How Geopolitics is Changing the Economics of Innovation

Aaron K. Chatterji * Fiona Murray†

July 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 pathways and production of innovation around the world - highlighting priorities for both innovation ecosystems and for the industrial base. And, at each stage of the innovation process, the focus on control of innovation is shaping considerations for the geographic distribution of participation. To enable greater control, nations are creating new institutions to shape the innovation ecosystem, guided by the logic of economic security as opposed to 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
Acknowledgement: This work was supported by the Ministry of Education of the Republic of Korea and the National Research Foundation of Korea (NRF-2018S1A3A2075175).

1 Introduction

Over the last 40 years, economists have developed extensive evidence to support the crucial role that innovation plays in driving economic growth. Consequently, there has been an increasing scholarly interest in the rate and direction of technological progress that facilitates that economic growth. However, most of this research has been carried out 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, especially through the rise of innovation ecosystems such as Silicon Valley. 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 i.e. with a focus on the early-stages of the innovation process. And, to enhance the speed at which commercialization and scaling 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 across a global stage into products serving large swaths of consumers and businesses. Along the continuum from idea generation to commercialization, scaled-up production, and growth, certain geographies would likely be favored for RD or alternatively for production at scale due to their endowments of human capital or natural resources. Furthermore, 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 not only for scholars but also for policy makers. In the domestic narrative on innovation, the emphasis during this era of globalization thus been to reinforce US advantage as an innovator in new products and services strengthening resources that drove unique innovation ecosystems towards ever more sophisticated ingenuity at the frontiers of knowledge. And at the same time, policymakers largely overlooked the US industrial base, instead emphasizing the ways in which global production and supply-chain networks often in China could serve to amplify and produce US ideas at scale; an approach most visibly characterized by the millions of iPhones a year being designed in Silicon Valley and produced in Shenzhen.

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 - even up to the publications of a follow-up volume that revisited the ideas of Nelson, Arrow and others (Lerner & Stern, 2012). More broadly, academic research on the economics of innovation historically focused on central questions that aligned with both a stable geopolitical context and the obvious globalization of innovation; What is the geographic distribution of technological expertise around the world and across the US? What are the underlying drivers of this expertise and advantage? To what extent do policy interventions shape this distribution by shaping 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 innovative outcomes?

The innovation topics that have been most studied by economists not only emphasized early-stage RD-driven innovation, but also 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. As part of industry focus, the economics of innovation also expanded its attention towards the role of startup entrants and related funding vehicles, most notably venture capital. Manufacturing-based industries were less widely examined, noting that topics such as the loss of manufacturing, shifting labor-market structures and the location of manufacturing were always of interest to those in fields such as regional economics. Across high-growth sectors, American companies (both incumbents and entrants) built on significant and growing investments in public RD by the U.S. government, and were enabled by a predictable set of rules and regulations, albeit with a range of antitrust challenges over the past several decades. As a result, the questions framed by economists of innovation were largely ones related to the distribution and effectiveness of RD-driven activities in a stable economy embedded within a global market. This backdrop provided innovation economists with the luxury of holding key variables fixed, to the point that politics and geopolitical dynamics effectively faded into the background except when useful as an exogenous shock.

That predictability has now given way to tremendous uncertainty. The rise of China as an economic and military superpower has created a new paradigm in geopolitics. We live in an era that is and will be shaped by superpower competition between the U.S. and China; one which has been increasingly 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 economists studying innovation, it is essential to examine how this new era of geopolitics is redefining the key questions that lie at the core of empirical and theoretical inquiry and which must be addressed in order to support effective innovation policy and strategy in high-tech industries. In short, we argue that because geopolitics is radically changing, so must the economics of innovation.

National security concerns are beginning to play a significant role in economic policy and business decisions around the world. This shift in priorities introduces new externalities to economic models and calls into question traditional assumptions underpinning how economists understand the desired aspects and outcomes of the innovation process. In particular, these externalities focus on shaping and controlling the direction of the early stages of the innovation process towards specific goals and later stages towards full-scale (domestic) production. And they shape beliefs around the value of different stages of the innovation process taking place in 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 at scale and develop national production 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 (e.g. for smaller nations), countries 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 and private sector incentives.

