to develop at least two quantum computers by 2032, with an emphasis on defense applications.

The U.S. government has also taken increasing steps to control participation by limiting access to cutting-edge quantum technologies by China. In May of 2024 for example, the U.S. government added 37 Chinese organizations to the Bureau of Industry and Security's entity list, restricting the sale of research tools such as advanced lasers by U.S. firms to these labs (Bureau of Industry and Security, 2024). One of the 37 organizations was China's famed University of Science and Technology of China (USTC), home to China's leading quantum scientist and prominently mentioned in the Quantum Dragon report.

There have also been efforts, even among smaller nations, to control the scaled manufacturing of quantum computers to domestic production, despite the financial and technical hurdles. The Danish government, for example, announced a $93 million initiative in 2023 to support quantum research and innovation (Ministry of Higher Education and Science, Denmark, 2023). These investments laid the foundation for the Novo Nordisk Foundation to invest in the creation of the Quantum Foundry P/S, a fabrication facility that will support the building of Denmark's first quantum computer in the coming decade. One of the four pillars of this initiative is "Safeguarding Intellectual Property and Sensitive Technologies" as "quantum technologies are] emerging as a strategic asset" (Invest in Denmark, 2025). The facility will conduct R&D with an explicit focus on scaling manufacturing of a quantum computer and an emphasis on national security reflect a new consensus on scaling innovation domestically. As quantum computing receives increasing attention due to highly publicized scientific breakthroughs by Google as well as large investments by venture capital and the establishment of scaled facilities around the world, geopolitical forces will continue to shape the trajectories of technological development and governments will seek to control them. On the one hand, quantum is the beneficiary of increased government support around the world, most notably in China. On the other hand, national security considerations may hamper collaboration and limit financing. Innovation scholars have been turning their attention to quantum, but the direction of innovation and fortunes of the public and private sector actors (incumbent and entrant) will be determined in part by geopolitical forces thus creating an opportunity for an expanded research agenda.

5.2 Semiconductors

Semiconductor technologies form the core of the most visible 'critical technology' being shaped by geopolitics. From the beginning, chipmaking was a global industry as early semiconductor manufacturers designed chips in the U.S. but built facilities in Asia to lower the cost of production with innovation then also moving to be more proximate to production. Over the subsequent decades, the industry grew to encompass a quintessential global supply chain, where the drive for efficiency and comparative advantage has dictated the distinctive locational choices of research, design and manufacturing. However, geopolitical shifts over the past few years have dramatically shifted the trajectory of the industry and the fortunes of its key companies. Today, geopolitical dynamics are strongly shaping the policy context for innovation with an emphasis on control.

The CHIPS and Science Act in the United States (which one of the authors was involved in crafting and implementing) and other industrial initiatives in the EU, Japan and China reflect a new consensus that the location of semiconductor manufacturing, particularly the most advanced generations, plays a critical role in national security; notably if production is taking place in a location that is outside the control of a country such as the U.S., this drives strategic vulnerability into the supply chain. Behind the various policy moves is therefore the recognition that computer chips are strategic - not least because of their use to train artificial intelligence models as well as being important components of consumer electronics, medical devices and military technologies. And as a consequence, nations have increasingly sought to exert control over the entire supply chain of chip innovation rather than over a particular part of the supply chain (for example research and design). The hypothetical scenario (that has recently featured in many different war games) - where a nation is cut off from accessing semiconductors - is rightly regarded as an economic and military disaster. The fact that the vast majority of the world's chips are produced by TSMC in Taiwan, itself a flashpoint in the geopolitical rivalry between China and the U.S., had made this fear all the more salient (Reuters Staff, 2024b).

The drive to exert greater national control over the semiconductor supply chain follows the three dimensions introduced above. First, with Moore's Law coming to an end, the direction of semiconductor innovation is at an inflection point. The U.S. CHIPS and Science Act which allocated $11 billion for R&D has emphasized a focus on advanced packaging, a method to bundle multiple chips in one electronic package (U.S. Congress, 2022). This reduces cost and power consumption. The U.S. government identified this as a key area with potential for domestic technological dominance to benefit firms working in the United States.

