Innovation and Its Discontents: National Models of Military Innovation and the Dual-Use Conundrum

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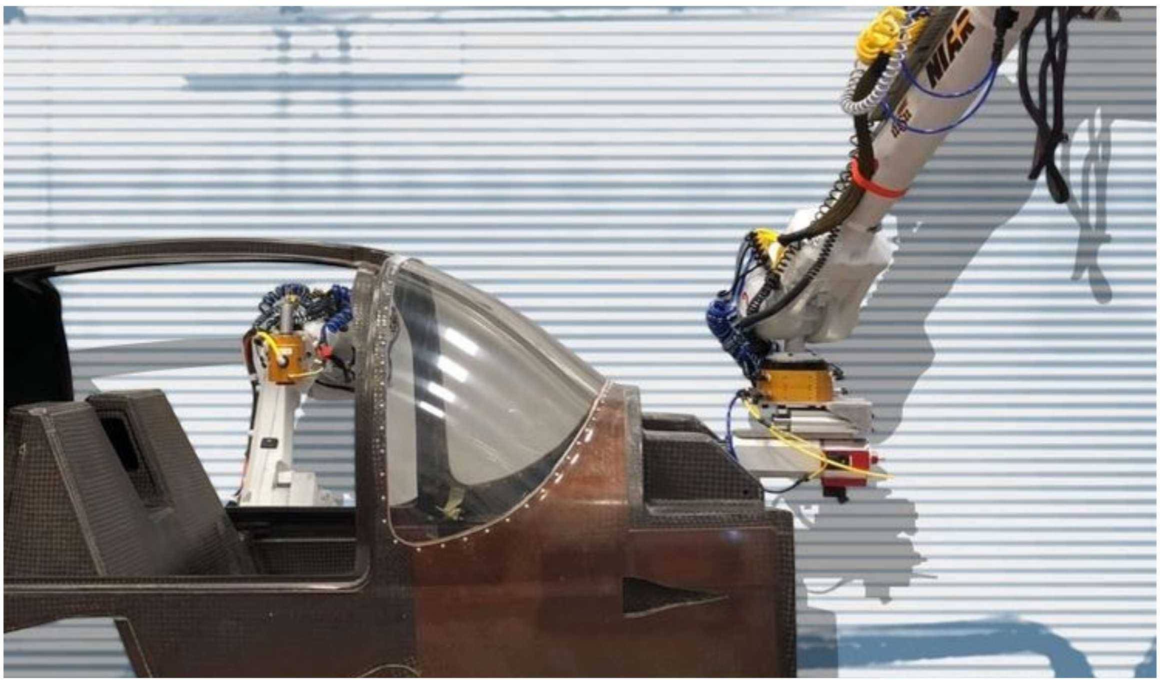

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Executive Summary

This study explores variations in national models of innovation, as well as the pathways or levers those models afford in controlling innovation's end product. This report focuses on dual-use, emerging technologies' "origin stories" and takes a big picture view of their emergence. It is bookended by an exploration of where these dual-use technologies come from and by an assessment of where they are going.[1] The report uses case studies of both U.S. and German investment in artificial intelligence and additive manufacturing to highlight national approaches to innovation, assessing each country's approach to regulating sensitive and dual-use technologies once they have been developed.

The report argues that within a national model of innovation, the way in which technology is procured by a state's military is linked with that state's ability to control or regulate an end-product and, in turn, prevent diffusion or proliferation. On national models of innovation, their evolution and variation, it finds:

- **The United States has restructured its innovation model with "military edge" in mind, seeking to "out innovate" rival states in the security domain, and, at the national level, is currently debating "how to get innovation right" for defense purposes**. Meanwhile, Germany has refocused its model to address retraining its workforce and maximizing market share. Both countries face high uncertainty about the future. **We do not yet know what a successful model for innovation looks like in this technological and political ecosystem, but every state's model can be understood as some combination of state-level investment in and the military integration of dual-use technologies**.
- **National models of innovation are being reshaped with state goals for dual-use emerging technologies in mind:** The U.S. and German national models of innovation are currently evolving to reap the benefits of private-sector innovation to achieve national goals. However, there are significant "growing pains" in the restructuring and evolution of both. States face increasing tradeoffs as the structure of their national models evolve to achieve chosen ends, making R&D infrastructure less flexible in the long run.
- **The U.S. model for innovation is characterized by the quest for superiority through the monopolization of military innovation. It follows that the U.S. approach to the export or sale of sensitive military and dual-use items is implicitly based on the assumption that the United States has a monopoly on technology innovation** (which yields superiority) and "helps" allies by exporting (selling) them sensitive items. This is no longer the case. The United States has a particularly difficult time considering any other paradigm and conceiving of European states as either competitors or collaborators.
- **In Germany, the pursuit of military advantage through innovation ended in the wake of World War II with the demise of Hitler and the Nazi regime.** In the post-War period, Germany channeled its engineering expertise into its workforce and economy. German capacity for engineering continues to be valued and is instantiated in the country's large network of innovation centers. This "Fraunhofer model" reflects the German understanding that "innovation must result in productivity gains that are widespread, rather than

[1] The question of how these technologies are proliferating or will proliferate is addressed in a companion report by Dr. Alexander Montgomery: (Montgomery, 2019)

concentrated in the high-tech sector of the moment."[2] Germany's national model of innovation has perpetuated the robustness of Germany's industrial base, which fuels its export-led economy. Germany has adopted a collective mentality of "huddling in the middle" and is reluctant to innovate in the pursuit of military advantage, an area in which it still operates as a penitent actor.[3]

Implications of the U.S., German models for Innovation:

- **Whereas the United States is better at defense integration than Germany, Germany spends more on innovation per GDP than does the United States. And Germany has a more efficient, profitable, and sustainable innovation model.** Germany out-innovates the United States in sustainable energy systems, molecular biotechnology, lasers, and experimental software engineering; it is better at "adapting inventions to industry and spreading them throughout the business sector"; and it is better at "infusing old products and processes with new ideas and capabilities or recombining elements of old, stagnant sectors into new, vibrant ones."[4]
- Because we are in a high uncertainty environment, characterized by rapid change, setting goals and establishing strategies for "winning the competition" in innovation is difficult. **The problem with all of this "competitive innovating" for defense and security is that, absent a strategy or concrete operational goal, the risk of not being successful (having measurable yield) is high.** There is an opportunity for the United States to establish the course and set the bar for innovation, as well as lead in establishing goals for innovation's yield. There is also ample opportunity and good reason to justify transatlantic cooperation in this realm.

By tracing the innovation process across U.S. and German national systems, this study highlights common patterns and critical divergences in order to assess the possibilities for and the obstacles to international cooperation in countering "next generation proliferation," or the multi-modal, global diffusion of dual-use technologies. The study explores U.S. and German investment and expertise in the development of two types of dual-use technologies: artificial intelligence (and two of its components: robotics and semi-conductor engineering) and additive manufacturing.

On Artificial Intelligence, it finds:

- The U.S. government spends far less on AI industrial application and more on defense relative to Germany.
- The U.S. has been comparatively slow to adopt a national AI strategy. Germany's strategy is focused mostly on AI's potential contribution to industry, while the U.S.'s on security.
- Consistent with Germany's national strategy for AI, Germany's efforts to integrate semiconductor and AI technologies into the German military are relatively nascent and opaque.
- U.S. AI efforts are geared at out-innovating adversaries, primarily in regards to battlefield applications of AI. However, the United States currently lacks metrics for gauging output with respect to AI battlefield application.

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[2] Dan Breznitz, "Why Germany Dominates the U.S. in Innovation," *Harvard Business Review*, May 27, 2014, https://hbr.org/2014/05/why-germany-dominates-the-u-s-in-innovation.
[3] Interview with anonymous German government official.
[4] Breznitz.

On Additive Manufacturing, it finds:

- In the United States, AM is benefiting from hub-like innovation and incubation centers that draw on government, university, and private-sector expertise. The United States is working to actively integrate AM into the military, while Germany is doing so to a much lesser extent. Instead, Germany is focusing on cultivating the technology with engineering and economic goals in mind.
- Given its regulatory and funding environment for AM, Germany could partner with allies to develop key technology applications while continuing to develop the R&D end. Germany may be doing this under the auspices of the European Defense Fund, but it is a lost opportunity for the United States.

On the ability of the two models to prevent the diffusion of dual-use technologies:

- **The desire to optimize innovation facilitates downstream risk in both the United States and Germany.** Those who think about innovation do not tend to think about the protection or proliferation of innovations.
    - In the United States, planners are primarily focused on "getting innovation right," preoccupied with the "success" of their innovative model; they give little consideration to protection or proliferation. They are motivated by concerns that the United States will be out-innovated by adversaries that have fewer constraints and can innovate faster. Increasingly, the United States must balance the ability to procure dual-use innovation for military applications relatively quickly with the need to have propriety over, regulate, or control that technology.
    - German officials are beginning to recognize the sensitivity of many of the dual-use innovations and industries burgeoning within German borders, and the country is working to implement recent EU-wide regulations for FDI screening and export controls—but it is behind the curve. Germany and the rest of Europe are also committed to open markets and are relatively permissive in allowing foreign entities to bid on domestic projects.
- Recent events have contributed to unique tensions in the U.S.-E.U. relationship and **there are profound obstacles to U.S.-E.U. defense cooperation**. U.S.-E.U. defense trade has served as a backbone of the transatlantic relationship. As Europe continues its inward turn, innovating indigenously for defense, the United States has begun calling for Europe to cease excluding U.S. defense companies. Tensions have reached an all-time high.

Recommendations

- **The United States should develop a framework for assessing competitors' models of innovation to enable the development of targeted strategies for effective competition.** At the national (NSC) level, the United States can employ national models as a useful indicator of both the technological capacity and the limitations of potential adversaries.
- **The United States must achieve better management of uncertainty and complexity at the policy-maker level and direct interagency processes to better frame downstream uncertainty, including about diffusion and proliferation**. Requirements for new military

technology must come with investment in preventing the diffusion of that technology and its component technologies.

- **The United States should actively work to resolve tension vis-à-vis E.U. defense innovation initiatives,** either by welcoming them, which would beget competition and, in turn, spur innovation; or healing the rift spawned by European defense innovation with track-one and -two dialogues. Dialogues could address the following:
    - If Europe wants to maintain its reliance on the United States within NATO to guarantee its security, it should consider "biting the bullet" and establishing regular consultations and partnerships with the United States on new European weapons and systems.
    - The United States could agree to an initial period of ITAR-free procurement (which precludes U.S. cooperation in the development of new systems) to allow Europe to "make a go of it," and to invest more in ongoing consultations on military innovation.
    - As an olive branch, the United States could also explore options for co-development of defense technologies, issuing an exemption from U.S. requirements that new weapons and systems be built on U.S. soil, for example, and allowing the resulting technology and capabilities to be jointly owned—by the United States and Europe.
- **The United States must cooperate with allies in this high-uncertainty, technology-security environment.** Cooperation stands to improve the odds of achieving strategic goals, maximizing innovation, and identifying targets for non-proliferation and arms control.
    - **The United States and its European allies should conduct regular consultations**. Consultations should focus on the development of specific dual-use technologies. This could, in turn, guide discussions on how to align indigenous capacities in critical areas and "out-partner" adversaries, and further assist in cultivating transatlantic cooperation.
    - **The United States and its allies should focus collaborative efforts on identifying a common threat**. A combination of dialogue and collaborative simulations and war-gaming should seek to provide insight into the range of strategic threats and the capabilities needed to address those threats and inform the necessary innovation. Collaborative efforts must focus on the risk of diffusion or proliferation of dual-use technologies by identifying the "crown jewels" of the new crop of weapons and systems. Doing so may help set guidelines for international agreements and regulations with respect to what are the most "sensitive" items—a kind of focused export control approach. Finally, we must assess how an accretion of actors (state and non-state) empowered by equivalent or analogous technologies changes the security space and then identify the weapons and systems least beneficial for conflict in the future. We may then be able to set targets for arms control—the elimination of weapons and systems with outdated or limited utility.

We human beings do have some genuine freedom of choice and therefore some effective control over our own destinies…[T]he decisive choice is seldom the latest choice in a series. More often than not, it will turn out to be some choice made relatively far back in the past.

-Arnold Toynbee, historian

Foreword

Increasingly, government investment in "emerging technologies" aims to harness dual-use, private-sector innovation to achieve national goals. But the details of this pattern vary from country to country. This report focuses on dual-use, emerging technologies' "origin stories" and takes a big picture view of their emergence. It is bookended on one end by an exploration of where these dual-use technologies come from and, on the other, by an assessment of where they are going.[5] By tracing this process across two national systems—American and German—the study highlights common patterns and critical divergences in order to assess the possibilities for and the obstacles to international cooperation in countering "next generation proliferation," or the multi-modal, global diffusion of dual-use technologies. To understand these patterns in even greater detail, the study explores U.S. and German investment and expertise in the development of two types of dual-use technologies: artificial intelligence (and two of its components: robotics and semi-conductor engineering) and additive manufacturing. In both the general analysis and specific case studies, the study draws conclusions about the variations between U.S. and German models with respect to their ability to succeed at dual-use innovation and their likely contributions to diffusion.

Dual-use technologies are increasingly critical to national economies, labor forces, and security. For major powers and innovators, governments and their private sectors both contribute to investment in technology development. This setup comes with varied risk factors. U.S. policy makers need to develop a systematic methodology for thinking about these risk factors and considering how they can partner with allies to mitigate them globally. In thinking about the links between innovation and dual-use technology, three general narratives are worth considering:

On one hand, the story about national models of innovation is one of supply-side proliferators—how states invest in, develop, and integrate technology for military purposes, where these technologies' exclusive home in the military domain is limited only by time. Alternatively, states may push these innovations directly to market with the aim of achieving economic competitiveness (and perhaps, in turn, security by economic means). The factors that determine the amount of time from the completion of an invention to its export or distribution ("duration-to-export") can vary as a function of the national model employed, lengthening or shortening a critical assessment and reaction period. Thus, we stand to learn a great deal about how to inform

[5] A companion report by Dr. Alexander Montgomery focuses on the potential for "diffusion" or proliferation of these dual-use technologies. See Alexander H. Montgomery, "The Effects of the Diffusion of Dual-Use Enabling Technologies on Strategic Stability" (CISSM Working Paper, n.d.).

any model or theory of next-generation proliferation by augmenting our knowledge of the variables that contribute to "duration-to-export"—whether that export occurs legally or illicitly. Where proliferation is an inevitable problem of innovation, understanding "new innovation" is an important component to countering that proliferation.

This study thus responds to the question: How do varying national models of innovation affect or predict a state's ability to innovate and compete in the dual-use space? We know something about pathways of proliferation[6], but relatively little about how, where, and to whom supply-side innovation drives dual-use diffusion and the proliferation to which it contributes.

