Introduction

Tai Ming Cheung

How do countries around the world approach and engage in defense innovation? Are there common patterns, catalysts, and enabling factors that identify and explain why some countries are successful while others struggle? This year's edition of research briefs from the University of California's Institute on Global Conflict and Cooperation (IGCC) Study of Innovation and Technology in China project examines these questions.

A workshop held at the University of California San Diego in December 2017 brought leading academic and policy experts on defense innovation from around the world to present research papers comparing a diverse array of countries and some functional areas. The workshop was led by Tai Ming Cheung (University of California San Diego and IGCC) and Thomas Mahnken (School of Advanced and International Studies at Johns Hopkins University and the Center for Strategic and Budgetary Assessments). Nine countries representative of key parts of the global defense innovation community were selected for study: small countries with advanced defense innovation capabilities (Israel, Singapore), closed authoritarian powers (North Korea); advanced industrialized nations (France, Sweden), large catch-up states (China, India), and advanced great powers (the United States). There were also case studies of emerging technologies (China's efforts in the development of artificial intelligence and quantum technologies) and historical periods (defense innovation in the inter-war era). The policy briefs in this compendium are highlights of the findings from the longer research papers that will be published later.

DEFINING INNOVATION AND ANALYTICAL FRAMEWORKS

This year's comparative perspective on defense innovation builds upon the detailed work that has been done in examining China's approach to defense innovation over the past decade. The intention was to see if findings from the Chinese case could be applied to the experiences of other countries that would help to generate more broadly applicable insights. A key question to address first is what, precisely, is meant by defense innovation. This is answered by Tai Ming Cheung, Tom Mahnken, and Andrew Ross in their overview brief, "Assessing the State of Understanding of Defense Innovation." They distinguish between military and defense innovation, of which the latter is defined as "the transformation of ideas and knowledge into new or improved products, processes, and services for military and dual-use applications." It refers to organizations and activities associated with the defense and dual-use civil-military science, technology, and industrial base. Military innovation is categorized as "warfighting innovation, modest or profound. It encompasses both product innovation and process innovation, and technological, operational, and organizational innovation, whether separately or in combination, intended to enhance the military's ability to prepare for, fight, and win wars."

A key contribution from the China project detailed in Tai Ming Cheung's policy brief on "Critical Factors in Enabling Defense Innovation" is the development of an analytical framework to identify, categorize, and assess a wide range of factors involved in the pursuit of defense innovation through an innovation ecosystem prism. Cheung defines a defense innovation system as a network of organizations that interactively pursue defense-related science, technology, and innovation activities to further the development of a country's defense, dual-use, civil-military, and strategic high-technology interests and capabilities. Cheung offers two approaches to make sense of the large array of factors. The first is to sort these factors into 'hard' and 'soft' innovation variants, and the second is to categorize them into several distinctive domains based on their functions, which include catalytic, input, process, institutional, and output factors.

DEFENSE INNOVATION IN MAJOR POWERS: FROM CHINA TO INDIA

Cheung applies this framework to China's efforts in developing its defense innovation capabilities in the brief entitled "How China's Defense Innovation System is Advancing the Country's Military Technological Rise." Cheung offers two key findings. One is the central importance of catalytic factors in pushing defense innovation systems to step up their innovation activities from routine to higher levels. Without these catalytic factors, there is little impetus for undertaking higher and more risky levels of innovation. Catalytic factors by themselves are insufficient to produce far-reaching change within the innovation system, however, and they need to coordinate with factors from other categories. A second insight is that the factors that are most effective correspond to the primary science, technology, and engineering activity taking place within the defense system at that time. For example, if absorption is the primary mode of activity, factors that are associated with the input of external technologies and knowledge and dealing with soft innovation capabilities such as improving management and quality control are more appropriate and useful.