Participation in the supply chain has also been transformed. The U.S. Bureau of Industry and Security introduced export controls in 2022 and 2023 to limit the sale of chipmaking equipment and advanced chips to China and other countries of concern (Bureau of Industry and Security, 2023). A 2025 rule also divided a much larger list of nations into tiers of access, limiting supply further (Bureau of Industry and Security, 2025). The U.S. also introduced regulations limiting the participation of Americans as employees in Chinese semiconductor manufacturing companies (Bureau of Industry and Security, 2022). For a globalized supply chain, these restrictions have been both disruptive and contentious. But such policies reflect a clear national strategy to control who has access to critical technologies, and one that has similarly been adopted by allies such as Japan and the Netherlands.

Finally, as might be expected, there have been efforts to control the ability to scale key parts of the chip supply chain. The Japanese Investment Corporation (JIC), which is governed by the Japanese government, took steps to intervene in the private sector to consolidate Japan's dominant position in photoresists - key materials used in the front-end of the semiconductor manufacturing process. JIC invested over $6 billion to acquire JSR, an important Japanese company in the space (Reuters Staff, 2024a). After delisting the company, management announced plans to scale via acquisition, cementing Japan's dominant position in a key part of the supply chain.

With national governments taking steps to shape the direction of, participation in and scale of innovation in the semiconductor industry, the economics of innovation has changed. The competitive environment for firms in an industry that, until recently, was recognized as the exemplar of a global supply chain is now being shaped by new rules, and at the same time, there are emerging norms with firms in the industry anticipating further controls, and for example, not taking Chinese investments in their startups. Scholars seeking to understand the rate and direction of innovation in semiconductors or the strategies of firms in the industry will thus have to incorporate these new realities into their analysis.

5.3 Fusion Energy Systems

We have selected fusion energy systems as our third example to illustrate how emerging critical technologies are subject to a new economics of innovation. It is particularly interesting because, unlike semiconductors, it presages the rise of an entirely new industry. And yet unlike quantum computing, it is being born from decades of academic collaboration on a global scale.

The study of fusion began in the early twentieth century as physicists started to explore the chemical reactions that powered stars. Using a particle accelerator, neutrons from fusion were first identified in 1933 and work theorizing the chemical reactions characterizing the fusion system completed in the late 1930s won the Nobel Prize in 1967 (Nobel Prize Outreach, 1967). Prior to that the first patented design of a fusion reactor was in 1946 by the UK's Atomic Energy Agency. Work continued among U.S., UK and other scientists. Soviet scientists also participated in progress suggesting a so-called tokamak design for a fusion energy system to make it easier to confine the powerful fusion reactor with British scientists visiting various demonstrations in the former U.S.SR in the 1950s and 1960s. But by the 1980s a series of international collaborative projects were well underway including those in the UK, France and Japan (including JET -the joint european Torus built just outside Oxford).

Building off decades of government funding, a decision to concentrate funding in one large-scale project of global collaboration sought to amplify the rate of innovation being derived from a more coordinated use of funding in the International Thermonuclear Experimental Reactor (ITER) project. Established in 2006, funding came from the EU (including the UK), Japan, the U.S., Russia, India, South Korea and China each contributing to many technical aspects of the project: including the design and manufacture of components such as the vacuum vessel and the magnets (Wald, 2009).

In a period of globalization projects such as ITER were held up as examples of global open science, with each nation contributing to an ambitious project with the potential to provide energy at extraordinarily low marginal cost. However, with the shifting geopolitical landscape, and the starving of national-level research efforts (in favor of focused funding for one international project), we have seen the emergence of new deep tech startup ventures focused on commercializing fusion. Researchers from around the world sought to bring their new innovations more rapidly to life by leveraging private capital and tapping into innovation ecosystems. As a result, fusion startups can be found in many nations from the U.S., UK and Canada, to Europe as well as China.