On the other hand, this is a story about national models of military innovation and the contrast between two of them in particular: the U.S. "military industrial complex" or defense industrial base, which traditionally has dwarfed all others, and Germany's investment in and dedication to innovation with a focus on jobs and an eye towards its export-based economy—to the deliberate exclusion of its own (and Europe's) military development. The story of these two almost-opposing models pits the U.S. system, which is historically predisposed to both lead in innovation *and* set the bar for the regulation needed to protect its investment and military edge, against that of pacifist contemporary Germany, which has historically derived national pride from its engineering capabilities and robust export-led economy, while maintaining a dividing line between civilian and defense research, and—more recently—has sought to lead in next-generation arms control and nonproliferation.

For the purposes of this analysis, national models are reduced to a combination of "R&D investment" and "procurement," where the focus of procurement is on the military integration of emerging, evolving dual-use technologies (as opposed to the bureaucratic processes of acquisition). Once we understand more about how states' national models relate to investment and integration, we can begin to assess the implications of these variations for: a) the successful production (or success rate) of new innovation and its military integration; b) the incentives, levers, and inclination for controlling resulting technologies and capabilities as a function of a state's propensity for oversight and regulation; and c) the feasibility of countries controlling (or even having the ability to control) the spread of their own innovations.

Finally, in many ways**,** this study can be understood as a story about a changed security landscape and a Western rivalry with China, a state which has historically sought to soak up advantage through acquisition, investment, and espionage, leveraging, at root, the national models of other sovereign states—the United States and Germany included.

Once upon a time, the United States was the most powerful and effective originator of military technology and innovation integration. It could decide to whom it would sell its materiel (e.g. to allies fighting the good fight in the Cold War).[7] Times have changed. The United States is no longer the ultimate innovator. The Soviet Union is no longer its only adversary: U.S. strategy

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[6] Montgomery.
[7] U.S. Congress, Office of Technology Assessment, "Arming Our Allies: Cooperation and Competition in Defense Technology" (Washington, DC: U.S. Government Printing Office, May 1990).

documents name China in equal stead with Russia as a peer competitor.[8] And allies and partners are no longer content to simply purchase their security from the United States.[9] Indeed, Europe's inward turn for military innovation and procurement stands to disrupt this previously consistent U.S. funding stream. Meanwhile, critical information relating to technologies is increasingly available in digital formats or produced by multinational firms, both of which make it easier to transfer the information quickly and without detection.

In sum, this study presents a story about civilizations and their discontents: the drive to achieve technological greatness and the eventual tyranny when technology "gets out." If we do our work right, however, it is possible to anticipate and disrupt the inevitable diffusion of specific technologies and avoid the worst of what we can imagine.

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[8] "2018 National Defense Strategy of the United States of America, Summary," n.d., https://dod.defense.gov/Portals/1/Documents/pubs/2018-National-Defense-Strategy-Summary.pdf.

[9] Major, Claudia, "Credible EU Defense Means Rethinking Sovereignty," *Strategic Europe* (blog), June 15, 2017, https://carnegieeurope.eu/strategiceurope/71260.

Introduction

This study explores variations in national models of innovation in the hope of beginning to shed light on the pathways or levers those models afford in controlling innovation's end product. It considers the "lifecycle" of *dual-use* innovation and resulting technologies in the United States and Germany by evaluating how these countries are adapting (or not) their national approaches to investment, development, and integration of dual-use innovation. It uses case studies of both U.S. and German investment in artificial intelligence and additive manufacturing to highlight national approaches to innovation consistent with each country's foreign policy and domestic goals. It also assesses each country's approach to regulating sensitive and dual-use technologies once they have been developed. Finally, drawing on a companion report by Dr. Alexander Montgomery, it examines proliferation concerns and national capacities for countering the proliferation of next-generation warfighting technologies that result from innovation.[10]

This approach allows us to consider how national goals, strategies, and values affect each country's approach to technology development. While the study examines U.S. and German national capacity in the development of additive manufacturing and artificial intelligence, it takes a "macro" view rather than focusing on detailed accounts of these technologies, their trajectories, and the threats they present. As such, the study distills shared values and opportunities for policy alignment along the trajectory of innovation's lifespan as a potential pathway or lever to generate increased cooperation and improved transatlantic coordination, as well as for increased security through improved technological capacity.

"Innovation" is a buzzword for our time. We are, it has been said, squarely in the throes of the Fourth Industrial Revolution,[11] which means that certain enabling technologies have given rise to a cascade of invention in a relatively short timeframe. Although states have innovated for economic and defense purposes since their inception, there is something categorically different about the nature of innovation today—and this is generating great concern for a number of reasons.

First, the dual-use nature of the technologies emerging from the current wave of innovation raises concerns at every stage of the innovation-security-proliferation cycle. The rapid innovation cycle distinguishes the current U.S. "offset strategy" from the previous one, because, while it relied on dual-use technology for precision-guided munitions (designed to reach further into enemy territory with greater impact while relying on a leaner force structure), the "second offset" occurred outside of the current innovation boom. Though it was a product of a revolution in satellite, laser and radar advances, the scope of the current innovation boom is far greater.

Second, defense officials at the highest levels across all the services have awareness of the military capabilities afforded by dual-use technologies and innovation. This is leading to deliberate decision-making aimed at optimizing new innovation for military integration and use. As a result, officials are restructuring policies and organizations around innovation in ways that

[10] Montgomery, "The Effects of the Diffusion of Dual-Use Enabling Technologies on Strategic Stability," n.d.
[11] "The Fourth Industrial Revolution: What It Means and How to Respond," World Economic Forum, accessed April 17, 2020, https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/.

will have long-lasting impacts, which is why officials and analysts emphasize the importance of "getting innovation policy right."[12]

And third, the nature of the technology resulting from the current wave of innovation is increasingly "digital" in nature, meaning that it is more easily transferred than previous generations of technology. For all these reasons, there is something different about this current national drive for innovation that makes it categorically different from previous efforts to, for example, put an astronaut on the moon or make a nuclear weapon.

This study begins with an assessment of the features of U.S. and German national models for innovation with military applications, and then explores them as they apply to two prominent areas of dual-use innovation: artificial intelligence and additive manufacturing. Drawing on these case studies, it then presents an analysis of national models of innovation and priorities with respect to investment in innovation and relevant regulations or policies for the cultivation of certain technologies. It then discusses the extent to which Germany and the United States are stoking the flames of innovation while simultaneously keeping an eye on its proliferation consequences.

I. National Models of Innovation: Research, Development and Procurement

For the purposes of this paper, "military innovation" is considered in terms of two stages or processes: 1) innovation investment and development (R&D), and 2) military integration or acquisition. While all countries tend to share this rudimentary framework, the answers to the question of *how* and *why* countries innovate differ. These differences tell a story of varied values, policies, and strategies associated with the current wave of rapid-fire innovation that is simultaneously driving shifts in national models and redefining them, as states seek to optimize the new generation of novel or advanced innovations.

The U.S. Model: Dual-Use Innovation and Research

When we refer to a "national model of innovation," we tend to think of the U.S. model, largely because so much has been written about it since President Dwight D. Eisenhower's "Military Industrial Complex" speech,[13] and because, in comparison to countries like Russia and China, the U.S. is relatively open about the workings of its national bureaucracy—innovation modalities included.

The U.S. model can be described in terms of shifts in both levels of funding and military integration over time. However, on the whole, "Attempts by the federal government to explicitly support commercial innovation were at best made in fits and starts and never really got off the ground."[14] Prior to WWII, a predominantly isolationist United States turned to industry,

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[12] Charles Lutes, "U.S. Defense Strategy and the Innovation Imperative," in *Getting Innovation Right*, ed. Mona Dreicer (Center for Global Security Research Lawrence Livermore National Laboratory, 2019).
[13] "Eisenhower's Farewell Address to the Nation," accessed February 2, 2020, http://mcadams.posc.mu.edu/ike.htm.
[14] Robert D. Atkinson, "Understanding the US National Innovation System" (The Information Technology and Innovation Foundation, June 2014), http://www2.itif.org/2014-understanding-us-innovation-system.pdf., p. 5.

incorporating it into the U.S. "innovation ecosystem."[15] In 1942, President Franklin D. Roosevelt established the War Production Board to oversee war production needs and to ensure that the military's demands for materials and services was met. The board was dissolved in 1945, upon the war's end, and quickly reimagined as the Civilian Production Administration. Both entities were early foundations of what U.S. President Dwight D. Eisenhower would call the "military industrial complex."[16]

After WWII, the United States turned to a more "science-based" system of innovation, relying on the large, corporate, U.S.-based R&D laboratories to drive innovation, and awarding federal funding to these labs for the development of software, hardware, aviation, and biotechnology.[17] With the creation of the Defense Advanced Research Projects Agency (DARPA) in 1958, the U.S. began allocating a portion of R&D monies to moonshot projects, designed with the explicit purpose of accelerating the development of innovative technologies "beyond the horizon."[18] By 1960, "defense research accounted for 80 percent of federal research and development funds. Mission-focused agencies—oriented towards achieving specific outcomes rather than 'basic' research directed at scientific exploration—provided much of this Cold War-era funding".[19] The U.S. government was funding innovation with warfighting in mind and, ultimately and with DARPA's help, paying the private sector and tapping the expertise of technologists outside of DoD to help. For instance, Defense Department-funded research supported vacuum tube research at Stanford University, which provided the foundation for later research that yielded GPS, magnetic random-access memory, and the Internet for society's greater good.[20]

In the 1970s, in response to economic challenges from Japan and Germany, federal policy makers created a number of new collaborative research ventures, including SEMATECH (a non-profit consortium that does research and development in the semi-conductor space), the National Science Foundation (NSF) Science and Technology Centers and Engineering Research Centers, and the National Institute of Standards and Technology (NIST) Advanced Technology Program.[21]

The United States has generally been slow to modify or dispose of its Cold War model for innovation, which was premised on geopolitical competition as a driver of technology development. Furthermore, U.S. officials and agencies "disengaged" from innovators at the end of the Cold War as firms walled off defense from civilian innovation and doubled down on the more-profitable civilian sector applications.[22] This resulted in the separation of military and civilian applications of the same technologies, creating a void in the civilian innovation

[15] Evans, Peter, "Preface," in *State of Innovation: The U.S. Government's Role in Technology Development* (Paradigm Publishers, 2011).
[16] "Eisenhower's Farewell Address to the Nation."
[17] Atkinson, "Understanding the US National Innovation System.", p. 4.
[18] Fred Block, "Innovation and the Invisible Hand of Governmentt," in *State of Innovation: The U.S. Government's Role in Technology Development* (Boulder, CO: Paradigm Publishers, n.d.), 1–26, p. 8.
[19] Darren E. Tromblay and Robert G. Spelbrink, *Securing U.S. Innovation: The Challenge of Preserving a Competitive Advantage in the Creation of Knowledge* (Lanham, Maryland: Rowman & Littlefield, 2016), p. 180.
[20] Tromblay and Spelbrink, *Securing U.S. Innovation*, p. 180.
[21] Atkinson, Robert D., "Understanding the US National Innovation System," p. 5.
[22] Tromblay and Spelbrink, *Securing U.S. Innovation*, p. 180.

landscape. Eventually, civilian innovations developed to such an extent that they now have military applications that, once again, stand to benefit government efforts and objectives.

Despite widespread capacity for innovation throughout the U.S. government, Fred L. Block and Matthew R. Keller, writing in their 2011 book *State of Innovation*, argued that the United States would soon have to reorganize indigenous innovation to optimize it—maximizing speed and qualitative production—to reach national security goals. In a chapter of this book, Peter Evans argued that the key to achieving this success would lay in creating "positive synergies" between "public support and private initiative, between government action and markets, between networks and corporate organizations to produce the innovations we need and want."[23] This broad focus would require the military use of non-military technologies coming directly out of the private sector.

A few years after the publication of Block and Keller's prescient book, U.S. officials announced the country's third-offset strategy, which identified "innovation" as key to sustaining and advancing U.S. military dominance.[24] The 2018 U.S. National Defense Strategy called for the creation of and increased support for a "National Security Innovation Base" to "effectively support Department operations" and "sustain security and solvency."[25] This "Innovation Base" primarily requires leveraging private-sector innovation and getting the acquisition of dual-use technologies "right."[26]

While much has been made of this turn toward private-sector innovation (so-called technology pull), public-private partnerships are not at all a new phenomenon for the U.S. Defense Department. The department has grappled with dual-use innovation (and its place in the U.S. military) since at least the early 1990s. Even further back, in announcing the second offset strategy in the late 1970s, U.S. Secretary of Defense Harold Brown said that the U.S. investment in private-sector technology development would allow the country to offset the quantitative advantages held by U.S. adversaries, maintain deterrence and restore strategic stability in Europe. At the time, scholars and analysts emphasized how this initiative led to contracts and regulations to promote the private defense industry's successes.[27]

In the wake of what had been announced as the third offset, the U.S. Defense Department moved beyond contracts and regulations and began to reorganize key elements of its bureaucracy with innovation in mind (e.g., the restructuring of AT&L) and making funds available for this purpose. On February 1, 2018, the AT&L offices split into the offices of the Undersecretary of Defense for Acquisition and Sustainment (USDA&S) and the Undersecretary of Defense for

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[23] Evans, Peter, "Preface," in *State of Innovation: The U.S. Government's Role in Technology Development* (Paradigm Publishers, 2011), p. v.
[24] Cheryl Pellerin, "Deputy Secretary Discusses Third Offset, First Organizational Construct," n.d., 3.
[25] National Defense Strategy, 2018.
[26] Charles Lutes, ed., "US Defense Strategy and the Innovation Imperative," *Getting Innovation Right* (Center for Global Security Research, Lawrence Livermore National Laboratory, September 2019), https://cgsr.llnl.gov/content/assets/docs/Getting-Innovation-Right.pdf.
[27] Teclemariam, 41.

Research and Engineering (USDR&E).[28] Within USDA&S, material readiness, support and logistics policy, and transportation policy are a main priority.[29,30] The Defense Advanced Research Projects Agency, the Defense Innovation Unit Experimental, the Strategic Capabilities Office, and the Missile Defense Agency are now housed under USDR&E.[31,32] According to former Deputy Secretary of Defense Patrick Shanahan, the transition from AT&L to USD A&S and R&E allows the department to focus on more than "just the development and deployment" of emerging technologies, by addressing the functions and implications of "high-end technologies."[33] Other examples abound throughout the services. For example, in August 2018, the Army Futures Command launched in Austin, Texas, tasked with the mission of the "continuous transformation of Army modernization in order to provide future warfighters with the concepts, capabilities and organizational structures they need to dominate a future battlefield." It marked one of the Army's most significant reorganization efforts since 1973.[34]

Additional research and development defense initiatives have sought to emulate the private sector's technology incubator structure to draw on industry in a more rapid and efficient way. Organizations within DOD, like JSOU, are streamlining procurement. It remains unclear, however, whether or not the government investment in these new organizations will yield the desired result of out-innovating our adversaries. Few governmental frameworks are in place to track and evaluate progress across these disparate organizations and interest groups.