At the same time as the geopolitical landscape is shifting, another shift is taking place; one that emphasizes what kinds of technology lie 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 deployed in future energy systems, communications systems, and defense systems (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, production of deep tech solutions requires not simply the distribution of software applications worldwide, but the complex, skills-based and cumulative production of solutions using the methods of advanced manufacturing, complex assembly of multiple sub-components, and sophisticated and entangled supply chains all the way down to critical materials. When combined with a desire for strategic autonomy, the materially complex production of deep tech solutions at scale is driving nations to assert control over direction of through to the full-scale production of an array of priority technologies ranging from quantum computing, 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 their 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 the two dimensions along which the economics of innovation has shifted with the return of geopolitics and rise of deep technology: the direction of innovation pathways at the start of the innovation process (i.e. the focus on specific technologies and trajectories) and the emphasis on the production of innovation at scale (i.e. the shift towards producing ideas at scale not simply producing inventions). At each stage of the innovation process, an emphasis on control also brings with it a focus on shaping participation in innovation. Put differently, given the desire of the US (and other nations) to be effective in each stage of innovation, who are the most appropriate allies and partners and, in an era of heightened geopolitics, to what extent should partnerships be limited and the participation of adversaries be curtailed? Our following section explores how government departments are adapting to shape innovation policies to intervene across both the early- and scaling-phase of innovation and adapting to adjudicate participation in each phase. Lastly, we provide case studies of three important technologies as examples of how innovation policy might develop differently under the new geopolitical 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 RD as a fundamental input into innovation (Arrow, 1962). The core argument for government involvement in RD, and innovation more broadly, was grounded in the importance of unexpected spillovers from RD that might lead to new early-stage ideas and subsequently generate significant economic benefit. As a result of these hard-to-predict outcomes, private actors (mainly large corporations but also start-ups) under-invested in RD. As a result, governments traditionally intervened to increase RD spending in hopes that this would boost spillovers and amplify important economic outcomes and the long-term prosperity that followed. Historically, it was only for a very narrow set of technologies and capabilities - such as those necessary for national security and defense - that government RD (especially directed towards classified and unclassified research in national labs) was justified less on its 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 - an argument that is closely aligned to the findings on defense versus non-defense RD spillovers (**?**).

Building on this framework, the economics of innovation research has emphasized analysis of the levels of RD 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 RD 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 lines all emphasize economic outcomes with a focus on the early stages of innovation especially patenting (often by universities and licensed to startups), with the relationship between the RD production function on the one hand and productivity, competitiveness and economic prosperity (including jobs) on the other being of central interest (**?**) (**?**).

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 innovation ecosystem but also the industrial base 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 and across the innovation journey from idea to production at scale 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. 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. Bringing these two dimensions together, the goal for today's public 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 a nation's security. While developing and leveraging advanced technology is critical to both endeavors, these dual policy objectives might often be at odds and the calculus and mapping between them is an entirely under-theorized aspect of innovation policy.

The origins of this shift to economic security 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 its 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 illustrated the ways in which China, much as in the U.S., increasingly saw 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 shaped 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, China's launch of a quantum communication satellite in 2016, incorporating research from a wide range of leading laboratories around the world (including the United States), emphasized the potential challenges of China's growing technological prowess as a vehicle for 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 in the direction of innovation. 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 - thus a renewed emphasis on controlling scaled production. 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 recognition of a new intersection between innovation and national security came a call to action to protect and control the fruits of innovation at every stage.

The fusion of economic and military strength is 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 at scale and away from simply increasing the rate of innovation. Moreover, the widening scope of national security across the innovation landscape (from early ideas to scaled production as well as across a wider frontier of innovative technologies) also increases the emphasis on using economic statecraft to align investment activities, supply chains and even trade policies 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 (**?**).

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 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."