When it comes to shaping and controlling innovation in a field as new as fusion energy, there are less defined policy interventions than identified in quantum or semiconductors. In addition, the national security issues that have been sharply outlined in quantum computing (due to the decryption potential) or semiconductors (essential in a range of defense equipment) are less obvious. That said, this emerging field is also confronting the emerging new economics of innovation with governments considering how to control this potentially transformative new area of innovation.

To control the direction of innovation, the U.S. has taken a relatively hands-off approach with private (and some public) sector funding supporting both magnetic (tokamaks) and laser confinement. In contrast, China has largely focused on the tokamak designs, following some of the leading U.S. private sector designs such as those from MIT spinout Commonwealth

Fusion Systems. The U.S. funding is also increasingly coming from the private sector (venture capital) while other nations, especially China have emphasized highly focused public sector funds. With regards to control of scaling, governments are wrestling with how to ensure that critical supply chain inputs such as high temperature superconducting magnetic tape and the critical minerals that it requires, can be accessed accordingly. But with the supply chain yet to be built, the underlying technologies are less clearly defined and hard to predict. Some national security agencies are attempting to explore the relative expertise of the U.S. versus China in some of the key supply elements to determine future paths of likely competition. And, as importantly, to ensure future scaled fusion, the DOE is funding fusion research emphasizing scale-up, with over $46M to eight companies with designs for utility-scale pilot plants (Gardner, 2023), alongside $112M to projects that are utilizing computing to advance fusion research (Office of Science, 2023).

6 Discussion

The economics of innovation is entering a new era where geopolitics matters again. We explain that rising U.S.-China tensions have motivated nations to exert more control over the direction of, participation in and scaling of innovation. Simultaneously, the technologies that are most important today are increasingly deep technologies that require scientific breakthroughs to come to fruition. This new paradigm is leading to the creation of new government institutions that will shape innovation policy, particularly in critical areas like quantum computing, semiconductors and nuclear fusion technologies.

Importantly, there are serious risks to this approach that could lead to retrenchment in the coming years. A less integrated economy might lead to slower growth as tit-for-tat economic statecraft reduces the gains from trade. As of April 2025, President Trump's decision to implement the highest levels of tariffs in nearly a century suggest a possible turn in this direction (Reuters Staff, 2025). Furthermore, less collaboration across countries could reduce the rate of innovation, slowing growth around the world. This risk is particularly acute for deep technologies because the scientific breakthroughs they rely upon are less likely in an innovation ecosystem with more frictions. In this sense, the "open" system of science that governed the previous era could actually be more supportive of deep technology compared to the more "closed" system that appears to be emerging. Ironically, while limiting participation in innovation is often justified on national security grounds, it could be possible that a more open innovation system is actually more conducive to developing the technologies that will keep us safe. In addition, to the extent that some security challenges are actually global, open science could become a necessity, for example in the case of the U.S. and China to collaborating on climate technologies and artificial intelligence.

The fusion of economic and national security policy, with twin objectives that both rely on advanced technologies pose a significant challenge for government agencies. Conversations between economists and national security leaders are still rare and the two groups lack a common language to identify common goals and execute against them. As new agencies become crucial to innovation, such as ministries of trade and commerce, economists will have to learn how they work to gain more insights on the rate and direction of innovation. While economists have extensively studied the NIH and NSF in the U.S., we should more deeply explore the role of defense agencies in innovation (e.g., Gross & Sampat, 2023) and nascent efforts like the U.K.'s new National Security Technology Committee that seek to bring together economic and defense analysis.

More broadly, economists who study innovation will have to shift our agenda to accommodate these new factors and revisit our older models to develop new insights. Scholars may investigate new (and old) questions given these new geopolitical realities. For example, can we quantify supply chain resilience or the externalities created by economic security? What is the impact of on-shoring of supply chains on innovation and the diffusion of knowledge? How should firms shift their non-market strategies in how they engage with governments given the return of industrial policy? Will geopolitics shape the financing of innovation and if so, which technologies will be most affected? What are the implications for industry structure and for entrepreneurship? What would be the impact of a trade war and increased tariffs on innovation in key sectors? How do national security concerns shaped the preference for "open" vs "closed" science systems and what are the implications workers, firms and governments? We expect innovation scholars to undertake these research agendas and more as we continue to provide useful insights to policymakers, business leaders and to the broader academic community.