Funding for R&D in the U.S. Model

To accomplish this restructuring and to capitalize on the radical innovation coming out of the private sector, the U.S. government has also adapted how it funds research. Today, how the U.S. government invests in basic and applied research for dual-use innovation—whether for defense, energy, or health-related innovation—is a key feature of its model of military innovation. The U.S. system for supporting scientific research has, by and large, two fundamental aspects: support for mission-oriented research (e.g., defense and health), which largely goes to federal labs, and support for basic research.[35] Within these two streams, research is funded in three stages: as basic research, applied research, or product development. The U.S. government funds more research at the basic research stage, where "the failure risk of ideas is the highest, and industry plays a smaller role," than at any other stage.[36] During the development phase, government and industry tend to share the funding burden, roughly equally.

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[28] Aaron Mehta, "Revealed: The new structure for the Pentagon's tech and acquisition offices," DefenseNews, 2018. https://www.defensenews.com/pentagon/2018/07/17/revealed-the-new-structure-for-the-pentagons-tech-and-acquisition-offices/
[29] Aaron Mehta, "This is the Pentagon's new acquisition structure," DefenseNews, 2017. https://www.defensenews.com/breaking-news/2017/08/02/this-is-the-pentagons-new-acquisition-structure/
[30] Office of the Under Secretary of Defense for Acquisition & Sustainment, United States Department of Defense. https://www.acq.osd.mil/
[31] Mehta, "This is the Pentagon's new acquisition structure," DefenseNews, 2017.
[32] Office of the Undersecretary of Defense for Research and Engineering, United States Department of Defense. https://www.cto.mil/
[33] Mehta, "This is the Pentagon's new acquisition structure," DefenseNews, 2017.
[34] "Futures | U.S. Army," www.army.mil, accessed June 21, 2020, https://www.army.mil/futures.
[35] Robert D. Atkinson, "Understanding the US National Innovation System."
[36] Nerayo Teclemariam, "The Building Blocks of a Successful Innovation Strategy," in *Getting Innovation Right*, ed. Mona Dreicer (Center for Global Security Research Lawrence Livermore National Laboratory, 2019), 41.

Although industry plays a smaller role at earlier research phases, these phases are particularly conducive to collaboration between government entities and the private sector alike. The Defense Department hosts governmental consortia in which members "agree on a research agenda that focuses on 'pre-competitive' challenges, which allows the pooling of funding to tackle the largest, cross-cutting barriers…[enabling] industry to compete against each other during the later applied and development stages of innovation." The Department of Energy's laboratory directed research and development (LDRD) program portfolio similarly focuses on "discovery class" research that "promotes high-risk, high-value exploration of innovations." [37]

Beyond collaborations, the U.S. government has relied on restructuring to preserve the integrity of scientific endeavors and to achieve critical dual-use innovations. The creation of Energy's National Nuclear Security Administration (NNSA) in 1999, for example, re-consolidated the department's "nuclear weapons, naval reactors, emergency response, and nonproliferation" missions under a single administrator, and moved DOE's "non-defense science, nuclear, and fossil R&D activities…under an undersecretary of science" which was a boon to research driven by consensus-based science with a "long-term approach."[38]

Creedon explains: "Like the rest of DOE, NNSA has a broad R&D mission…with a broad variety of tools available to ensure world-class science…[including] the participation of small businesses and universities using funds specifically set aside for work with university consortia and historically black colleges and universities (HBCU)." NNSA typifies the template for research success across the DOE: NNSA continues to have the advantage of no-year money, the Strategic Partnership Program (that facilitates partnerships with the national labs in cooperation with DOD) and, most importantly the ability to use discretionary funds for laboratory and facility-directed research, in addition to significant mission-related funding.[39]

Certainly, there are additional funding streams now aimed at specific areas of innovation, but this section is meant to be more illustrative of the United States' long-term model and funding ethos and, as such, is not comprehensive. It is hard to know whether these and other adaptations in U.S. research funding are sufficient. There continues to be a lack of agreement in governmental and nongovernmental sectors about what exactly drives innovation in a broader sense: Is it money, in the form of long-lasting funding lines? Streamlined procurement and fewer legislative and regulatory obstacles? Both? Or something else altogether? Meanwhile, the lack of an operating concept for innovation (how the innovation will be used) and a strategy for using these innovations (why innovation will be used), could end up derailing existing innovation efforts, or lead to a failure of execution. "We lack the ability to harness innovation effectively," argues Kehler.[40] Paul Bernstein agrees: "We need realistic, strategy-driven, measurable goals," that are

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[37] Teclemariam, 41.

[38] Creedon, Madelyn, "S&T Innovation for National Security: A DOE Perspective," in *Getting Innovation Right*, ed. Mona Dreicer (Center for Global Security Research Lawrence Livermore National Laboratory, 2019), 20–29, https://cgsr.llnl.gov/content/assets/docs/Getting-Innovation-Right.pdf, p. 23.

[39] Creedon, Madelyn, 24.

[40] Robert Kehler, "Getting Focused: Innovation in a 20th Century Context," in *Getting Innovation Right*, ed. Mona Dreicer (Center for Global Security Research, Lawrence Livermore National Laboratory, 2019), 11, https://cgsr.llnl.gov/content/assets/docs/Getting-Innovation-Right.pdf.

derived from efforts towards achieving "specific operational challenges."[41] In the absence of an operating concept and a strategy, U.S. innovation is increasingly being driven by what our adversaries are doing.

U.S. Procurement and Downstream Risks: Linking Innovation and Proliferation

Current U.S. regulations that guard against the "misuse" of U.S. military innovation have their origins in the Cold War, when "national security imperatives were the fuel for this nation's innovation engine."[42] This period was arguably the peak of strategic competition between the United States and USSR. In 1976, Congress passed the U.S. Arms Export Control Act (AECA), giving the president the authority to control (or delegate) the import and export of defense articles and services. The Act allowed for U.S. military and defense manufacturers to export defense articles and services to other countries, provided a number of conditions were met, including that the receiving government intended to use armaments for legitimate self-defense. The AECA prohibited the export of U.S.-origin defense articles to end users where doing so "would contribute to an arms race, aid in the development of weapons of mass destruction, support international terrorism, increase the possibility of outbreak or escalation of conflict, or prejudice the development of bilateral or multilateral arms control or nonproliferation agreements or other arrangements."[43] The AECA also intended to restrict U.S. manufacturers by prohibiting them from selling certain sensitive technologies to proscribed actors.

The 1976 International Traffic in Arms Regulations (ITAR) implemented the AECA's requirement to restrict and control the export of sensitive defense articles and services that appear on the U.S. Munitions List, or "USML." While the State Department's Directorate of Defense Trade Controls oversees the licensing and export of USML items, the Commerce Department's Bureau of Industry and Security (BIS) does this for dual-use items that have non-military uses. The overarching goal of these controls were to prevent arms and dual-use item exports to Eastern Bloc countries, as negotiated by the multilateral Coordinating Committee for Multilateral Export Controls (now the Wassenaar Arrangement).

The U.S. Treasury Department is also home to the Committee on Foreign Investment in the United States (CFIUS), which was founded in 1975 and has been amended several times since. One of CFIUS's primary functions at present is to vet the potential acquisition of U.S. companies by foreign entities and to recommend termination of such an acquisition when U.S. national security is at risk.

While U.S. regulations have historically set the bar internationally on implementing export controls and the vetting of foreign investment, the rise in the theft of sensitive dual-use military technologies, primarily by Russia and China, have challenged notions of how to control the outputs of innovation. What previously might have been seen as foreign intelligence activities are increasingly being seen as proliferation risks. The boom in dual-use innovation has only

[41] Paul Bernstein, "'Innovating' Versus 'Out-Innovating': Innovation as a Form of Strategic Competition," in *Getting Innovation Right*, ed. Mona Dreicer (Center for Global Security Research Lawrence Livermore National Laboratory, 2019), https://cgsr.llnl.gov/content/assets/docs/Getting-Innovation-Right.pdf.
[42] Lutes, Charles, "US Defense Strategy and the Innovation Imperative," 4.
[43] "Arms Export Control Act," Pub. L. No. Public Law 90–629, 87 (2018), Sec. 38 (2).

fueled this phenomenon.[44] Tromblay and Spelbrink charge that the United States has been slow to respond to "this narrowing gap between the U.S. and the rest of the world" as technology "gets out" and innovation of dual-use technology goes global.[45]

A significant factor in both this narrowing gap and the U.S. response to date has been the shift from "requirements pull" to "technology push" in driving U.S. innovation. During the Cold War, the U.S. Defense Department drove technological innovation through requirements: "requirements pull." Today we see a different phenomenon on the rise, "technology push," where commercial off-the-shelf products (COTS)—particularly information technology software and hardware—are seen as ready solutions to government requirements.

The benefits of COTS tend to be a high-level of expertise (e.g. Microsoft is a provider) and quick procurement; the drawbacks include a host of vulnerabilities—in particular the U.S. government's inability to control the end product and safeguard the technology through its lifecycle. Moreover, although COTS are comparatively low cost in the near-term, they generally cost more in the long run, due to faster obsolescence and the need for quicker replacement. And while procurement time is comparatively short, the risk of diffusion or widespread adoption is comparatively high.

As dual-use innovations continue to be procured from the private sector, the scale and intensity of these proliferation challenges are likely to broaden.[46] For example, Tromblay and Spelbrink predict that not only will nations have the benefit of technological diffusion but that terrorist and criminal actors that rely on private technologies will also have the capacity to thwart law enforcement, while intelligence and law enforcement agencies won't have the tools to disrupt their activities.

The German National Model

Once upon a time, innovation fueled German military strategy: Blitzkrieg exploited the combustion engine, message encryption, and the radio to create and facilitate decisive, overwhelming force. It afforded Germany military dominance that ended only when their encryption advantage was leveled by Allied codebreakers and the firepower of Blitzkrieg was offset by the allied offensive bombing of Germany's industrial base. The German pursuit of military advantage through innovation ended in the wake of World War II with the demise of Hitler and the Nazi regime.

In the post-War period, Germany channeled its engineering expertise into its workforce and economy. German capacity for engineering continues to be valued and is instantiated in the country's large network of innovation centers, largely made up of the Fraunhofer Institutes—Germany's large-scale, partially government-supported centers of research that act as hubs for small and medium businesses and the government to innovate together—as well as the Leibniz Institutes, to a lesser extent.[47] Each Fraunhofer location focuses on a different engineering area,

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[44] Tromblay and Spelbrink, *Securing U.S. Innovation*, 2016, viii.
[45] Tromblay and Spelbrink, *Securing U.S. Innovation*, 2016, xiv.
[46] Montgomery, "The Effects of the Diffusion of Dual-Use Enabling Technologies on Strategic Stability," n.d.
[47] Resembling the US Bell Laboratories model of the post-war era.

including additive manufacturing, semiconductors, robotics, and 5G, to name a few. The Fraunhofer model reflects the German understanding that "innovation must result in productivity gains that are widespread, rather than concentrated in the high-tech sector of the moment."[48]

The Fraunhofer Group for Defense and Security serves as a consortium for all research components supporting the German Ministry of Defence (BMVg) and German Armed Forces (Bundeswehr).[49] The institutes' support a range of strategic and tactical capabilities in areas ranging from conventional warfare to electronic and cyber warfare, counterterrorism, border security, and crisis management.[50]

Germany's national model of innovation has perpetuated the robustness of Germany's industrial base, which fuels its export-led economy. Germany continually trains and re-trains its workforce when necessary, keeping unemployment low. German-made machinery produces much of the products we buy from around the world. In short, "Germany is better at sustaining employment growth and productivity, while expanding citizens' real incomes."[51] Today, Germany is listed on the Bloomberg Innovation Index as the second most innovative economy in the world, courtesy of German innovations in AM.[52]

Whereas the United States prides itself on home-grown innovation and dominance in the defense sector, German national character has adopted a collective mentality of "huddling in the middle" and reluctance to innovate in the pursuit of military advantage, an area in which Germany still operates as a penitent actor.[53] Across all political parties in Germany, defense spending is unpopular, and the desire to lead globally in spending and defense innovation is non-existent.

In comparing the U.S. and German national models of innovation, Germany's capacity for innovation, particularly with respect to "radical" technologies, stands out:

> The fairy tale that the U.S. is better at radical innovation than other countries has been shown in repeated studies to be untrue. Germany is just as good as the U.S. in the most radical technologies.[54]

In fact, Germany out-innovates the United States in sustainable energy systems, molecular biotechnology, lasers, and experimental software engineering and Germany is better at "adapting inventions to industry and spredding them throughout the business sector" and "infusing old products and processes with new ideas and capabilities or recombining elements of old, stagnant

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[48] Dan Breznitz, "Why Germany Dominates the U.S. in Innovation," *Harvard Business Review*, May 27, 2014, https://hbr.org/2014/05/why-germany-dominates-the-u-s-in-innovation.
[49] "Fraunhofer Group for Defense and Security VVS," Fraunhofer-Gesellschaft, n.d., https://www.fraunhofer.de/en/institutes/institutes-and-research-establishments-in-germany/fraunhofer-groups/defence-security.html.
[50] "Fraunhofer Group for Defense and Security VVS."
[51] Breznitz, "Why Germany Dominates the U.S. in Innovation."
[52] Michelle Jamrisko, Lee J. Miller, and Wei Lu, "These Are the World's Most Innovative Countries," *Bloomberg*, 2019. https://www.bloomberg.com/news/articles/2019-01-22/germany-nearly-catches-korea-as-innovation-champ-u-s-rebounds
[53] Interview with anonymous German government official.
[54] Breznitz, "Why Germany Dominates the U.S. in Innovation."

sectors into new, vibrant ones."[55] These capacities are largely due to high-level political awareness that Germany's workforce depends on the adaption of inventions to the business sector and the melding of old and new innovations. As evidence, Germany invests 43 percent more in federal funding than the United States (on a GDP basis) on industrial research.[56]

Another significant difference in the two countries' innovation models is that, unlike the United States, Germany is not looking to leverage private-sector innovation to improve its armed forces and attain offsetting capabilities. Yet, because of low defense spending and competing demands on the German Ministry of Defence by NATO (to augment cyber capacity) and the EU (to fund European defense with initiatives to collaborate with EU countries on new weapons and systems designed to fill "capability gaps"), Germany's own armed forces are decidedly "hollowed out."[57] Germany is (slowly) working to shore up its own forces, but much of the emphasis on *military* innovation in Germany is occurring bilaterally (with France and Italy) and at the level of the European Union.

Germany's reliance on EU-level initiatives for its military innovation was made explicit in 2017, when the EU launched Permanent Structured Cooperation (PESco) to integrate the armed forces of 25 European nations and serve as a springboard for new defense innovation to fill capability gaps. The European Parliament and the Council of the European Union then established the European Defense Industrial Development Program in 2018 with the aim of supporting the competitiveness and innovative capacity of the European Union's defense industry.

The program complements the existing European Defense Fund (EDF), which will have €13 billion Euro from the EU and member states' individual contributions (made over a seven-year period) to support research, development, innovation and the testing of new capabilities derived from emerging technologies. Together, these funds will serve as a proverbial honey jar that will collect €36 billion from member states per year in defense spending if commitments and budgeting pan out.[58] This experimental approach—which will increase EU equipment expenditure by 18 percent—lasts five years, after which, it could be renewed. If successful, the EDF model promises to increase European and, by extension, transatlantic, security, with Europe being a "bigger, better ally," more capable in burden sharing overall.