Although 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 two dimensions: i) the direction or path of the earliest stages of innovative activity (i.e. what goals are targeted) and ii) the importance of production at scale of those innovations (i.e. how much is production and supply chains are emphasized. Within our new economics of innovation framework, we can understand policy interventions as being framed not simply by the degree to which they drive innovation, technology development, and subsequent economic advancement increasingly across the entire innovation process, but also whether they enhance national security through control of the geography of these activities, the partners with whom they are shared and the adversaries who are deterred (**?**).

First, nations like the U.S. and China are increasingly seeking to control the paths of innovation i.e. the direction of selected projects, in order to align with their own national security priorities. Since many of the critical technologies of our time – including generative AI, vaccines, and post-quantum encryption – are obviously directly relevant to, and critical for, 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. Furthermore, the introduction of the 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, learning from the Covid-19 era, governments have sought to shape investments in biotechnology to emphasize efforts directed at rapid vaccine development and production as well as platforms for rapid viral analysis. Nations also increased their emphasis on efforts to build so-called post-quantum encryption. And encryption methods that are resistant to powerful quantum computers have been supported 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 as demonstrated by recent DARPA challenges (see below).

Understanding this renewed emphasis in the U.S. and around the world toward directing innovation pathways towards critical missions is of central importance to the emerging new economics of innovation. Controlling the direction of innovation is not entirely new: 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. Similarly, DARPA has long served as a mechanism to control the direction of innovation by spurring activities towards national priorities (especially those with defense applications). In recent years, 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 RD 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 autonomy or pandemic preparedness), 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, the list was short and emphasized military and communications technology. In 2018 the 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. For the new economics of innovation, questions of prioritization and direction setting must be front and center: Are mechanisms to direct innovation successful? What are the benefits of various tools from supply- and demand-side perspectives? And what are the tradeoffs of such an approach compared to a more open-ended perspective on spillovers and serendipity?

Questions such as this serve as a centerpiece for the new economics of innovation. However, in the context of early-stage innovation and the market for ideas, government policy has increasingly examined the geography of networks of participation and collaboration. As such, the new economics of innovation must do so as well. In the past, the economics literature was largely focused on the war for talent and 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 were examined as opportunities to tap into different complementary expertise or as a source of soft power. In turn, these networks and the mobility that came with them were analyzed as a boon for innovation and entrepreneurship - whether 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). Of course, issues of control were never far below the surface (in the policy context if not the scholarly one): 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) to ensure that individuals from the Soviet Union were not involved in sensitive defense projects nor posed a threat to national security. Today, attention has shifted more fully to control of 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). As a consequence, the economics of innovation must incorporate these topics into the consideration of innovation direction of RD. Immigration policy, research security and even capital flows (e.g. CFIUS) are now key elements of innovation policy shaping control of early-stage ideas and thus worthy of analysis especially of the relevant tradeoffs **?**. Exemplified by the rising interest in research security at U.S. federal agencies and universities, and recent high-profile prosecution of espionage cases, the emerging approach to control 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 thus worthy of study.

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), (**?**). As a result of rising control of academic and other early-stage research by both the US and other nations such as China, there is room for extensive scholarship on whether such interventions shape productivity by limiting cumulative innovation, but also whether they shape the direction - by striving to bifurcate scientific networks and ambitions. Of course, these and related questions on the early paths of innovation must also be examined against the range of more philosophical debates over the nature of the academy.

The second central question for the new economics of innovation relates to policies and practices that encourage and control the production of innovation at scale - both manufacturing and supply chains. In other words, as the shift in innovation policy moves away from economic prosperity and global comparative advantage towards economic security, leaders are assuming it is not enough to simply operate in the market for ideas even if that market is being driven towards comparative advantage in important and desirable innovations. It is also now deemed essential to control (at least some) production at scale. More specifically, while economic advantage has traditionally come from having ideas and contracting across a diverse range of countries and geographically distributed partners for production at scale (and access to supply chains), national security increasingly relies upon control of ideas as they scale. This is a new approach to innovation as production was only considered to be essential for a very narrow range of items such as defense technologies (e.g. F-35s), satellites and space launch, and nuclear technology.