References

Arrow, K. (1962). Economic welfare and the allocation of resources for invention. In *The rate and direction of inventive activity: Economic and social factors* (p. 609-626). Princeton University Press. Retrieved from http://www.nber.org/chapters/c2144

Australian Strategic Policy Institute. (2025). *Critical technology tracker.* Retrieved 2025-04-23, from https://techtracker.aspi.org.au/

Azoulay, P., Fuchs, E., Goldstein, A. P., & Kearney, M. (2019). Funding breakthrough research: promises and challenges of the "ARPA model". *Innovation policy and the economy*, *19*(1), 69–96.

Azoulay, P., Graff Zivin, J. S., Li, D., & Sampat, B. N. (2019). Public R&D investments and private-sector patenting: evidence from NIH funding rules. *The Review of economic studies*, *86*(1), 117–152.

Borjas, G. J., & Doran, K. B. (2012). The collapse of the Soviet Union and the productivity of American mathematicians. *The Quarterly Journal of Economics*, *127*(3), 1143–1203. Retrieved 2025-04-18, from https://academic.oup.com/qje/article-abstract/127/3/1143/1921708 doi: 10.1093/qje/qjs015

Bradsher, K. (2025, April 13). China tightens grip on rare earths, raising concerns over global supply chains. *The New York Times*. Retrieved 2025-04-18, from https://www.nytimes.com/2025/04/13/business/china-rare-earths-exports.html

Bureau of Industry and Security. (2018, November 19). *Review of controls for certain emerging technologies: Advance notice of proposed rulemaking* (Tech. Rep. No. 83 FR 58201). U.S. Department of Commerce. Retrieved 2025-04-18, from https://www.federalregister.gov/documents/2018/11/19/2018-25221/review-of-controls-for-certain-emerging-technologies (Published in the Federal Register, Vol. 83, No. 223)

Bureau of Industry and Security. (2022, October 7). *Commerce implements new export controls on advanced computing and semiconductor manufacturing items to the People's*

Republic of China (PRC) (Tech. Rep.). U.S. Department of Commerce. Retrieved 2025-04-23, from https://www.bis.doc.gov/index.php/documents/about-bis/newsroom/press-releases/3158-2022-10-07-bis-press-release-advanced-computing-and-semiconductor-manufacturing-controls-final/file

Bureau of Industry and Security. (2023, October 25). *Export controls on semiconductor manufacturing items* (Tech. Rep.). U.S. Department of Commerce. Retrieved 2025-04-23, from https://www.federalregister.gov/documents/2023/10/25/2023-23049/export-controls-on-semiconductor-manufacturing-items

Bureau of Industry and Security. (2024, May 14). *Additions of entities to the entity list. Federal Register*, Vol. 89, No. 94, pp. 41886–41895. Retrieved 2025-04-23, from https://www.federalregister.gov/documents/2024/05/14/2024-10485/additions-of-entities-to-the-entity-list (FR Doc No: 2024-10485)

Bureau of Industry and Security. (2025, January 15). *Framework for artificial intelligence diffusion* (Tech. Rep.). U.S. Department of Commerce. Retrieved 2025-04-23, from https://www.federalregister.gov/documents/2025/01/15/2025-00636/framework-for-artificial-intelligence-diffusion

Cabinet Office. (2022, October 12). *New National Science and Technology Council established* (Tech. Rep.). Retrieved 2025-04-23, from https://www.gov.uk/government/news/new-national-science-and-technology-council-established (Withdrawn on 8 February 2023)

Dasgupta, P., & David, P. A. (1987). Information disclosure and the economics of science and technology. In *Arrow and the ascent of modern economic theory* (pp. 519–542). Springer.