Germany seems content to outsource most of its security needs to the EU and NATO, with the exception of a few bilateral projects. In January of 2019, Germany and France signed the Aachen Treaty, designed to serve as a roadmap for defense innovation cooperation in the decades to follow. Projects stemming from this treaty include joint programs for a new tank and a new fighter aircraft (joint Future Combat Air System).

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[55] Breznitz.
[56] Robert D. Atkinson, "Understanding the US National Innovation System" (The Information Technology and Innovation Foundation, June 2014), 17, http://www2.itif.org/2014-understanding-us-innovation-system.pdf.
[57] "Germany Faces an Awkward Struggle to Build and Maintain Its Armed Forces," Los Angeles Times, February 14, 2019, https://www.latimes.com/world/la-fg-germany-armed-forces-20190213-story.html; Kyle Mizokami, "Is Germany's Military Dying?" The National Interest (The Center for the National Interest, September 1, 2015), https://nationalinterest.org/feature/germanys-military-dying-13748; "The Real Roots of Germany's Defense Spending Problem," accessed April 25, 2020, https://warontherocks.com/2018/07/the-real-roots-of-germanys-defense-spending-problem/.
[58] Whether this can happen in a post-COVID European Union remains to be seen.

While Germany and France have embarked on a mostly successful partnership to develop these systems, the robustness of the two countries' partnership in the long run is often called into question. France has invited Germany to partner in the "refounding of Europe" and share political-military leadership on the continent. But it has been frustrated with Germany's perceived reluctance, preferring a more middling-role in the Europe-wide project instead.[59]

The Aachen Treaty did more than establish future pathways for cooperation between Germany and France. A subsequent annex to the agreement provides shared veto power in the export (sale) of jointly innovated military equipment. In general, the agreement empowers each country to approve exports of innovative equipment when it has contributed equally to the technology development. But it also allows for each state to have veto power when its "direct interests or national security are compromised."[60] When one partner contributes relatively little to a program, that country loses its right to a veto. This arrangement has already created tension in the bilateral relationship, when, for example, France sought to sell Meteor missiles to Saudi Arabia and Germany exercised its veto on the grounds that it had banned all exports to any states parties fueling the conflict in Yemen.[61] In this case, Germany's adherence to principles of limiting sales abroad on foreign policy grounds trumped France's desire to "share" the technology and reap the economic payout.

While it is expanding its own defense innovation capacity, Europe still wants U.S. support in its military innovation initiatives. But U.S. officials are less than enthusiastic to continue their support under existing conditions. In February of 2018 at the Munich Security Conference, Permanent Representative of the United States to NATO Kay Bailey Hutchinson admonished the EU:

> Certainly, we do not want [PESCO] to be a protectionist vehicle for EU. And we're going to watch carefully because if that becomes the case, then it could splinter the strong security alliance that we have.[62]

Currently, U.S. companies are only somewhat eligible to compete for projects funded by EDF. Although U.S. companies with entities in the E.U. are eligible to bid on EDF projects, their bidding comes with the stipulation that the intellectual property that results from any collaborative research will stay entirely within the E.U., as justified by the "security interest of

[59] Barbara Kunz and Ronja Kempin, "The Treaty of Aachen. New Impetus for Franco-German Defense Cooperation?," accessed February 11, 2020, https://www.ifri.org/en/publications/editoriaux-de-lifri/treaty-aachen-new-impetus-franco-german-defense-cooperation.

[60] "European Dispute over Arms Exports Tests Germany's Stance of 'Nein!,'" accessed April 25, 2020, https://www.defensenews.com/global/europe/2019/02/25/european-dispute-over-arms-exports-tests-germanys-stance-of-nein/.

[61] "German Ban on Arms Exports to Yemen Conflict Called into Question | Germany| News and In-Depth Reporting from Berlin and beyond | DW | 20.01.2018," accessed February 18, 2020, https://www.dw.com/en/german-ban-on-arms-exports-to-yemen-conflict-called-into-question/a-42238475.

[62] Aaron Mehta, "US Warns against 'Protectionism' with New EU Defense Agreement," Defense News, February 14, 2018, https://www.defensenews.com/smr/munich-security-forum/2018/02/14/us-warns-against-protectionism-with-new-eu-defense-agreement/.

E.U. and member states."[63] These requirements have resulted in significant U.S. consternation, and European bewilderment.

Some experts believe that the EU is facing a "valley of death" between research and development, and implementation of military innovation.[64] Developing innovative technology is one thing, integrating it into the military at strategic, operational and tactical levels is entirely another. This lack of capacity is already seen in the integration of the F-35: it is unclear how the Dutch and Norwegians will self-organize to take advantage of the F-35's capabilities.

Skepticism of the EU's capacity to achieve its defense innovation goals is coming from within Europe, as well. Ulrich Speck, for one, argues that EU institutions don't innovate, they consolidate, drawing on the innovations of member states. This dynamic creates a "stepping up" effect where collective forces are concerned, rather than altering the battlefield with large-scale innovation. Moreover, the current EU market is full of duplication and inefficiencies, Speck suggests, which hampers capability development, readiness, and posture.[65]

German Procurement

German public procurement involves a mostly open, centralized system that operates largely without prejudice to goods produced within Germany. The system's guiding principle is that the most economically advantageous tender (MEAT) is awarded the public contract, a process that is thought to unlock innovation in the economy by promoting new technologies and boosting adoption rates. As designed, however, it primarily maximizes efficiency in government spending.

German participation in the European common market requires it to prohibit the automatic or exclusive patronage of domestic markets.[66] While defense and security articles procured by Germany are subject to general EU (and German) procurement law, certain articles are exempt under the European Act Against Restraints of Competition. For example, the Act, in conjunction with Article 346 of the Treaty on the Functioning of the European Union (TFEU), allows a procurement law exemption if it is necessary for the essential interests of a member state's security. Germany also adheres to the EU Directive on Defense and Security (Directive 2009/81/EC), which allows for "restraints on competition" and allows preferences to for bidders that meet criteria in specific areas, including utilities, defense and security, and related concessions.

For explicit military procurement, Article 87b of the constitution of the Federal Republic of Germany assigns the task of directly satisfying the procurement needs of the armed forces to the Federal Defence Administration. The contracts required for providing the necessary equipment to the armed forces are awarded to industry, trade, and commerce by the designated civilian

[63] Daniel Fiott, "Strategic Autonomy: Towards 'European Sovereignty' in Defence?," 2018, 8.
[64] Kamil Mazurek, "European Offensive in Defense Sphere-EEDF, PESCO and CARD," accessed April 25, 2020, https://pulaski.pl/wp-content/uploads/2018/11/European_offensive_in_defense_sphere_EEDF_PESCO_and_CARD.pdf.
[65] Sophia Besch, "The European Commission in EU Defense Industrial Policy," Carnegie Europe, accessed May 31, 2020, https://carnegieeurope.eu/2019/10/22/european-commission-in-eu-defense-industrial-policy-pub-80102.
[66] EU Directives 2007/66/EC, 2009/81/EC, and 2014/24/EC.

authorities of the Federal Defence Administration in compliance with a number of regulations.[67] Central procurement means that the entire demand of the armed services is jointly determined and procured. Thus, studies, research and development contracts, the supply of defense materials, including repair work, for the armed services are all awarded centrally.

Germany's internal process for determining and meeting the demand of the Bundeswehr (unified armed forces) lies in its "Customer Product Management" (CPM) directive. The CPM streamlines and harmonizes certain procedures, including the establishment of development and procurement timelines and of administrative procedures. It also conducts regular Bundeswehr-wide capability analyses to determine demand, and to clearly distinguish between military and civilian responsibilities. In all its work, the CPM attempts to optimize costs, performance, and timelines, giving preference to the procurement of off-the-shelf or commercially available materiel (COTS). It also delivers "proof of producibility" assessments to minimize risk before a procurement contract is finalized (fly before you buy principle).[68]

Germany's Approach to Regulation

By and large, the one unifying policy position across all German political parties is a visceral adherence to values associated with personal data privacy. In 2016, Germany implemented the German Federal Data Protection Act, preempting the 2017 Europe-wide General Regulation Protection Regulation (GDPR) and its prescribed data protections that prevent the sharing of personal data.

Germany also implements a (relatively new) system of export controls similar to that of the United States: Article 26 Paragraph Two of the German Constitution allows the export of weapons under the condition that the German government has granted an export license. Germany also implements the German Government Principles of 2000, which permits weapon exports to NATO countries and major allies, but places greater restrictions on other states.[69] Under the 1998 EU Code of Conduct on Arms Exports (EU Code) and its successor, the 2008 EU Common Position on Arms Exports, Germany is required to adopt eight principles in granting an export license, including compliance with international commitments and human rights standards, as well as taking into account national security and development issues, with no delivery of materiel granted to parties engaged in active conflicts. The EU codes endeavor to harmonize standards across the union and increase consultations among EU member states to

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[67] These include the following laws and regulations: Part IV of the German Act against Restraints of Competition (GWB); the Regulation on the Award of Public Contracts (VgV); the Utilities Regulation (SektVO); the Procurement Regulation on Defence and Security (VSVgV); the Procurement Regulation on Construction Works (VOB/A); the Procurement Regulation on Concessions (KonzVgV); and
the Procurement Regulation on the Award of Public Contracts under the EU thresholds (UVgO) for the Federal republic and the Federal states Bavaria, Hamburg and Bremen.
[68] Dorothee Frank, "Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support," *European Security & Defence* (blog), September 25, 2019, https://euro-sd.com/2019/09/articles/14809/federal-office-of-bundeswehr-equipment-information-technology-and-in-service-support/.
[69] Interview with anonymous German government official.

coordinate export control positions and licensing, and they have had the effect of increasing transparency across the EU concerning arms exports.[70]

While Germany appears "better" at imposing sanctions and embargoes (e.g., on Syria, Iran, Russia) than its EU counterparts, reporting exports (denials and sales) to the EU as required by the Common Position has declined recently among all three of the EU's largest arms exporters (Germany, France and the United Kingdom). This could suggest that member states are struggling to "measure" their exports, in an environment of increasing dual-use innovation (generously speaking). Alternatively, it may suggest a broader difficulty or reluctance to implement export controls. Indeed, in signing the Aachen Treaty, Germany effectively softened its stance on arms exports, agreeing to work with France to "develop a common approach to arms exports with joint projects" and refrain from "[obstructing] a transfer or an export to third countries."[71]

On FDI screening, Germany was late to implement regulations. Only recently, after Chinese company Midea took over German robotics company Kuka, allowing the transfer of sensitive robotics technology to the Chinese, did Germany seek to implement restrictions on FDI in dual-use innovation.[72] After the 2019 passage of EU FDI-screening legislation to prevent acquisitions like Kuka's, Germany began its own implementation process[73] which allowed the Federal Ministry for Economic Affairs and Energy (BMWi) to review the acquisition of German firms by foreign buyers on a case-by-case basis, where "foreign buyers" included any investors outside EU territory. These reviews are designed to determine whether a potential acquisition represents a "sufficiently serious and present threat which affects a fundamental interest of society."[74] They are triggered by 25 percent ownership of a Germany company by a non-EU investor, and 10 percent ownership for companies operating in "sensitive security areas."[75] For the latter, reviews consider whether the acquisition "poses a threat to essential security interests of the Federal Republic of Germany." Germany places an unusual constraint on its own review process, presumably to prevent hampering economic growth: the review must be conducted within a three-month period (the U.S. CFIUS process has no similar time constraint). Like the U.S. CFIUS process, the BMWi consults with other federal ministries when relevant to a particular case.

[70] Bromley, Mark, "The Review of the EU Common Position on Arms Exports: Prospects for Strengthened Controls," Non-Proliferation Papers (EU Non-Proliferation Consortium, January 2012), https://www.sipri.org/sites/default/files/Nonproliferation7.pdf.
[71] Deutsche Welle (www.dw.com), "Germany's Angela Merkel Makes Arms Export Pact with France | DW | 18.02.2019," DW.COM, accessed February 19, 2020, https://www.dw.com/en/germanys-angela-merkel-makes-arms-export-pact-with-france/a-47568557.
[72] Reuters News, "China's Midea Receives U.S. Green Light for Kuka Takeover," December 30, 2016, 2.
[73] The Foreign Trade and Payments Act (year?) and the Foreign Trade and Payments Ordinance (year) provide legal basis.
[74] BMWi Investment Reviews webpage
[75] Sensitive security areas include "war weapons and other key military technologies, specially designed engines and gearboxes for military tracked armoured vehicles, and products with IT security features that are used for processing classified government information." BMWi Investment Reviews Website

II. Indigenous Capacity: Case Studies

While an historical analysis of the origins of innovations generally, or of discrete military innovations in particular, lies outside the scope of this report, a discussion of how governments generally approach innovation and the distinctive characteristics of innovation in the 21st Century are critical to understanding national models of military innovation. The section below outlines U.S. and German efforts and capacity in cultivating two "emerging technologies" in particular, artificial intelligence and additive manufacturing. These technologies were selected because their development stands to both alter warfighting and contribute to proliferation, both countries are making significant investments, and for the availability of information on each countries' investments and capabilities.

Artificial Intelligence and Supporting Technologies

Artificial intelligence (AI) is an umbrella term for technologies and innovations that rely on computing capacity and advanced computer programming to develop next-generation capabilities (e.g., self-driving cars and other autonomous systems, quantum computing for big data analysis and enhanced digital encryption, and advanced wireless networks that offer unprecedented connection speeds and security).[76] As such, semiconductors are a vital *enabling* technology. AI is particularly notable for its next-generation battlefield implications. According to former U.S. Deputy Secretary of Defense Robert O. Work, AI is driving "new and more novel warfighting applications involving human-machine collaboration and combat teaming…the primary drivers of an emerging military-technical revolution."[77]

The U.S. AI Ecosystem

The United States has a strong AI ecosystem, with ample public and private investment (around $2 billion and $6 billion, respectively to date),[78] high-quality human capital, and a technological advantage in AI hardware design. A recent report found that the United States is the leader in AI talent, research, development, and hardware, and is a close second to China on the adoption of AI and data for the development of AI capabilities.[79] In terms of firm-level metrics, the United States is home to about 40 percent of all AI companies in the world.[80]

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[76] Semiconductor Industry Association, "Winning the Future: A Blueprint for Sustained Leadership in Semiconductor Technology," April 2019, https://www.semiconductors.org/wp-content/uploads/2019/04/FINAL-SIA-Blueprint-for-web.pdf.
[77] Govini, "Department of Defense Artificial Intelligence, Big Data, and Cloud Taxonomy," n.d., https://www.govini.com/wp-content/uploads/2019/06/Govini_DoD_AI_BigData_Cloud_Taxonomy.pdf.
[78] Jory Heckman, "US CTO Forecasts AI Research Spending next Year to Nearly Double 2016," *Federal News Network*, September 10, 2019, https://federalnewsnetwork.com/artificial-intelligence/2019/09/federal-cto-spending-on-ai-research-nearly-doubled-since-2016/.
[79] Daniel Castro, Michael McLaughlin, and Eline Chivot, "Who Is Winning the AI Race: China, the EU, or the United States?" (Center for Data Innovation, August 19, 2019), https://www.datainnovation.org/2019/08/who-is-winning-the-ai-race-china-the-eu-or-the-united-states/.
[80] Yixiang Xu, "Meet China's AI Competition: Germany's Drive toward AI Innovation Needs Sound Policy and Partnership with U.S.," American Institute for Contemporary German Studies, March 29, 2019, https://www.aicgs.org/2019/03/meet-chinas-ai-competition-germanys-drive-toward-ai-innovation-needs-sound-policy-and-partnership-with-u-s/.