Today, the desire to control production has expanded across the growing list of priority technologies. And, as a result, nations also wish to control participation in entire supply chain networks so that they can develop and deploy, and thus control when and where their ideas are produced at scale rather than be subject to hold-up. In recent years, for example, we have observed broad efforts in the United States to exert more control over energy infrastructure production (Loan Porgrams Office, 2023)), biological drugs (U.S. Department of Health and Human Services, 2020), and computer chips (U.S. Congress, 2022).

The focus on production at scale raises new questions for the economics of innovation: What are the potential economic costs and benefits of ensuring scaled innovation? What are the most effective policy interventions for driving the location of facilities in the US rather than elsewhere? And what are the potential job losses associated either domestic or global production?

Such a desire to scale innovations 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.). That said, the contemporary narrative also emphasizes driving the ability to use technological innovation as a tool of economic statecraft to deter or damage adversaries i.e. to reduce dependency on specific nations (namely China) and to have the ability to use supply chains for more offensive rather than defensive purposes: this consideration has been highlighted in recent months following decisions by China to limit the sale of key drone components to innovative companies such as Skydio due to their sales to Taiwan (noted above). As a result of the geopolitical nature of production and the industrial base innovation policy is now driven towards the inclusion or exclusion of specific nations in networks of innovative production at scale. Control over bio-manufacturing, for example, given the vulnerabilities that otherwise arise from having essential medicine production (and design) controlled by adversaries - is an especially interesting example of the desire for production at scale driving innovation policies given the otherwise globalized nature of the industrial production base.

Recent sanctions placed on essential critical minerals and materials (CMMs) by China - (including in response to U.S. sanctions) - have highlighted the vulnerability of globally distributed supply chains not simply manufacturing and production. (Bradsher, 2025). Innovation policy therefore now incorporates the design of supply chains for innovative products with a desire to localize supply chains and reshape the geography of dependency throughout the supply chain network. For example, the Department of Energy CMM Program (U.S. Department of Energy, 2021) represents the most recent attempt to remove vulnerabilities that arise from uncontrolled participation when it comes to production at scale. This 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 it 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 with the geography of dependencies taking center stage.

Taken together, policy shifts towards controlling (and supporting) innovation at scale and removing dependencies from specific nations 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. They provide a new context in which to reexamine questions that animated economic historians of technology who have long placed manufacturing, production and supply chains more broadly (including industrial espionage of essential manufacturing technologies)at the core of their inquiry. And they shape a series of questions around how and under what circumstances these tradeoffs are most effectively implemented.

Shaping two dimensions of control over the innovation journey; directing pathways and scaling production are not entirely new tasks for governments and as such not entirely new ideas for economists of innovation. Indeed, national security and geopolitical concerns have shaped innovation for decades, though more prominently in some eras compared to others. The Manhattan Project was an initiative borne out of the desire to shape the direction of atomic physicists with a clear pathway towards building weapons, controlling who had access to them and enabling their scalability for the United States alone. Further along the innovation journey, RADAR was first developed by the U.K. and then deliberately transferred to the U.S. in the hopes that this would allow for Allied control of scaled production, and to ensure that technological capabilities did not fall into the hands of Nazi Germany. Moreover, economic history is replete with examples of technological capabilities being subject to attempts at disruption to rapidly limit the pathways of innovation open to adversaries (including Allied attempts at disrupting heavy water developments in occupied Norway). And, the role of blockades to divert much needed scaled production (included Saltpetre from Chile essential as an input into explosives being limited by German blockade. 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 and essentially faded into the background of a global stage. Now is an important moment to re-evalute this understanding and open up entirely new avenues for analysis.

In making the turn towards a more geopolitically informed economics of innovation, away from the geopolitically neutral stance of the economics literature around innovation, growth and productivity, scholars might be informed by two important streams of prior literature. The first is the quite narrowly focused economics of military and nuclear technologies. Scholars in this tradition have sought to examine "The Economics of Defence,", for example in the volume edited by Hartley and Sandler (2001), by explored the economic implications of military spending, the cost-benefit analysis of defense expenditures, and how military spending interacted with economic growth. From a more technological lens, Herman Kahn's work understanding how arms races and military strategy interacted with economic factors is a useful case study: 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).