Dunne, J. P., & Tian, N. (2013, April). Military expenditure and economic growth: A survey. *The Economics of Peace and Security Journal*, *8*(1). Retrieved from https://www.epsjournal.org.uk/index.php/EPSJ/article/view/143 doi: 10.15355/epsj.8.1.5

Executive Office of the President. (2017, December 18). *National security strategy of the United States of America.* Retrieved 2025-04-18, from https://trumpwhitehouse.archives.gov/wp-content/uploads/2017/12/NSS-Final-12-18-2017-0905.pdf

Friedberg, A. L. (2019). The changing relationship between economics and national security. In *Power, Economics, And Security* (pp. 134–146). Routledge.

Fry, C. V. (2022). Bridging the gap: Evidence from the return migration of African scientists. *Organization Science*, *34*(1), 404–432. Retrieved 2025-04-18, from https://doi.org/10.1287/orsc.2022.1580 doi: 10.1287/orsc.2022.1580

Gardner, T. (2023, May 31). Us announces $46 million in funds to eight nuclear fusion companies. Retrieved 2025-04-23, from https://www.reuters.com/business/energy/us-announces-46-million-funds-eight-nuclear-fusion-companies-2023-05-31/

Giles, M. (2018, December 19). The man turning China into a quantum superpower. *MIT Technology Review*. Retrieved 2025-04-18, from https://www.technologyreview.com/2018/12/19/1571/the-man-turning-china-into-a-quantum-superpower/

Gross, D. P., & Sampat, B. N. (2022). Crisis innovation policy from World War II to COVID-19. *Entrepreneurship and Innovation Policy and the Economy*, *1*, 135-181. Retrieved from https://doi.org/10.1086/719253 doi: 10.1086/719253

Gross, D. P., & Sampat, B. N. (2023, December). America, jump-started: World War II R&D and the takeoff of the US innovation system. *American Economic Review*, *113*(12), 3323–56. Retrieved from https://www.aeaweb.org/articles?id=10.1257/aer.20221365 doi: 10.1257/aer.20221365

Hals, T., & Klayman, B. (2013, January 29). Chinese firm wins A123 despite U.S. tech transfer fears. *Reuters*. Retrieved 2025-04-18, from https://www.reuters.com/article/business/chinese-firm-wins-a123-despite-us-tech-transfer-fears-idUSBRE90S0JO/

Hartley, K., & Sandler, T. (Eds.). (2001). *The economics of defence* (Vol. 128). Edward Elgar Publishing. Retrieved 2025-04-18, from https://www.e-elgar.com/shop/usd/

the-economics-of-defence-9781852789459.html (Three-volume set compiling over 100 influential articles in defence economics)

Invest in Denmark. (2025, March 17). *Denmark's special quantum fabrication facility: Advancing the future of computing* (Tech. Rep.). Retrieved 2025-04-23, from https://investindk.com/insights/denmarks-special-quantum-fabrication-facility-advancing-the-future-of-computing

Kahn, H. (1962). *Thinking about the unthinkable.* Horizon Press.

Le Monde with AFP. (2021, January 21). Emmanuel Macron présente un plan quantique de 1,8 milliard d'euros sur cinq ans. *Le Monde*. Retrieved 2025-04-23, from https://www.lemonde.fr/politique/article/2021/01/21/emmanuel-macron-presente-un-plan-quantique-de-1-8-milliard-d-euros-sur-cinq-ans_6067037_823448.html

Lerner, J., & Stern, S. (2012). *The rate and direction of inventive activity revisited.* University of Chicago Press.

Loan Porgrams Office. (2023, August 22). *Inflation Reduction Act of 2022* (Tech. Rep.). U.S. Department of Energy. Retrieved 2025-04-18, from https://www.energy.gov/lpo/inflation-reduction-act-2022 (Accessed via the U.S. Department of Energy's official website)

Milmo, D., Hawkins, A., Booth, R., & Kollewe, J. (2025, January 27). 'Sputnik moment': $1tn wiped off US stocks after Chinese firm unveils AI chatbot. Retrieved 2025-04-18, from https://www.theguardian.com/business/2025/jan/27/tech-shares-asia-europe-fall-china-ai-deepseek