The U.S. military has increased its spending on AI in recent years (Appendix C). In 2019, the Department of Defense spent an estimated $1 billion on AI (although the official number is classified), and plans to spend an estimated $3.4 million on autonomy research in FY2020 (though it is unclear how much overlap there is between these figures).[81] DARPA, one of the key agencies for military research and development, has established a program with $2 billion in funding for AI research for 2018-2023.[82]

Underpinning these robust investments in AI, the U.S. semiconductor industry remains relatively strong in comparison to global competitors. In 2019, the U.S. government spent $1.5 billion on research and development for semiconductors, while the private sector invested around $39 billion.[83] The United States leads the industry in the design of semiconductors and is home to six of the top fifteen semiconductor suppliers in the world as of 2018 (See Appendix B). Increasingly, however, the United States ships the manufacturing of these chips overseas, primarily to Taiwan—consistent with a world-wide industry trend.[84] Intel and GlobalFoundries, both U.S. companies, are two of the four companies worldwide that have developed extreme ultraviolet lithography (EUV) capabilities (through both acquisition and innovation), which are expected to drive the next generation of chips.[85]

In 2019, semiconductor industry stakeholders expressed concern that, despite all of this investment, the U.S. government is not spending enough on AI to out-innovate adversaries like China. It charged that most U.S. private-sector investment is allocated to applied research and product development—not the basic research needed for long-range, fundamental technology breakthroughs.[86] In response, the U.S. government has expanded its approach to AI investment and research.

In 2018, the Department of Defense released its Artificial Intelligence Strategy, entitled "Harnessing AI to Advance our Security and Prosperity."[87] The document identified the department's strategic goals in this area, which include a mix of security and workforce aspirations: delivering AI-enabled capabilities, fostering research and development, cultivating an AI workforce, establishing security and ethics standards, and promoting public, private, and international partnerships. The strategy also created the Joint Artificial Intelligence Center (JAIC), which is intended to serve as a focal point for all of Department of Defense AI innovation and for the integration of that innovation into military operations. JAIC has already

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[81] Jon Harper, "Pentagon Underinvesting in Artificial Intelligence," *National Defense Magazine*, August 19, 2019.
[82] "DARPA Announces $2 Billion Campaign to Develop Next Wave of AI Technologies," Defense Advanced Research Projects Agency, September 7, 2018, https://www.darpa.mil/news-events/2018-09-07.
[83] Semiconductor Industry Association, "Winning the Future."
[84] "Industry Report: Electronics," Industry Study (The Dwight D. Eisenhower School for National Security and Resource Strategy, June 2017), https://es.ndu.edu/Portals/75/Documents/industry-study/reports/2017/es-is-report-electronics-2017.pdf.
[85] John VerWey, "The Health and Competitiveness of the U.S. Semiconductor Manufacturing Equipment Industry" (USITC, July 2019), https://www.usitc.gov/publications/332/working_papers/id_058_the_health_and_competitiveness_of_the_sme_industry_final_070219checked.pdf.
[86] Semiconductor Industry Association, "Winning the Future."
[87] U.S. Department of Defense, "Summary of the 2018 Department of Defense Artificial Intelligence Strategy: Harnessing AI to Advance Our Security and Prosperity," February 12, 2019, https://media.defense.gov/2019/Feb/12/2002088963/-1/-1/1/SUMMARY-OF-DOD-AI-STRATEGY.PDF.

begun systematically identifying important capability needs and coordinating stakeholders to with a range of goals in mind: merging research and operations by creating standardized processes to test and evaluate prototypes; breaking down barriers between components; sharing lessons learned to ensure that the department is investing in a relevant, timely, and efficient manner; and facilitating the scaling and adoption of prototypes across the department. The JAIC is also working with industry, academia, and the national labs to help scale the needed technologies.

In support of Department of Defense initiatives, in 2019, the Trump administration unveiled the American AI Initiative, which outlines a whole-of-government approach (beyond DOD) to promoting artificial intelligence innovation and security. Per Executive Order 13859, "Maintaining American Leadership in Artificial Intelligence," the United States is taking a multipronged approach with five key areas of emphasis: 1) promoting investment in AI Research and Development; 2) increasing access to federal data and computing resources; 3) setting AI governance standards, including technical regulations and privacy standards; 4) building an AI workforce through education and training programs; and 5) protecting U.S. AI advantage in key strategic areas, while still promoting an open global market.[88]

Later that year, the Trump administration issued another order for a "refresh" on the National Artificial Intelligence R&D Strategic Plan, which identified eight strategic priorities for the United States: 1) encouraging long-term investments in AI research; 2) developing effective methods for human-AI collaboration; 3) fostering better understanding of the ethical and legal implications of AI; 4) ensuring the safety and security of AI systems; 5) developing shared public datasets and environments for AI training and testing; 6) establishing standards and benchmarks to evaluate AI technologies; 7) addressing AI R&D workforce needs; and 8) expanding public-private partnerships to accelerate advances in AI. (Appendix A shows the overall strategic framework of these 8 priorities.)

U.S. AI & Semiconductor Regulations

While the U.S. semiconductor industry has suffered from exploitative Chinese acquisition of its technologies, the U.S. government has recently "gotten smart" on protecting this technology. The 2019 National Defense Authorization Act (NDAA) advocates the regulation of AI-related technologies, including the use of Foreign Investment Risk Review Modernization Act (FIRRMA), a law that reforms CFIUS and "effectively ends the possibility of U.S. semiconductor companies being acquired [by foreign entities] ...for the foreseeable future."[89] The Export Control Reform Act (ECRA) of 2018 also explicitly mentions semiconductors as the likely subject of stricter export controls.[90]

The U.S. Congress has also introduced legislation to mitigate ethical and data-privacy risks related to AI. These include House Resolution 153, which supports the development of ethical guidelines for AI, and the Algorithmic Accountability Act, which would create some data

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[88] The White House, "Accelerating America's Leadership in Artificial Intelligence," WhiteHouse.gov, February 11, 2019, https://www.whitehouse.gov/articles/accelerating-americas-leadership-in-artificial-intelligence/.
[89] VerWey, "Competitiveness of Semiconductor Manufacturing Equipment Industry," 18.
[90] VerWey, "Competitiveness of Semiconductor Manufacturing Equipment Industry."

protection regulations on companies using AI.[91] Other legislation has been introduced to manage the impact of AI on the workforce and economy, namely the FUTURE of AI Act 2017 and the AI JOBS Act of 2018.[92]

Germany's AI Ecosystem

Representing just three percent of the global market share, Germany does not have a vibrant AI ecosystem.[93] Germany lacks the abundance of venture capital available to its competitors, and is scarce on "tech giants" that can compete with U.S. and Chinese companies.[94] Appendix D shows a mapping of the German AI landscape. Government spending on AI in Germany has also been relatively weak owing to data privacy concerns associated with AI development,[95] with only €50 million budgeted for spending on artificial intelligence in 2019.[96] However, Germany has since resolved to pursue both AI innovation and simultaneously preserve data privacy. Spending has since increased and Germany has recently made a significant push of late to improve its AI ecosystem.[97]

In 2018, Germany released its comprehensive strategy for artificial intelligence, "AI Made in Germany," which reflects a desire to make German-made AI "a seal of quality recognized all over the world."[98] The government plans to invest €3 billion ($3.9 billion) in this effort over the next 7 years.[99] The strategy also establishes twelve priority-action goals: 1) strengthen research and create an AI ecosystem; 2) create clusters of innovation; 3) strengthen small and medium-sized enterprises; 4) attract more venture capital and AI firms; 5) manage structural economic shifts brought on by AI; 6) attract AI talent; 7) integrate AI into state/administrative tasks; 8) make government data available while protecting privacy rights; 9) adapt regulatory frameworks for an AI world; 10) establish AI standards; 11) foster international cooperation, especially with other EU members and the U.S; and 12) deepen public-private partnerships.[100] Appendix A compares these strategic goals with those of the United States' AI strategy.

Notably, the strategy is focused mostly on AI's potential contribution to German industry—rather than security. A 2019 U.S. Congressional Research Service report summarized the

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[91] Future of Life Institute, "AI Policy - United States," futureoflife.org, n.d.
[92] Future of Life Institute.
[93] Fabian Westerheide, "Global Artificial Intelligence Landscape: Including Database with 3,465 AI Companies," *Medium* (blog), May 22, 2018.
[94] Xu, "Meet China's AI Competition."
[95] Westerheide, "Global Artificial Intelligence Landscape."
[96] Janosch Delcker, "Germany's 3B Plan to Become an AI Powerhouse," *Politico*, November 14, 2018, https://www.politico.eu/article/germanys-plan-to-become-an-ai-powerhouse/.
[97] Delcker.
[98] Sebastian Sprenger, "Germany Wants Its Own Version of DARPA, and within the Year," *DefenseNews*, July 18, 2018, https://www.defensenews.com/global/europe/2018/07/18/germany-wants-its-own-version-of-darpa-and-within-the-year/.
[99] Kate Brady, "Germany Launches Digital Strategy to Become Artificial Intelligence Leader," *Duetsche Welle*, November 15, 2018, https://www.dw.com/en/germany-launches-digital-strategy-to-become-artificial-intelligence-leader/a-46298494.
[100] C. Koch, "AI Made in Germany - The German Strategy for Artificial Intelligence," *Towards Data Science* (blog), June 1, 2019, https://towardsdatascience.com/ai-made-in-germany-the-german-strategy-for-artificial-intelligence-e86e552b39b6.

German strategy as follows: Its priorities are to expand AI research, transfer research findings and AI methods to businesses, support innovation competitions, create incentives for start-ups, develop international and European frameworks for AI in the labor market, fund and attract international scientists and talent, use AI in public administration, make data available and usable, revise the regulatory framework to ensure legal certainty if necessary, set standards, network on a national and international level, and engage in dialogue with different stakeholders.[101] As such, it is profoundly lacking in "foreign policy and defense elements of AI."[102]

The Germany semiconductor industry, though small in global terms, is a leader in microelectronics in Europe, with one out of every three European semiconductors made in Europe coming from Germany. The government, in partnership with private industry and academia, has also taken steps to improve the country's semiconductor capacity through its "Microelectronics from Germany Initiative," which has provided public funding of €1 billion from 2016-2020. Additionally, Germany's "Research Fab Microelectronics Germany" Initiative, undertaken through a partnership between the Fraunhofer Institutes and two Leibinz institutes, aims to integrate the research, design, and manufacturing clusters in the microelectronics industry in 4 focus areas: silicon-based technologies, compound semiconductors, integration, and design/testing (Appendix E).[103] This initiative has received €350 million in funding through 2020.

Consistent with its national strategy for AI, Germany's efforts to integrate semiconductor and artificial intelligence technologies into the German military are relatively nascent and opaque. Available information indicates that these efforts primarily focus on the use of datamining and analysis for intelligence purposes. Germany has no immediate plans to acquire autonomous weapon systems,[104] however, the German Defence Ministry recently created a Cyber Innovation Hub to identify domestic startups with potential defense applications, and AI startups will soon be eligible for federal/public funding. Former German Defence Minister Ursula von der Leyen also recently announced plans to create a new government agency, the Agentur für Disruptive Innovationen in der Cybersicherheit und Schlüsseltechnologien (ADIC), to study disruptive, security-relevant technologies. Her model for this agency is DARPA.[105]

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[101] Library of Congress, "Regulation of Artificial Intelligence: Europe and Central Asia," July 22, 2019, https://www.loc.gov/law/help/artificial-intelligence/europe-asia.php#germany.

[102] Ulrike Franke and Paola Sartori, "Machine Politics: Europe and the AI Revolution" (European Council onf Foreign Relations, July 11, 2019), https://www.ecfr.eu/publications/summary/machine_politics_europe_and_the_ai_revolution#a3.

[103] Research Fab Microelectronics Germany, "One-Stop-Shop for Technologies and Systems" (Fraunhofer Group for Microelectronics in cooperation with Leibinz Institutes FBH and IHP, n.d.), https://www.forschungsfabrik-mikroelektronik.de/content/dam/ipms/forschungsfabrik-mikroelektronik/de/Allgemein/Flyer_Broschueren/11_2018-FMD_Brosch%C3%BCre.pdf.

[104] "German Military Has No Plans to Acquire Robot Weapons - General," *Reuters*, February 15, 2018, https://www.reuters.com/article/germany-security-robots/german-military-has-no-plans-to-acquire-robot-weapons-general-idUSL8N1Q57GG.

[105] Sprenger, "Germany Wants Its Own Version of DARPA."

German Regulations

In terms of AI controls, regulations, and protections, Germany is bound first and foremost by strict data privacy laws implemented as a function of the EU's Data Protection Regulation, which have the effect of constraining the AI sector.[106] The 2018 German AI strategy, however, signaled a willingness to loosen some regulations at the domestic level in order to promote AI innovation.[107] Germany has also established an Ethics Commission on Automated Driving.[108] By comparison, China's "relaxed" privacy laws allow for the collection of massive amounts of data from its citizens that can be fed into AI applications. Some analysts also believe that Chinese entrepreneurs possesses the drive, beyond its previous "copycat" and "acquisition-driven" endeavors, to excel in AI. The development of AI in China further benefits from widespread government support, including financial expenditure at the federal, state, and local levels.[109]

Additive Manufacturing

Digital or additive manufacturing (AM) is a process in which physical objects are formed by adding, rather than subtracting or removing, thin layers of metals, plastics, and other materials.[110] In addition to its multiple commercial uses, AM is an *enabling* technology that can facilitate the rapid production of components of "modern weapons systems"—such as drones, missiles, and rocket engines, and is accessible to both state and non-state actors.[111] In an extreme case, AM can increase the risk of weapons of mass destruction (WMD) proliferation through "[the cheap, accessible] production equipment for fissile material, chemical or biological payloads" it affords.[112]

U.S. AM Ecosystem

The U.S. additive manufacturing landscape is an amalgam of several distinct communities. The private sector, do-it-yourself (DIY) communities, and government research facilities, such as Los Alamos and Oak Ridge national laboratories are, together leading AM innovation.[113] At the center of the digital manufacturing movement in the United States is America Makes, the National Additive Manufacturing Innovation Institute (NAMII). America Makes was designed to help initiate and coordinate public-private sector AM partnerships and innovation—much like the German Fraunhofer Institutes. Under the direction of the Obama Administration, the U.S.