Further examining defense RD and innovation, Arrow and others cited defense technologies as a classic public good that is non-excludable (i.e. everyone benefits from national defense, regardless of who contribute to funding) and non-rivalrous (i.e. 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. The focused on specific defense spending during the Cold War era has been examined by Mowery and Rosenberg (1998) and Gross and Sampat (2023). Beyond this analysis, scholars emphasized the economics of military spending and focused on the (limited) impact of defense expenditure on economic growth Dunne and Tian (2013). By examining the relationship between military spending and economic performance, particularly in terms of its effects on capital accumulation, industrial output, and technological innovation, they opened up a topic more recently revived by Moretti, Steinwender, and Van Reenen (2019) and **?**.

Against the traditional backdrop of the economics of defense spending and specifically defense RD, scholars of innovation should not forget that 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 with early-stage idea pathways generated from a range of disciplines from the life sciences and chemical sciences to material science and advanced physics. And, later-stage production based on globally distributed and highly sophisticated manufacturing and supply chains. As a result, many questions and contexts in the new economics of innovation must not only take geopolitics into account but also a wider technological landscape as well as develop a renewed focus on the impact of controlling innovation, often through industrial policies.

Together, this direction for scholarship opens up exciting new questions: What are the tradeoffs that arise at each stage of the innovation process when we aim to control first the pathways for innovation and second, the production of innovations? What are the impacts on productivity and on security of policy interventions, particularly those that also aim to re-shaping the geography of participation at the different stages of innovation? What are the tradeoffs to be considered and over what time horizons? This agenda is already starting to take shape. In this volume, the Chapter by Paine **?** examines the specific implications of the Foreign Investment Risk Review Modernization Act (FIRRMA) which seeks to control capital flows. The paper carefully lays out the pros and cons of controlling the geography of participation in early-stage innovation. Other work is looking at whether it is efficient or effective for many nations to have their own programs for a priority technology such as quantum computing and examining the impacts on productivity and **?** and on the direction of of innovation **?**. More work is clearly on the horizon.

Leaders around the world have already started the process of building new institutions and reforming old ones to adapt to this new era. And, at the same time, scholars in the law and economics tradition have started to explore the inherent frictions associated with the raft of legal structures that shape control of key inputs into the innovation process (including talent, capital and ideas) **?**. In this 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

Government leaders are adapting their innovation institutions in an effort to ensure alignment with economic security priorities and to expand 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, especially given the tradeoffs implicit in balancing economic and security outcomes.

Scholars of the innovation economy have examined how particular institutions shape the productivity of innovative activities and the ways in which expenditures on RD are 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 RD funding organizations have increased the rate of innovation. Most notably, in the defense and security context, Azoulay, Fuchs, Goldstein, and Kearney (2019) explored the ways in which the allocation and management of funding at 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 innovative outputs (Azoulay, Graff Zivin, Li, & Sampat, 2019), following a long tradition of evaluating the large amount of research funding allocated through this department. Overall, this work provides a strong foundation upon which to examine the institutions of the new economics of innovation.

As a starting point for scholars interested in the (re) organization of innovation, we first highlight some notable government programs and units that are being adapted and expanded to control the direction, as well as participation, at the earlier stages of innovation, often building on but extending a long tradition of directional control. The U.S. Department of Defense - already home to DARPA, has expanded its range of programs emphasizing the direction and control of innovation: the Defense Innovation Unit and the Office of Strategic Capital respectively support startups develop dual-use solutions to military problems and provide support that extends programs like SBIR. Likewise, InQTel and CIA Labs are aligned with the U.S. intelligence community and aim to control the direction of innovation by providing investment capital (equity and grant-style capital) to startup ventures with innovative projects that are of potential value 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 in areas such as fusion, batteries, and grid scale storage. And within the 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 mechanisms for funding.