Ministry of Higher Education and Science, Denmark. (2023, June 21). *The Danish government is ready with a dedicated investment of one billion DKK as first part of a new quantum strategy* (Tech. Rep.). Retrieved 2025-04-23, from https://ufm.dk/en/newsroom/press-releases/2023/the-danish-government-is-ready-with-a-dedicated-investment-of-one-billion-dkk-as-first-part-of

-a-new-quantum-strategy

Mokyr, J. (2002). *The gifts of Athena: Historical origins of the knowledge economy*. Princeton University Press. Retrieved 2025-04-18, from https://press.princeton.edu/books/paperback/9780691120133/the-gifts-of-athena

Moretti, E., Steinwender, C., & Van Reenen, J. (2019, November). *The intellectual spoils of war? Defense R&D, productivity and international spillovers* (Working Paper No. 26483). National Bureau of Economic Research. Retrieved from http://www.nber.org/papers/w26483 doi: 10.3386/w26483

Moser, P., Voena, A., & Waldinger, F. (2014, October). German Jewish émigrés and US invention. *American Economic Review*, *104*(10), 3222–55. Retrieved from https://www.aeaweb.org/articles?id=10.1257/aer.104.10.3222 doi: 10.1257/aer.104.10.3222

Mowery, D. C., & Rosenberg, N. (1998). *Paths of innovation: Technological change in 20th-century America*. Cambridge University Press. Retrieved 2025-04-18, from https://www.cambridge.org/core/books/paths-of-innovation/B698D676A2D15D0C78228BF1A4227B4B

Mozur, P. (2017, July 20). Beijing wants A.I. to be made in China by 2030. *The New York Times*. Retrieved 2025-04-18, from https://www.nytimes.com/2017/07/20/business/china-artificial-intelligence.html

Murray, F., Stern, S., Campbell, G., & MacCormack, A. (2012). Grand innovation prizes: A theoretical, normative, and empirical evaluation. *Research Policy*, *41*(10), 1779–1792.

National Research Council. (2004). *Scientists, engineers, and track-two diplomacy: A half-century of U.S.-Russian interacademy cooperation* (G. E. Schweitzer, Ed.). Washington, DC: The National Academies Press. Retrieved from https://nap.nationalacademies.org/catalog/10888/scientists-engineers-and-track-two-diplomacy-a-half-century-of doi: 10.17226/10888

Nelson, R. R. (Ed.). (1962). *The rate and direction of inventive activ-*

ity: Economic and social factors [Book]. Princeton University Press. Retrieved from https://www.nber.org/books-and-chapters/rate-and-direction-inventive-activity-economic-and-social-factors

Nobel Prize Outreach. (1967). *The Nobel Prize in Physics 1967.* Retrieved 2025-04-23, from https://www.nobelprize.org/prizes/physics/1967/summary/

Nye, J. S. (2023). *Soft power and great-power competition: Shifting sands in the balance of power between the united states and china.* Springer Nature.

Office of Public Affairs. (2016, April 14). *U.S. nuclear engineer, China General Nuclear Power Company and Energy Technology International indicted in nuclear power conspiracy against the United States* (Tech. Rep.). United States Department of Justice. Retrieved from https://www.justice.gov/archives/opa/pr/us-nuclear-engineer-china-general-nuclear-power-company-and-energy-technology-international (Accessed: 2025-04-18)

Office of Science. (2023, August 14). *Department of Energy announces $112 million for research on computational projects in fusion energy sciences* (Tech. Rep.). U.S. Department of Energy. Retrieved 2025-04-23, from https://www.energy.gov/science/articles/department-energy-announces-112-million-research-computational-projects-fusion

Office of the Spokesperson. (2024, September 9). *New partnership with India to explore semiconductor supply chain opportunities* (Tech. Rep.). U.S. Department of State. Retrieved 2025-04-18, from https://2021-2025.state.gov/new-partnership-with-india-to-explore-semiconductor-supply-chain-opportunities/ (Accessed via the U.S. Department of State (2021-2025 Archive))