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[106] Franke and Sartori, "Machine Politics."
[107] Delcker, "Germany's 3B Plan."
[108] Access Now, "Mapping Regulatory Proposals for Artificial Intelligence in Europe," November 2018, https://www.accessnow.org/cms/assets/uploads/2018/11/mapping_regulatory_proposals_for_AI_in_EU.pdf.
[109] Mona Dreicer, ed., "Getting Innovation Right" (Center for Global Security Research, Lawrence Livermore National Laboratory, September 2019), https://cgsr.llnl.gov/content/assets/docs/Getting-Innovation-Right.pdf.
[110] Simon Veronneau, Geoffrey Torrington, and Jakub Hlavka, "3D Printing: Downstream Production Transforming the Supply Chain" (RAND Corporation, 2017), 3, https://www.rand.org/pubs/perspectives/PE229.html.
[111] Simon Veronneau, Geoffrey Torrington, and Jakub Hlavka, "3D Printing: Downstream Production Transforming the Supply Chain."
[112] Christopher Daase, "WMD Capabilities Enabled by Additive Manufacturing," *NDS Report 1908, Negotiation Design and Strategy (NDS) Report 1908*, 2019, 16.
[113] *Manufacturing Demonstration Facility (MDF) at Oak Ridge National Laboratory*, n.d., https://www.energy.gov/eere/amo/manufacturing-demonstration-facility-mdf-oak-ridge-national-laboratory.

Departments of Commerce, Defense, and Energy, as well as the National Aeronautics and Space Administration (NASA) and the National Science Foundation (NSF) jointly invested in America Makes.[114] In 2015, America Makes received over $50 million in federal funding, plus an additional $39 million from industry investments and state-based funding from Ohio, Pennsylvania, and West Virginia.[115] According to a recent Government Accountability Office (GAO) report, America Makes has received additional non-federal funding in subsequent years.[116]

In 2018, the Trump Administration expanded the U.S. strategy on AM: The Strategy for American Leadership in Advanced Manufacturing directs the National Science and Technology Council Subcommittee on Advanced Manufacturing to revitalize the manufacturing workforce and improve the domestic U.S. manufacturing supply chain (Appendix H outlines key goals of the strategy).[117] Advanced manufacturing, as well as artificial intelligence, quantum information science, and 5G, are four key "industries of the future" identified by the current administration as principal investments for the United States.[118]

US investment in AM has coincided with an increase in AM use. A 2016 survey of 120 U.S. AM manufacturers found that 71% of the larger manufacturing sector had used AM for either prototyping or developing goods, an increase over the previous year's numbers.[119] Between 2006 and 2016, the number of at-home AM units in use increased by 1,400,[120] and the DIY community was catalyzed by lowered barriers to entry to establish fabrication laboratories or "Fablabs" and makerspaces.[121]

Despite the interest in and use of AM in a wide number of sectors, the largest players in the U.S. AM industry are large corporations, including 3D Systems, one of the oldest U.S. 3D printing companies; Stratasys, the parent organization of notable 3D printing subsidiaries MakerBot, RedEye on Demand, Solid Concepts, and GrabCAD; and General Electric, the leading AM developer in the aerospace industry.[122] The large investments made in this sector have given the United States the highest global capacity for AM, with roughly 38 percent of global market share

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[114] *We Can't Wait: Obama Administration Announces New Public-Private Partnership to Support*, 2012, https://obamawhitehouse.archives.gov/the-press-office/2012/08/16/we-can-t-wait-obama-administration-announces-new-public-private-partners.
[115] Tim Caffrey, Ian Campbell, and Terry Wohlers, "3D Printing and Additive Manufacturing State of the Industry," Wohlers Reports (Wohlers Associates, n.d.), https://wohlersassociates.com/state-of-the-industry-reports.html.
[116] John F Sargent Jr. and R.X Schwartz, "3D Printing: Overview, Impacts, and the Federal Role" (Congressional Research Service, August 2, 2019), 9, https://fas.org/sgp/crs/misc/R45852.pdf.
[117] *Strategy for American Leadership in Advanced Manufacturing*, 2018, https://www.whitehouse.gov/wp-content/uploads/2018/10/Advanced-Manufacturing-Strategic-Plan-2018.pdf.
[118] *America Will Dominate the Industries of the Future*, 2019, https://www.whitehouse.gov/briefings-statements/america-will-dominate-industries-future/.
[119] "3D Printing Comes of Age in US Industrial Manufacturing" (PWC, April 2016), 2, https://www.pwc.com/us/en/industrial-products/publications/assets/pwc-next-manufacturing-3d-printing-comes-of-age.pdf.
[120] "3D Printing Comes of Age in US Industrial Manufacturing."
[121] Trevor Johnston, Troy Smith, and J. Luke Irwin, "Additive Manufacturing in 2040: Powerful Enabler, Disruptive Threat" (RAND Corporation, 2018), 5, https://www.rand.org/pubs/perspectives/PE283.html.
[122] Joseph Flynt, "6 Best Publicly-Listed 3D Printing Companies," *3DInsider*, March 19, 2019, https://3dinsider.com/public-3d-printing-companies/.

(Appendix F).[123] And the U.S. AM industry is expected to grow by 23 percent, 15 percent, and 23 percent in the aerospace, automotive, and medical technology fields, respectively.[124]

AM technology is also integral to the Department of Defense's mission to develop its third offset strategy, which sought to develop "enabling dual-use digital technologies," including AM, in partnership with the private sector.[125] This strategy has led to growing "pressure to integrate [AM] technology into ongoing defense projects."[126] Indeed, 3D Systems has employed metal AM technology to print parts for the Navy, and it received a $15 million contract to improve the Army's combat vehicles, long-range munitions, missile defense, and supply chain.[127] Stratasys' MakerBot has partnered with D&H Labs and supported DoD training applications (for a list of top AM companies, see Appendix J).[128] The Army relies on GE to design and prototype aerospace fuel nozzles and commercial aircraft engines, such as the Leading Edge Aviation Propulsion or "LEAP" engine.[129]

U.S. government emphasis has also led to new departmental units aimed at integrating AM capabilities. Since 2015, DoD has invested in the Army's Rapid Equipping Force, the Navy's Print the Fleet operation, and the Defense Advanced Research Projects Agency (DARPA)'s Defense Sciences Office's in-house research and development (R&D).[130] An Air Force research unit recently developed custom, durable steel alloy powder for use in AM,[131] and NASA is working on a specific copper-chromium-niobium alloy for rocket development.[132]

U.S. AM Regulation

Several international regulatory regimes address the specific implications of AM, and the United States implements regulations to comply with these recommendations. Following the online release of the "Liberator"—a 3D printed plastic firearm developed by the Texas-based nonprofit,

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[123] "Additive Manufacturing in Aerospace and Defense" (Roland Berger, May 2017), https://www.rolandberger.com/publications/publication_pdf/roland_berger_additive_manufacturing.pdf.
[124] *Beyond Prototyping: Accelerating the Business Case for 3D Printing*, 2018, https://www.pwc.nl/nl/assets/documents/pwc-whitepaper-3d-printing-2018.pdf.
[125] Alexander H. Montgomery, "The Effects of the Diffusion of Dual-Use Enabling Technologies on Strategic Stability," *Reed College*, 2019, 7.
[126] Connor M. McNulty, Neyla Arnas, and Thomas A. Campbell, "Toward the Printed World: Additive Manufacturing and Implications for National Security," *Defense Horizons* 73 (2012): 7, https://ndupress.ndu.edu/Portals/68/Documents/defensehorizon/DH-73.pdf.
[127] "3D Systems and Huntington Ingalls Industries Partner to Transform U.S. Navy Shipbuilding," *3D Systems*, May 10, 2018, https://www.3dsystems.com/press-releases/3d-systems-and-huntington-ingalls-industries-partner-transform-us-navy-shipbuilding.
[128] Stratasys, *MakerBot Partners with D&H to Distribute 3D Printers and Scanners in Education, Healthcare and Government Verticals*, 2015, http://investors.stratasys.com/news-releases/news-release-details/makerbot-partners-dh-distribute-3d-printers-and-scanners; *Sheppard Air Force Base 3D Printing Case Study*, 2008, https://www.stratasys.com/resources/search/case-studies/sheppard.
[129] Kelsey Wilbanks and Armani Vadiee, "Beyond Prototyping 3DP in Government Contracts," *Procurement Lawyer* 52, no. 2 (2017): 10, http://www.smithpachter.com/post-detail.php?id=29196.
[130] *Defense Additive Manufacturing: DOD Needs to Systematically Track Department-Wide 3D Printing Efforts*, 2015, https://www.gao.gov/assets/680/673099.pdf.
[131] *Researchers 3-D Print Ultra-Strong Steel Parts from Powder*, 2019, https://www.arl.army.mil/www/default.cfm?article=3371.
[132] K.G. Cooper, *Three-Dimensional Printing Grcop-42*, 2018, https://ntrs.nasa.gov/search.jsp?R=20190001243.

Defense Distributed—the U.S. Department of State (DoS) and Directorate of Defense Trade Controls (DDTC) mandated the removal of the gun blueprints from design databases.[133] Citing the U.S. International Traffic in Arms Regulations (ITAR), the DoS and DDTC reemphasized that the digital proliferation of weapons design plans and AM technical data constitute a violation of export controls.[134] Similarly, the Wassenaar Arrangement, of which the U.S. and Germany are both members, establishes technical parameters for the export of laser technology and Nuclear Suppliers Group control lists prohibit the transfer of "proliferation-sensitive" nuclear-related equipment and materials.[135] Given that AM is slated to have the biggest impact on nuclear weapons delivery, current control regimes may need to be retrofit to mitigate the global risks of illicit activity and increased WMD proliferation.[136]

Protections for the intellectual property (IP) associated with AM remain equally fraught. The accessible, "decentralized nature" of AM technology impacts regulatory ability to protect IP. The evolution of "software-driven supply chains" decreases the barrier to IP noncompliance, increasing the risk of IP theft and privacy violations.[137] The open market nature of modern supply chains is inherently vulnerable to corruption.[138] Continued advancements in AM additionally expose the AM sector to "increased privacy threats [and] external attacks."[139] Non-state actors, such as hackers or hobbyists, may digitally obtain access to military and industry AM files.[140] Individuals may be inclined to "reproduce classified parts for defense operations" or modify and manipulate AM hardware and software undetected, changing the nature of the product.[141]

U.S. IP protections remain outdated as far as AM is concerned.[142] In the United States, only by obtaining specific copyright protections can AM innovators prevent the "unlawful reproduction" of AM technology, including its digital elements, such as CAD files,[143] and there are limits to the application of U.S. copyright and IP law to AM. The widespread consumer adoption of 3D printing and the online exposure of AM technology risk a level of liability and infringement even the Digital Millennium Copyright Act (DMCA)—a domestic U.S. copyright law governing the

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133 Adam D. Thierer and Adam Marcus, "Guns, Limbs, and Toys: What Future for 3D Printing?," *Minnesota Journal of Law, Science, and Technology* 17, no. 2 (2016): 833, https://scholarship.law.umn.edu/mjlst/vol17/iss2/6.
134 Adam D. Thierer and Adam Marcus, "Guns, Limbs, and Toys: What Future for 3D Printing?"
135 "Additive Manufacturing and Nuclear Nonproliferation: Shared Perspectives on Security Implications and Governance Options," in *Policy Dialogue Brief* (The Stanley Foundation, 2018), 4, https://stanleycenter.org/publications/pdb/AddManfPDB1018.pdf.
136 Daase, "WMD Capabilities Enabled by Additive Manufacturing," 61.
137 Adam Brown, "Legal Aspects of Protecting Intellectual Property in Additive Manufacturing," in *Critical Infrastructure Protection X* (10th International Conference on Critical Infrastructure Protection (ICCIP, 2016), 64.
138 Brown, 10.
139 Brown, 10.
140 Bonnie Kersch, "Additive Manufacturing Brings About New National Security Concerns," *Braumiller Law Group* (blog), August 15, 2019, https://www.braumillerlaw.com/additive-manufacturing-brings-about-new-national-security-concerns/.
141 Bonnie Kersch.
142 Brown, "Legal Aspects of Protecting Intellectual Property in Additive Manufacturing."
143 Bryan J. Vogel, "Intellectual Property and Additive Manufacturing / 3D Printing: Strategies and Challenges of Applying Traditional IP Laws to a Transformative Technology," *Minnesota Journal of Law, Science, and Technology* 17, no. 2 (June 2016): 900, https://scholarship.law.umn.edu/cgi/viewcontent.cgi?article=1410&context=mjlst.

illegal production and sale of copyrighted goods and services—cannot control.[144] The absence of government oversight and AM technical standards undermines efforts to legislate and establish international norms.