By contrast, Eugene Gholz and Harvey Sapolsky argue that the US defense innovation system has a very different and unique set of factors that allows the country to enjoy "tremendous advantages that other countries cannot readily replicate" and consequently keeps the country far ahead of any potential rivals: 1) the accumulation of capabilities and know-how over many decades of funding and experimentation that dwarf other countries' efforts; 2) a unique political system that favors substituting technology for labor; 3) a welcoming approach to immigration that has allowed for the importation of new ideas; and 4) the promotion of competition among decentralized organizations to solve national security challenges, especially inter-service competition. Gholz and Sapolsky conclude that the constant worry that the United States is losing its defense innovation advantages because of a dysfunctional Congress and a bloated, slow-moving acquisition bureaucracy that cannot keep up with agile rivals is simply not true and they are "much more sanguine" that "the sources of US military-technological advantage are enduring and are unlikely to be replicated by others."

A leading rival to the United States, besides China, is Russia, which has been drawing global attention to its defense innovation developments recently. President Vladimir Putin's state of the nation address in March 2018 showcased the country's new generations of defense high-technology capabilities. Vasily Kashin's brief examines Russia's current defense innovation efforts and he points out that Putin's speech "provides a clear picture of Russia's prioritization of radical over incremental innovation, sometimes to the detriment of current battlefield readiness." Key areas of technical focus include hypersonics, lasers, autonomous underwater systems, and nuclear powered cruise missiles. The Russia case also shows the critical importance of high-level leadership attention for countries looking to engage in disruptive forms of innovation.

One major country that has lagged badly in defense innovation is India, which is the focus of the brief by Laxman Kumar Behera. The sub-optimal performance of India is due to a wide range of factors, of which the most important are: 1) inefficiency and a lack of reforms of the main research, development, and manufacturing actors; 2) meager funding levels for research, development, and procurement; 3) poor human resources management; 4) lack of strong political leadership support; and 5) a weak acquisition system. From a methodological perspective, Behera uses a self-reliance index to measure India's industrial performance as well as a discussion of the country's 'hard' and 'soft' innovation capabilities.

DEFENSE INNOVATION IN SMALL- AND MEDIUM-SIZED STATES

Turning to the experience of small countries, Richard Bitzinger offers a fascinating tale of different experiences and outcomes in the cases of Israel and Singapore. The two share similar attributes—small populations, no strategic depth—and both see technology as a crucial force multiplier. Israel has been much more successful than Singapore in cultivating indigenous defense innovations, which Bitzinger attributes to geostrategic and cultural factors. Israel faces a far greater and immediate threat that demands more military-technological innovation. Socially, Israel has an informal and anti-hierarchical society that more amenable to risk-taking and experimentation compared to Singapore.

Dmitry Adamsky offers more detail on Israel's approach to defense innovation in his brief. He agrees with Bitzinger that Israel's embrace of defense innovation has been a function of geopolitical drivers and shaped by the social-organizational characteristics of the Israeli strategic mentality and strategic culture. The most important social-organizational attributes, according to Adamsky, include: 1) not playing by the rules; 2) high tolerance for risk-taking; 3) assertiveness; 4) flexibility towards planning and a strong ethos of improvisation; and 5) social informality and a cult of simplicity.

Another small country with a strong recent track record in defense innovation, and specifically in the development of nuclear and bal-

listic weapons capabilities, is North Korea. As Stephan Haggard and Tai Ming Cheung document in their brief, North Korea's strategic weapons innovation system rests on "the steady accretion of domestic capabilities" through an "authoritarian mobilization" model. This highly centralized, state-led and top-down "big engineering" approach consists of a number of key characteristics: 1) a top leadership that prioritizes the development of strategic weapons capabilities; 2) a state that mobilizes and concentrates the country's science, technology, and heavy industrial resources on a select number of programs; 3) a nuclear and ballistic missile scientific community that is tightly integrated with the country's civilian and military leadership; 4) a leadership that prioritizes the support of research institutions and trading entities tasked with securing technology and needed inputs from abroad; and 5) an ability to absorb, reverse engineer, and ultimately innovate that rests on a sprawling nuclear and missile infrastructure spanning the entire value chain in each industry.

As for medium-sized states, Martin Lundmark compares the defense innovation systems of France and Sweden in his brief. Historically, both have deep-seated traditions of homegrown innovation and a high degree of self-reliance, but their paths have diverged since the end of the Cold War in the 1990s.