Office of the Under Secretary of Defense for Research and Engineering. (1986, October). *Militarily critical technologies list* (Tech. Rep.). U.S. Department of Defense. Retrieved 2025-04-18, from https://hdl.handle.net/2027/uiug.30112105156761 (Cover title; October 1986 edition)

Office of the United States Trade Representative. (2018, March 22). *Findings of the investigation into China's acts, policies, and practices related to technology transfer, intellectual property, and innovation under Section 301 of the Trade Act of 1974* (Tech. Rep.). Executive Office of the President. Retrieved from https://ustr.gov/sites/default/files/Section%20301%20FINAL.PDF (Accessed: 2025-04-18)

Reuters Staff. (2024a, March 14). Japan's JIC to start tender offer for JSR on March 19 after Chinese approval - Bloomberg News. Retrieved 2025-04-23, from https://www.reuters.com/markets/deals/japans-jic-start-tender-offer-jsr-march-19-after-chinese-approval-bloomberg-news-2024-03-14/

Reuters Staff. (2024b, May 8). US official says Chinese seizure of TSMC in Taiwan would be 'absolutely devastating'. Retrieved 2025-04-23, from https://www.reuters.com/world/us/us-official-says-chinese-seizure-tsmc-taiwan-would-be-absolutely-devastating-2024-05-08/

Reuters Staff. (2025, April 22). IMF cuts growth forecasts for most countries in wake of century-high us tariffs. Retrieved 2025-04-23, from https://www.reuters.com/business/imf-cuts-growth-forecasts-most-countries-wake-century-high-us-tariffs-2025-04-22/

Shepardson, D. (2024, June 26). US, Japan, South Korea vow strategic cooperation to boost security, economies. *Reuters*. Retrieved 2025-04-18, from https://www.reuters.com/world/us-japan-south-korea-vow-strategic-cooperation-boost-security-economies-2024-06-27/

State Council of the People's Republic of China. (2015, May). *Notice of the State Council on the publication of "Made in China 2025"* (Tech. Rep.). Center for Security and Emerging Technology. Retrieved from https://cset.georgetown.edu/publication/notice-of-the-state-council-on-the-publication-of-made-in-china-2025/ (Translation of the original document dated May 8, 2015. Translated March 8, 2022.)

Strider Global Intelligence Team. (2019, November). *Quantum dragon: How China is* *exploiting western government funding and research institutes to leapfrog in dual-use quantum technologies.* Retrieved 2025-04-23, from https://www.striderintel.com/resources/quantum-dragon-report/

U.S. Congress. (2022, August 9). *Chips and Science Act of 2022.* Public Law No. 117-167. Retrieved 2025-04-18, from https://www.congress.gov/bill/117th-congress/house-bill/4346/text (Enacted August 9, 2022)

U.S. Department of Energy. (2021, January 15). *Critical minerals and materials: U.S. Department of Energy's strategy to support domestic critical mineral and material supply chains (FY 2021–FY 2031)* (Tech. Rep.). U.S. Department of Energy. Retrieved 2025-04-18, from https://www.energy.gov/sites/prod/files/2021/01/f82/DOE%20Critical%20Minerals%20and%20Materials%20Strategy_0.pdf (Accessed via the U.S. Department of Energy's official website)

U.S. Department of Health and Human Services. (2020, May 15). *Trump administration announces framework and leadership for 'Operation Warp Speed'* (Tech. Rep.). Retrieved 2025-04-18, from https://web.archive.org/web/20201216233803/https://www.hhs.gov/about/news/2020/05/15/trump-administration-announces-framework-and-leadership-for-operation-warp-speed.html (Archived via Wayback Machine)

Wald, M. L. (2009, April 30). Fusion energy gains support as oil prices rise. Retrieved 2025-04-23, from https://www.nytimes.com/2009/04/30/business/energy-environment/30fusion.html

Wong, E. (2016, August 16). China launches quantum satellite in bid to pioneer secure communications. *The New York Times*. Retrieved from https://www.nytimes.com/2016/08/17/world/asia/china-quantum-satellite-launch.html (Accessed: 2025-04-18)