Germany's AM Capacity

German AM development is built on its own "triple helix" of public and private partnerships within the government, industry, and academia.[145] The German government's focus on innovation in AM is defined by *Bundesdigitalministeriums*, a similar initiative to America Makes, that spearheads all aspects of the German initiative, "Industrie 4.0."[146] Industrie 4.0 was born out of Germany's "High Tech 2020" strategy to revitalize the workplace and economy through digital manufacturing.[147] Between 2003 and 2013, the German government invested €21.2 million in AM research and development.[148] As of 2017, €200 million in funding has been allocated to various educational and private-sector entities, including the Fraunhofer-Gesellschaft and the National Academy of Science and Engineering (Acatech), to improve cyber-physical production systems (CPS) and internet of things and services (IoTS).[149]

In 2014, the *Verband Deutscher Maschinen- un Anlagenbau e. V.* (VDMA) engineering association created the German Additive Manufacturing Association to address the following eight government recommendations for AM implementation: 1) standardization; 2) innovation; 3) communication infrastructure; 4) safety and security mechanisms; 5) learning metrics; 6) training models; 7) regulatory frameworks; and 8) streamlined efficiency.[150] Thus far these initiatives have improved German AM productivity, revenue growth, employment, and investment.[151]

Of the 72 Fraunhofer-Gesellschaft research institutes, 18 institutes are specifically devoted to AM (Appendix G).[152] Known as the Fraunhofer Additive Manufacturing Alliance, the 18 institutes divide research functions into the following areas: "mesoscopic lightweight design, biomimetic structures, high-performance tools for hot sheet metal forming, ceramic components,

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[144] Bryan J. Vogel, 901.
[145] Montgomery, "The Effects of the Diffusion of Dual-Use Enabling Technologies on Strategic Stability," 2019, 9.
[146] Michael Petch, *German Minister Announces Plan to Take the Lead in the New Digital Era of Manufacturing*, 2017, https://3dprintingindustry.com/news/german-minister-announces-plan-take-lead-new-digital-era-manufacturing-101953/.
[147] *German Industrie 4.0*, 2017, 3, https://ec.europa.eu/growth/tools-databases/dem/monitor/sites/default/files/DTM_Industrie%204.0.pdf.
[148] Laura Bechthold, Veronika Fischer, Andre Hainzlmaier, Daniel Hugenroth, Ljudmila Ivanova, Kristina Kroth, Benedikt Römer, Edyta Sikorska and Vincent Sitzmann, "3D Printing: A Qualitative Assessment of Applications, Recent Trends and the Technology's Future Potential," Studien Zum Deutschen Innovationssystem (Commission of Experts for Research and Innovation, November 17, 2015), https://econpapers.repec.org/paper/zbwefisdi/172015.htm.
[149] *German Industrie 4.0*, 3.
[150] Bechthold et al, "3D Printing: A Qualitative Assessment of Applications, Recent Trends and the Technology's Future Potential," 67.
[151] Michael Rüßmann, *Industry 4.0: The Future of Productivity and Growth in Manufacturing Industries,"*, 2015, http://www.inovasyon.org/pdf/bcg.perspectives_Industry.4.0_2015.pdf.
[152] "Fraunhofer Additive Manufacturing Alliance," Fraunhofer-Gesellschaft, accessed May 2, 2020, https://www.fraunhofer.de/en/institutes/institutes-and-research-establishments-in-germany/fraunhofer-alliances/additive-manufacturing.html.

printable biomaterial, large size plastic components, integrating sensory-diagnostic and actuator therapeutic functions."[153]

Despite the strength of the Fraunhofer Additive Manufacturing Alliance, there have been only a few notable AM developments that have defense applications. In 2019, a German research organization pioneered the use of "hot isostatic pressing (HIP) post-processing techniques," an example of advanced material coating technology using titanium.[154] SGL Carbon GMHB, a German AM company, recently streamlined the process of carbon-fiber prototyping, a means of 3D printing which could "be useful for handling corrosive chemical weapons precursors and coping with high temperatures."[155]

German companies and universities are also active in AM research. The German University of Paderborn founded the Direct Manufacturing Research Center (DMRC) to connect AM developers and producers.[156] Private-sector AM activity is driven by companies such, as Prontotype e.K., ALL.RAPID 3D-Druck & Design, and RAYLASE AG, while stalwarts such as Siemens, EOS, and TRUMPF also play a considerable role.[157] EOS has also partnered with Daimler and Premium Aerotec to create NextGenAM, an effort to improve automation in AM and refine the manufacturing of aluminum for aerospace and motor vehicles.[158] The German Armed Forces is using AM for 3D printing obsolete parts directly in the field,[159] although the convergence of AM and national defense is much less noticeable in Germany than the U.S. [160]

Though AM innovation is thriving in Germany, the sector is plagued by a "low survival rate of [German] AM printing startups" and Germany does not have a strategic plan for AM investment at the national level.[161] Demand for the technology is low, limited to a small user-base of small and medium-sized enterprises (SMEs).[162] Additionally, the overall domestic market for AM is relatively small: Germany possesses only 9 percent of all installed industrial AM systems, while the United States develops and installs 40 percent.[163] Without improved management, financial support, and AM standardization in SMEs, there is a distinct "non-technical barrier" to achieving

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153 Bernhard Muller, "Fraunhofer Additive Manufacturing Alliance: From Data Straight to Highly Complex Products," in *Digital Transformation* (Springer-Verlag GmbH Germany, 2019), https://link.springer.com/chapter/10.1007%2F978-3-662-58134-6_10.
154 Daase, "WMD Capabilities Enabled by Additive Manufacturing," 33.
155 Daase, 30.
156 Daase, 52.
157 Felix W. Baumann and Dieter Roller, *Overview of German Additive Manufacturing Companies*, 2017, https://www.mdpi.com/2306-5729/2/3/23/pdf.
158 Fabian Wanke and Will Hastings, "Additive Manufacturing Disrupts Automotive Industry," *Automation World*, July 22, 2019, https://www.automationworld.com/home/blog/13320015/additive-manufacturing-disrupts-automotive-industry.
159 "German Armed Forces Use 3D Printing to Redesign an Obsolete Part," 3DPrint.com | The Voice of 3D Printing / Additive Manufacturing, October 17, 2018, https://3dprint.com/227587/german-armed-forces-3d-print-obsolete-part/.
160 "Additive Manufacturing (3D Printing)" (Office of Technology Assessment, March 2017), 11, https://www.tab-beim-bundestag.de/en/pdf/publications/tab-fokus/TAB-Fokus-015.pdf.
161 Daase, "WMD Capabilities Enabled by Additive Manufacturing," 56.
162 *German Industrie 4.0*, 3.
163 Jaime Bonnin Roca et al., "Policy Needed for Additive Manufacturing," *Nature Materials* 15 (2016): 817, https://www.nature.com/articles/nmat4658.

German Industry 4.0 objectives.[164] Failure to "broaden the industrial user base" in Germany may stifle AM innovation, delaying the development of certain 3D printing applications.[165]

As of 2018, Germany is partnering with other EU member states—Finland, France, the Netherlands, Poland, Sweden, and Norway—under the auspices of the European Defence Agency (EDA) on the Additive Manufacturing Techniques for Energetic Materials (AMTEM) project.[166] Within AMTEM, 15 European research institutes and private companies are working to understand and mitigate the risks of using AM in the production of explosives and propellants.[167] Still, research suggests the German armed forces—as well as those of Japan, Switzerland, Sweden, and Australia—are stifled by a lack of "strategic motivation" in military innovation, which includes the integration of AM.[168]

Germany's AM Regulations

The German system to minimize the potentially adverse effects of AM development and use has been slow to evolve. Computer aided design (CAD) files are explicitly protected by German copyright law.[169] Although intellectual property mandates are limited in Germany, all rights to designs, blueprints, and names lie with the originator. By contrast, rights regarding decision and exploitation are not necessarily extended to the creator or originator in the U.S.[170] In terms of data rights or laws governing data protection, Germany encourages companies to stipulate specific "rights to technical data generated by machines."[171] This soft law approach, however, fails at providing protection to AM innovators.

While German AM manufacturers have active export control compliance programs to minimize the proliferation risk from dual-use technology, universities and research organizations, such as Fraunhofers, exist outside the military realm and operate outside the scope of export controls.[172] As such, they may also "offer a convenient conduit" for proliferators to gain the necessary tacit knowledge, capabilities, and materials to engage in WMD activity.[173] The accessibility and openness of collaborative academic and research environments will continue to pose unique risks to current control regimes.

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[164] "Additive Manufacturing (3D Printing)."
[165] "Additive Manufacturing (3D Printing)."
[166] Grant Turnbull, "3D Printing: Where Next for Additive Manufacturing in Defence?," Global Defense Technology, accessed May 2, 2020, https://defence.nridigital.com/global_defence_technology_jun19/3d_printing_where_next_for_additive_manufacturing_in_defence.
[167] Grant Turnbull.
[168] Montgomery, "The Effects of the Diffusion of Dual-Use Enabling Technologies on Strategic Stability," 2019, 19.
[169] Klaus M. Brisch and Marco Muller-ter Jung, "3D Printing: Rights to Data and IT Security in the Field of Additive Manufacturing," *DOT Magazine*, July 2017, https://www.dotmagazine.online/issues/digital-production/driving-digital-transformation/3d-printing-rights-to-data-and-it-security-in-the-field-of-additive-manufacturing.
[170] Klaus M. Brisch and Marco Muller-ter Jung.
[171] Klaus M. Brisch and Marco Muller-ter Jung.
[172] Daase, "WMD Capabilities Enabled by Additive Manufacturing."
[173] Montgomery, "The Effects of the Diffusion of Dual-Use Enabling Technologies on Strategic Stability," 2019, 59.

The United States and Germany have collaborated on some aspects of AM regulation. A 2018 U.S.-German standards panel on the future of "smart technologies" proposed the need for improved Industrial Automation and Control Systems (IACS) and bilateral, industry-led collaboration to promote AM standardization, information sharing, and security.[174] Indeed, multilateral efforts to collaborate on AM standards and governance will be essential to mitigating risks associated with AM, particularly as the digitization and diffusion of emerging technologies continues to accelerate.

Thus far, Germany has benefitted economically from a lack of strict AM regulations. However, this may be changing: Prior to the implementation of EU FDI screening legislation, Germany absorbed the economic risk of decreased exports and profits by accepting FDI, particularly from China.[175] In the absence of foreign investment, German companies are more vulnerable.

AM Conclusions

Although the current U.S. Administration continues to fund AM research and development, the current administration's primary priority is a return to "traditional manufacturing jobs."[176] Germany, in comparison, is defined by "strong development" but "weak application" of AM.[177] The German market is plagued by a national supply and demand issue and a tension between traditional and advanced manufacturing sectors.[178] Germany's Industry 4.0 model is innovative, but may prove self-defeating due to German reliance on traditional supply chain structures and "conventional equipment."[179] Having dominated conventional manufacturing for so long, the German government and industry actors have a blind spot with respect to emerging applications of AM technology.[180]

In terms of defense integration of AM, the United States bests Germany, which is largely avoiding defense integration.[181] Yet, while America Makes successfully accelerates 3D printing research at the intersection of commercial AM application and defense, the U.S. does not have the same level of national investment in AM as Germany. Instead, the U.S. government relies on private companies to develop AM at the tactical and strategic level.[182]

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[174] *U. S. - GERMAN Standards Panel 2018: Securing Future Technologies – Cybersecurity and Other Challenges and Solutions for Smart Manufacturing, Mobility and Agriculture*, 2019.
[175] Montgomery, "The Effects of the Diffusion of Dual-Use Enabling Technologies on Strategic Stability," 2019, 11.
[176] Jack Karsten, *Trump Administration Brings a Different Approach to Manufacturing*, 2017, https://www.brookings.edu/blog/techtank/2017/07/14/trump-administration-brings-a-different-approach-to-manufacturing/.
[177] "Additive Manufacturing (3D Printing)."
[178] Montgomery, "The Effects of the Diffusion of Dual-Use Enabling Technologies on Strategic Stability," 10; Richard A. D'Aveni, *The 3-D Printing Playbook*, 2018, https://hbr.org/2018/07/the-3-d-printing-playbook.
[179] D'Aveni, *The 3-D Printing Playbook*.
[180] "Additive Manufacturing (3D Printing)."
[181] Daase et al., "WMD Capabilities Enabled by Additive Manufacturing," 2019, 12-13.
[182] See Daase et al., WMD Capabilities Enabled by Additive Manufacturing," 2019; Montgomery, "The Effects of the Diffusion of Dual-Use Enabling Technologies on Strategic Stability, 2019;" and Wilbanks and Vadiee, "Beyond Prototyping 3DP in Government Contracts," 2017.

III. Findings and Implications

Findings

Innovation: Accelerated Cycles lead to Rapid Evolution

Technological innovation has historically yielded a competitive military advantage. But this advantage appears increasingly fleeting in an era of broad-scale military integration of dual-use technologies. As we've already seen, the rapid acquisition and adoption of COTS solutions, for example, can provide states with near-term military capabilities, but competitors will likely offset early adopter advantages either through licit or illicit pathways. The ability to regulate and control proliferation pathways of dual-use technologies will be limited, as economic factors compete with purely security factors. As a result of this cycle of "early adopter" and "fast follower," states will be compelled to regularly re-invest in COTS solutions to ensure either advantage or parity on the battlefield. This will accelerate the cycle, relative to past eras, of innovation, proliferation, and the pursuit of off-setting technologies.

In response to this accelerated cycle, national models of innovation are being reshaped with governmental goals for dual-use emerging technologies in mind. As this study shows, the U.S. and German national models of innovation are evolving to reap the benefits of private-sector innovation to achieve national goals—albeit in different ways. However, there are significant "growing pains" in the restructuring and evolution of both systems. Countries face tradeoffs in structuring their national models to achieve chosen short-term goals and making R&D infrastructure less flexible in the long run.

The United States is restructuring with "military edge" in mind, seeking to "out innovate" rival states in the security domain. This involves serious and iterative debate over "how to get innovation right" for defense purposes. Meanwhile, Germany is restructuring to retrain its workforce and maximize technological market share. Both states' models can be understood to combine state-level investment in and the military integration of dual-use technologies with regulations crafted to enforce the aims of the model. But both also face high uncertainty about what a successful model for innovation will look like in this emerging ecosystem.

As can be seen from the examination of AI and AM ecosystems in the two countries, both face significant challenges in evolving their innovation pipelines. In general, Germany spends more federal dollars on innovation per GDP than does the United States and has a more efficient, profitable, and sustainable model for integrating technological developments into its economy, which ultimately relies on exports. The U.S. government spends far less on the industrial application of AI (and more on defense application) relative to Germany. The United States has also been comparatively slow to adopt a national AI strategy, but the German strategy is focused mostly on AI's potential contribution to industry—rather than security.

Innovation within the AM sector in both countries is benefiting from hub-like, innovation centers that draw on government, university, and private-sector expertise. However, while America Makes successfully accelerates AM research at the intersection of commercial application and defense, the U.S. government doesn't invest in fundamental AM research as much as Industry

4.0 does in the German AM sector. The relatively robust German investment has seen Germany's AM institutes and universities develop into a hybrid model, where together they are able to offer the research capabilities of think tanks, the R&D capabilities of scientific research laboratories, and production of top AM developers.[183]

Military Integration: U.S. leads, Germany Lags

These challenges have a significant effect on military integration of both AI and AM technologies. In general, the United States is better than its peer allies (Germany included) at defense integration of novel emerging and evolving technologies. Consistent with Germany's national strategy for AI, Germany's efforts to integrate semiconductor and artificial intelligence technologies into the German military lag behind the U.S's. In contrast, U.S. efforts are explicitly geared toward out-innovating adversaries, with a focus on the potential battlefield applications of AI.

Despite U.S. efforts, there are few metrics for gauging the integration of AI battlefield applications. In terms of AM defense integration, the United States clearly bests Germany, which is largely avoiding AM defense integration.[184] Given its AM regulatory and funding environment, Germany is likely to continue partnering with allies to develop key technology applications, while domestically investing primarily in R&D. Germany may already be doing this under the auspices of the European Defense Fund, but it is unable to partner with the United States under this mechanism. In the United States, in lieu of strong federal AM investment, private U.S. companies rely instead on government contracts to develop and apply AM technologies at the tactical and strategic level.[185]

Regulation: Innovation risks Proliferation

The U.S. defense model for innovation relies on superiority through the monopolization of military innovation. While this approach may have worked in previous eras, it is unlikely to work today. The dual-use technologies, such as AI and AM, that are fueling military competition are too widespread, and the cycles of competition too fast to reset to rely on monopolization alone. The United States has a particularly difficult time considering other paradigms for achieving military superiority or conceiving of European states as either competitors or collaborators, rather than recipients of technological largesse.

Previous decades of cooperation on export controls also do not portend future cooperation. Not only are the predominant forms today's dual-use technologies digital in form, and thus inherently accessible, technological development is increasingly derived from the private sector. This considerably complicates the process of preventing the diffusion of next-generation dual-use innovations capable of driving instability.