France continues to pursue self-sufficiency in defense technology development and maintains close state control of defense innovation and industrial activities. Sweden has significantly reduced its ambitions and now is limited to focusing on just three areas: fighter aircraft, underwater capabilities, and cyber. Moreover, Sweden has opened up its defense industry to allow for foreign investment and ownership and has increased defense cooperation with the United States. France, however, has been far more cautious in opening up its defense innovation system, even with the United States. Lundmark also points out that both France and Sweden have been making efforts to become more involved and help increase coordination and collaboration in defense innovation within the European Union, especially in research and development.

DEFENSE INNOVATION IN HISTORICAL AND EMERGING TECHNOLOGY CASES

Turning to the historical perspective, Tom Mahnken looks at defense innovation in the period between the two world wars, which he notes offers plenty of evidence that includes the development of armored warfare, strategic bombing, close air support, carrier aviation, amphibious warfare, and radio and radar.

Mahnken focuses in particular on the development of tanks in Britain, the United States, and Germany, which he says qualifies as a case of disruptive innovation and highlights the role of catalytic factors. For Great Britain, despite its initial lead in tank technology, the lack of a strategic or operational challenge that demanded innovation in tank warfare hampered innovation, as did the lack of leadership support, constrained resources, and organizational culture. The United States also lagged in tank development but adapted quickly once a threatening security environment emerged. For Germany, a pressing set of strategic and operational challenges, senior military leadership support, the unique resource constraints imposed by the Versailles Treaty, and organizational culture together created a hothouse of innovation. As a result, Germany moved to the forefront by World War II. The main conclusion that Mahnken draws is that history shows that catalytic factors are central in bringing about disruptive innovation.

Defense innovation in emerging technologies represents another analytical challenge. Elsa Kania examines Chinese efforts in the military applications of artificial intelligence (AI) and quantum technologies. She notes that China quickly become a AI powerhouse and has set its sights on becoming the world's premier AI innovation center by 2030. Chinese researchers also have achieved a track record of consistent advances in basic research and the development of quantum technologies. The state is playing a central role in both industries. It issued a long-term AI development plan in 2017 and is also harnessing private enterprises. The Chinese government is building the National Laboratory for Quantum Information Science, which will become the world's largest quantum research facility.

Kania believes that China's approach to defense innovation in AI and other emerging technologies offers a new development model based upon military civil fusion and focusing upon the recruitment and training of high-level talent. Chinese defense innovation will "concentrate on the advancement of a national strategy of military-civil fusion," Kania says.

CONCLUSIONS

A number of general themes emerge from these case studies. First is the critical importance of catalytic factors. The threat environment and the role of high-level leadership support are highlighted in a number of the cases, especially Israel, North Korea, China, and the interwar era. Catalytic factors are especially critical for the pursuit of disruptive innovation.

A second cluster of attributes identified as having considerable impact on innovation are social and strategic culture-related factors, although their influence is more in an indirect context of providing a positive supporting environment rather than

playing a direct role. In the case of the United States, for example, social and political dynamics related to technology substitution for labor and an immigration-friendly social environment are viewed to have had an important role in shaping the US defense innovation culture. The influence of social traits is even more pronounced in Israel, with the prevalence of assertive, risk-taking, and non-hierarchical norms a key factor behind its free-wheeling disruptive innovation environment. The opposite is true in Singapore, where a more risk-adverse and hierarchical social order means that the preference is for more routine incremental innovation.

A third takeaway is that the nature and intensity of innovation will depend on the level of sophistication and development of a state's defense innovation system. Advanced and well-funded systems such as the United States, France, and Sweden are more able to pursue higher-end innovation than underdeveloped catch-up countries that will be limited to imitation and lower-end innovation.

A final point is that the linkages between factors, especially different categories of factors, are important. Close working connections between catalytic factors and input, process, and institutional-related factors seem to enable higher levels of innovation outcomes. If top leadership support is closely linked to budgets and acquisition processes, for example, this would identify pathways for innovation to take place. But if leadership support is isolated and affiliated with critical enabling factors elsewhere in the innovation system, then the pathways to progress will be absent.