To date, policymakers have attempted to extend their control over researcher participation by expanding existing approaches such as visas. And they have aimed to shed light on the underlying rationale of the threats (observed by the government) of wider global access to science of national importance. This is a new dimension of government policymaking because, of course, traditional approaches relied upon the existence of a small handful of laboratories with security clearances and strict participation controls. But as the technology frontier widens this is no longer an effective path forward and participation must be mediated in new ways with new structures. Efforts by government departments such as the FBI have engaged NSF and academia more broadly in the debate over limits to entirely open participation in scdience, but these initiatives have been met with challenges. Recent briefing papers made available to university leaders have attempted to outline government concerns regarding 'foreign malign influence' at universities. More specifically, government departments providing research funding (including the NIH) have started research security efforts. For example, 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. The general chilling of the climate for foreign students and researchers is the subject of new lines of economic analysis **?**.

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 total budget 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 including 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.

Beyond institutions shaping the direction of early-stage innovation are those new policies, programs and units established to drive how innovation is controlled at scale. Here we emphasize how the U.S. government is developing its innovation institutions to try and ensure that ideas are not simply 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. The most notable efforts have been deployed by the DoE whose so-called tech-to-market and "First of a Kind" (FOAK) programs emphasized 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 (especially in its work with startup ventures). New entities within the DoD include the Office of Strategic Capital with approximately $1 billion in capital to invest in 2025 to fund domestic supply chain and manufacturing investments and thus scale innovations at a level that has been lacking from previous DoD efforts. Increasingly, their focus is also on funding the wider 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 through this new Directorate to RD, 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 established to exert greater control over 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

In this last section, we draw out the implications of our argument through three cases of priority technologies that are evolving under the new geopolitical paradigm, with the shifting economics of innovation it implies. Through the examples of quantum computing, semiconductors, and fusion energy we demonstrate how geopolitical shifts are leading nations to exert more control over the technologies being developed at the frontier of knowledge and increasingly scaled up as "deep tech" within particular nation states rather than across a global terrain.

5.1 Quantum Computing

Quantum computing - a domain within computer science that is adapting quantum mechanics to develop new technologies - has experienced a surge of popular and investor interest in the past decade. Rather than simply produce new and more powerful classical computers, quantum computers promise to solve previously intractable problems in new ways. In prior decades, building such a working hardware system was 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 research efforts and collaborations turned towards building quantum devices including designing the sophisticated and complex quantum chips that would actually form the core of such machines. What followed has also been the creation of a large number of quantum computing startup ventures focused on deploying alternative approaches to engineering working-scale quantum computers.

Given the timing of the explosion of quantum computing research, this field has proven to be one of the first areas of technology initiated in an era 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 steps to control the direction 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 year 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. But quantum also has the potential to solve other extremely challenging problems in drug discovery, material science and the financial markets. Adding to the desire to be autonomous in quantum expertise is growing concern that the global diffusion of knowledge has undermined national security goals. A 2019 report by Strider's Global

Intelligence Unit entitled The Quantum Dragon, for example, documented how the Chinese government exploited the open orientation of the quantum innovation system to leverage technologies for their own military (Strider Global Intelligence Team, 2019). Over a ten-year period, the CCP executed a strategic plan to acquire knowledge from returning scientists who had worked in American and European research institutes to become a quantum leader. This report and similar data from sources like the Australian Strategic Policy Institute'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 the explicit aim to exert more control over the direction and scale of quantum computing and a desire to carefully control the geographic distribution of these activities at each stage in development. 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 purposefully, 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 also aimed to foster close ties between its domestic academic institutions and entrepreneurial community to shape the direction of research towards scale up. Notably, these efforts to shape the direction of quantum research have also, 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. Building on U.S. experience, smaller nations have also launched efforts to control the scaled manufacturing of quantum computers to domestic production, despite the obvious 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 RD 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 today. From the beginning of the industry, chipmaking was a global industry with early semiconductor manufacturers designing chips in the U.S. and making chips in facilities in Asia to lower the cost of production. Over time, earlier stages of innovation then moved to be more proximate to production and the U.S. lost a significant lead in early stage innovation as well as loss of control over supply. 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 as a source of economic security (**?**).