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[183] Daase et al., "WMD Capabilities Enabled by Additive Manufacturing."
[184] Daase et al., "WMD Capabilities Enabled by Additive Manufacturing," 2019, 12-13.
[185] See Daase et al., WMD Capabilities Enabled by Additive Manufacturing," 2019; Montgomery, "The Effects of the Diffusion of Dual-Use Enabling Technologies on Strategic Stability, 2019;" and Wilbanks and Vadiee, "Beyond Prototyping 3DP in Government Contracts," 2017.

The U.S. desire to optimize innovation in the current era likely facilitates downstream risk. Innovators do not tend to think about the protection or proliferation of their innovations. In the United States, the same goes for government planners who are primarily focused on "getting innovation right," with little to no consideration given to downstream effects. U.S. officials are also increasingly concerned that the United States will be out-innovated by Russia and China, which both have fewer constraints on investment and innovation. In contrast, German officials are beginning to recognize the sensitivity of many of the dual-use innovations and industries emerging from within German borders, and the country is working to implement recent EU-wide regulations for FDI screening and export controls, which may prove limited in effectiveness for dual-use items.

Implications

Innovation without Regulation leads to Proliferation

Although there is a gap in the literature and our knowledge about how models of national innovation relate to the proclivity of a supplier country to proliferate, national governments necessarily are driven to protect investments critical to their security, particularly those that yield competitive military advantage. States also are incentivized to manage and guard investments that have the potential to yield high economic returns in the global marketplace. While the linkage between protecting security-related and economically significant investments seems logical, there is strong *a priori* evidence to the contrary.

The structure of government efforts belies this lack of linkage. Procurement and nonproliferation efforts live in decidedly different parts of *any* bureaucracy and generally have little interaction. There is also recent anecdotal evidence that these two parts of government only connect after a crisis or if a security threat forces existential reconciliation—for both the United States and Germany. By and large, processes in place to prevent the spread or transfer of sensitive information or technologies are decidedly reactive.

Emerging technologies—including AI and AM—are likely to increase drivers of supply-side proliferation that stem from national models of innovation. Because these technologies are relatively new and evolving quickly, the full scope and scale of their military applications are not readily apparent. If we don't know which technologies and capabilities will serve military purposes, it is infeasible to limit their proliferation. The dual-use nature of most of these technologies, relative to previous eras, complicates this identification problem, because early investments in technology development need not be made with explicit military purposes in mind. When regulation is determined to be needed in this context, designing and implementing it is a heavier lift than if it were begun earlier in the cycle of innovation. Private enterprises, the source of much of this innovation, want free and unfettered access to open markets for profit—profit that is critical to the funding feedback loop that leads to further development and, in turn, competitiveness. As economic competitiveness is increasingly cast as a national security objective, the specter of regulation of any sort will also appear increasingly burdensome to innovators, making governance an even "heavier lift."

A state may be motivated to control or regulate the sale of sensitive military equipment or technology because of concerns about competitiveness, proliferation, or end-use. Yet, controls that dictate to whom a state may sell sensitive weapons and technologies could run up against other foreign policy objectives; for example, policies intended to support economic competition could undercut national security interests in limiting the spread of specific technologies and capabilities.

One alternative outcome is that cultural mindset prevails over national models of innovation. For instance, Germans have a general proclivity towards accepting the limits of human rationality and implementing safeguards to guard against human bias and decision making under uncertainty. For instance, companies like Germany-backed Airbus assume that aircrafts' automated systems actually know better than human pilots and, therefore, ought to have final decision-making authority. As such, Airbus "defines hard tight envelope limits, beyond which the pilot cannot go regardless of circumstance. By contrast, [U.S.-based] Boeing sets soft limits that pilots can go beyond if they deem it necessary."[186] As the pace of dual-use innovation and its integration increases, Germans may be more cautious in making innovation decisions that have military or proliferation implications, given their cultural predilection towards accepting the limits of their own rationality.

The U.S. innovation model also has an opening for similar, preventive thinking. DARPA's Explainable AI (XAI) Program is working to create new machine learning systems that can explain their rationale for options executed, as well as communicate self-understanding of likely future behavior.[187] Likewise, its Safe Gene Program endeavors to develop genetic "turn-off" switches for built in biosafety from the beginning. The goal of both of these programs is to anticipate and trace technology development so as to better assess its military applicability and the potential for regulation.

Peer Competition and Countering Proliferation requires Cooperation

Military innovation steeped in dual-use technology will "get out" faster than did military innovation in previous eras. The duration-to-export of potentially sensitive emerging technologies is shortening because of "multi-hub" innovation and multi-state competition, which has also evolved due to the dual-use nature of contemporary innovation. Because a country's model of innovation is closely tied with the way in which technology is procured and integrated in military use, it is also closely tied to a state's ability to regulate end-product use and prevent diffusion or proliferation.

The United States, and Germany to a lesser extent, will need to develop a new approach to balancing the ability to procure dual-use technology for military applications relatively quickly and the ability to maintain propriety over or regulate that technology. Existing German and U.S. controls are ill-suited for protecting military innovations and technologies in this environment.

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[186] Richard Danzig, "Managing Loss of Control as Many Militaries Pursue Technological Superiority," *Center for a New American Security*, June 2018, 15. https://s3.amazonaws.com/files.cnas.org/documents/CNASReport-Technology-Roulette-DoSproof2v2.pdf?mtime=20180628072101
[187] David Gunning, "Explainable Artificial Intelligence (XAI): Program Report," https://www.darpa.mil/attachments/XAIProgramUpdate.pdf.

For example, while German universities and research centers may be a boon to German AM innovation at the basic research level, their perceived isolation from military applications allows them to operate outside the scope of regulations that would protect sensitive technologies (with potential military applications). This makes such centers vulnerable and potential points of proliferation. Developing adequate AM regulations on either the international and domestic level has proven challenging because of the high cost of "regulatory acceptance" of AM.[188] Still, members of the Wassenaar Arrangement are committed to adapting the agreement to include AM applications, even as participating states recognize the limited enforcement capability of the export regime.[189]

The U.S. response to innovation-related proliferation challenges has often been to innovate more quickly. Given the pace of current innovation and the likelihood of leakage due to the dual-use nature of many of the resulting technologies, the likelihood that one state will be able to "out innovate" another is low, augmenting the cooperative imperative.

Current Transatlantic Relations Hinder Regulation and Cooperation

Existing transatlantic relations hinder cooperation on both regulation and peer competition. The United States and Germany are neither allies in innovation nor pure competitors. Recent German and European defense initiatives have contributed to increased tensions in the U.S.-E.U. defense cooperation, yet there is still an imperative for transatlantic cooperation. U.S.-E.U. defense trade has served as a backbone of the transatlantic relationship for decades. As Europe continues its inward turn, innovating indigenously for defense, the United States has called for Europe to be more inclusive of U.S. defense companies.

Some of this competition is inevitable as the new European "honey pot" model is meant to diverge from past practice. Though the EDF requirements introduce new obstacles to transatlantic defense cooperation, U.S. labels of unfair protectionism are likely an overreaction. The EDF represents only 1 percent of member states' military spending and, according to some, is not likely to revolutionize European procurement. The transatlantic relationship's need for "interoperability" for NATO defense missions serves as a bulwark against major deterioration of defense cooperation. But if European models prove more successful than presently demonstrated, the end result could yield new asymmetries among western countries.

Recommendation: The United States should actively work to resolve tension vis-à-vis E.U. defense innovation initiatives, either by welcoming the EU investments, which would beget competition and, in turn, spur innovation; or healing the rift spawned by European defense innovation with track-one and -two dialogues. If Europe wants to maintain its reliance on the United States within NATO to guarantee its security, it should consider "biting the bullet" and establishing regular consultations and partnerships with the United States on new European weapons and systems.

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[188] "Additive Manufacturing in Aerospace and Defense," 2017.
[189] Philip Griffiths, "The Wassenaar Arrangement, The Wassenaar Arrangement: Recent Developments," 24th Asian Export Control Seminar, 2017.
http://www.wassenaar.org/wp-content/uploads/2015/06/24th-ASIAN-EXPORT-CONTROLSEMINAR.pdf

The United States could agree to an initial period of ITAR-free procurement (which precludes U.S. cooperation in the development of new systems) to allow Europe to "make a go of it," and to invest greater effort in ongoing consultations on matters pertaining to military innovation. As an olive branch, the United States could also explore options for co-development of defense technologies, issuing an exemption from U.S. requirements that new weapons and systems be built on U.S. soil, for example, and allowing the resulting technology and capabilities to be jointly owned—by the United States and Europe.

In the 1970s, the U.S. innovation system began to change in the face of "competitiveness" challenges from Japan and Germany. In the mid-1970s, under President Jimmy Carter, the U.S. government began a targeted focus on "the promotion of technology, innovation, and competitiveness," which, today, may underlay the U.S. struggle to see Germany as a collaborator: the U.S.-German relationship—in recent decades—has been defined by competition.

Robert Atkinson explains how the relationship might instead be optimized:

> While innovation is about competition, it's also about 'coopetition'—and cooperation—in other words, groups working together to drive innovation. This has become more important to enabling innovation, especially as innovation has become more challenging with more organizations embracing open innovation.[190]

Former Secretary of the Navy Richard Danzig suggests that a third party like the United Nations could be "encouraged to make assessments and, optimally, to coordinate with national efforts so as to sensitize all nations about risks that can be understood at least in unclassified contexts."[191] Failing that, the United States and Germany could share risk analysis and engage in data/intelligence exchange.

Ultimately, should prevention in the proliferation of military-use emerging technologies fail, international cooperation and coordination will be necessary in response. Danzig argues for "increased multilateral planning with our allies and our opponents so that we are cooperatively better able to recognize and respond to accidents, catastrophic terrorist events, and unintended state conflicts," to improve security in and around emerging, digital, dual-use technologies. Abstractly, a state would have little incentive to control or regulate a particular technology knowing that other countries may "release" it. Danzig is spot on here: "All nations employing advanced destructive technologies need to share perceptions of risks and safeguards."[192] The United States and Europe did this previously (e.g. during the Nunn-Lugar Program era); perhaps they can do it again.

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[190] Atkinson, "Understanding the US National Innovation System," 5.
[191] Danzig, Richard, "Technology Roulette: Managing Loss of Control as Many Militaries Pursue Technological Superiority" (Center for a New American Security, June 2018), https://www.cnas.org/publications/reports/technology-roulette.
[192] Richard Danzig, "Managing Loss of Control as Many Militaries Pursue Technological Superiority," *Center for a New American Security*, June 2018, 11. https://s3.amazonaws.com/files.cnas.org/documents/CNASReport-Technology-Roulette-DoSproof2v2.pdf?mtime=20180628072101

Recommendation: The United States and its European allies should conduct regular consultations. Consultations should focus on the development of specific dual-use technologies. This could, in turn, guide discussions on how to align indigenous capacities in critical areas and "out-partner" adversaries, and further assist in cultivating transatlantic cooperation.

The United States and its allies should focus collaborative efforts on identifying a common threat. A combination of dialogue and collaborative simulations and war-gaming should seek to provide insight into the range of strategic threats and the required capabilities needed to address those threats and inform the necessary innovation. Collaborative efforts must focus on the risk of diffusion or proliferation of dual-use technologies by identifying the "crown jewels" of the new crop of weapons and systems. Doing so may help set guidelines for international agreements and regulations with respect to what are the most "sensitive" items—a kind of focused export control approach. Finally, we must assess how an accretion of actors (state and non-state) empowered by equivalent or analogous technologies changes the security space and then identify the weapons and systems least beneficial for conflict in the future. We may then be able to set targets for arms control—the elimination of weapons and systems with outdated or limited utility.

IV. Conclusion

This analysis aims to inform questions of "optimality": How are innovations achieved in a timely and efficient manner and how they are best integrated into the defense arena? It considers the downstream effects of innovation, with awareness about the limits on understanding long-term effects of choices in this arena. This study takes a broad approach to understanding which national models yield the greatest chance of "success" and how the United States might achieve success in this space. It also seeks to inform assessments about the impact of emerging technology investments on strategic stability. Models of innovation are susceptible to further change as policies and strategies crystallize. As such, it is the opportune moment for engagement, dialog, and allied consultations.

The United States needs to develop a framework for assessing different states' models of innovation to enable the development of targeted strategies for effective competition and cooperation. At the national (NSC) level, the United States can employ national models as a useful indicator of both the technological capacity and the limitations of potential adversaries. National models can isolate key factors driving innovation and, in turn, competition. They may also identify modalities of compatibility in innovation and capabilities, and drive cooperation.

In general, the United States needs to make choices about investment in innovation with the long game in mind, particularly given the profound consequences of policy misalignment, including the possibility of inhibiting much-needed cooperation in this realm. The diffusion of most innovation over time is inevitable. For this reason, anti-diffusion efforts aimed at thwarting the likes of China will never solve the proliferation problem completely. But there are uncertainties about to whom, how, and on what timeline technologies spread.

"Fear can be our friend," says Danzig. "Properly acknowledged fear can be a powerful bonding agent." "A clear-eyed view of militaries as inadvertent actors may open a path to taming our capacities for destruction." Not all allies are equal, and Germany, for one, is trying. We must leverage shared threats, as well as concerns and fears where possible. Right now, there's an opening on the other side of the Atlantic for partnership—but it may not last much longer.

Author Bio

Amy J. Nelson is a research associate at CISSM and a research fellow at the National Defense University's Center for the Study of Weapons of Mass Destruction. Her research focuses on disruptive technologies and their impact on proliferation, as well as improving the efficacy of arms control. She was previously a Robert Bosch Fellow in residence at the German Council on Foreign Relations (DGAP) in Berlin, Germany where her research focused on the current state of German military innovation and prospects for US-German competition and cooperation.

Nelson was previously a nonresident fellow at the Stimson Center, a Stanton Nuclear Security Fellow at the Council on Foreign Relations, and a policy analyst in the State Department's Bureau of Political-Military Affairs, Directorate of Defense Trade Controls in Washington, DC. She held pre-doctoral fellowships at the Stimson Center and SIPRI North America, and conducted research as a member of the US arms control delegation to the Organization for Security and Cooperation in Europe (OSCE), which maintains the Conventional Forces in Europe (CFE) Treaty.

Nelson is currently working on a book on next generation arms control. Drawing on recent findings from the decision sciences, the book presents a new theory of arms control as a tool of uncertainty management. The book also uses the analysis of a novel dataset to incorporate empirically derived best practices into the negotiation of arms control agreement to overcome the effects of uncertainty. Finally, using the dataset, the book tracks trends in arms control over time, and provides analysis of recent events and developments in weapons technology to assess the current state of arms control and its likely future.

Nelson's writings have appeared in Foreign Affairs, Strategic Studies Quarterly, theNational Interest, The Washington Post, War on the Rocks, the International Business Times, the Millennium Journal of International Studies, Political Psychology and the Journal of Neurophysiology. She received her AB in Philosophy with honors from Stanford University, has an MA in Intellectual History from Columbia University, and an MA and PhD in Political Science from the University of California, Berkeley.

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