The 2022 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 outside the control of a country such as the U.S., this drives strategic vulnerability into the supply chain. Behind various policy moves is therefore the recognition that computer chips are strategic - not just because of their use to train artificial intelligence models but also as components of consumer electronics, medical devices and military technologies. 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 gaming efforts) - 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 model outlined in the new economics of innovation 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 RD 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.

Second, 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 photo-resists - 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.

Beyond proactively shaping the domestic supply chain, the U.S. has sought to more aggressively shape its global configuration. In 2022 and 2023 under the Biden Administration, the U.S. Bureau of Industry and Security introduced export controls 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.

With national governments taking steps to shape the direction of and scale of innovation in the semiconductor industry, as well as its geographic boundaries, 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 anticipating further controls and acting accordingly. Scholars seeking to understand the direction and control of innovation in semiconductors and the implications of these new choices on the rate of innovation in the industry will thus have to incorporate these new realities into their analysis.

5.3 Fusion Energy

We have selected fusion energy 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 filed 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 reaction. British scientists visited various demonstrations in the former U.S.S.R in the 1950s and 1960s and by the 1980s international collaborative projects were well underway in the UK, France and

Japan (including JET -the joint European Torus built just outside Oxford). Leveraging decades of government funding and global collaboration, in 2006, a decision was made to concentrate funding in one large-scale global project to amplify the rate of innovation via a more coordinated use of funding: the International Thermonuclear Experimental Reactor (ITER) project was established. Funding came from the EU (including the UK), Japan, the U.S., Russia, India, South Korea and China with each nation contributing to different technical aspects of the project including the design and manufacture of components such as the vacuum vessel and the magnets (Wald, 2009).

In an era of globalization, projects such as ITER were held up as examples of global open science. However, with the shifting geopolitical landscape and advent of an era of geopolitics, the starving of national-level research efforts in favor of focused funding for one international project were seen as increasingly detrimental to both rate, direction and control. As a result, 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 few defined policy interventions as compared to 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 and ensure that lessons of past supply chains lost are not repeated (**?**).

To control the direction of innovation, the U.S. has taken a relatively hands-off approach with private (and some public) sector funding supporting distinctive directions of innovation:

magnetic (tokamaks) and laser confinement. In contrast, China has largely focused on the tokamak designs (and emphasized highly focused public sector funds). 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). 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 also 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. Much as with other priority technologies, the case of fusion energy opens up a wide range of possible research questions for scholars interested in the ways in which previously open collaborative models of science are being replaced by more nationally-controlled approaches. And, fusion presents an opportunity to examine emerging supply chains whose structure is shaped entirely within an era of geopolitics rather than globalization.

6 Discussion

The economics of innovation is entering a new era where geopolitics matters once again. We explain that rising U.S.-China tensions have motivated nations to exert more control over the direction and scaling of innovation shaping both pathways and production. In each stage of the innovation journey, geopolitics is also guiding considerations of which nations are working in collaboration to develop and scale innovations, and which are establishing boundaries and even proactively disrupting others. 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 new geopolitical approach that could lead to retrenchment in the coming years especially at the intersection of economic and security goals. A less integrated global economy may 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. On the other hand, when deep technologies are also sources of national security and their production facilities and supply chains a source of strategic vulnerability, it may be that closed systems are more effective. The role of allies and partners is likely to be essential to the balance in these various goals (**?**).

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 remain rare and the two groups typically lack a common language to identify common goals and execute against them. As economics and security become crucial to innovation, economists and those in ministries of trade and commerce will have to learn how to work effectively with the national security community. Both sides will have to gain more insights into how their priorities and policies shape the rate and direction of innovation and how methods to establish control are likely to impact desirable outcomes. 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, as economists who study innovation we will have to shift our agenda to accommodate these new factors and revisit our old 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 explore these research questions 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

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

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 activity: 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 Nu-*

clear 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)