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Imitation, innovation, disruption: challenges to NATO's superiority in military technology

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Analysts, academics and observers are worried that NATO countries may lose their industrial leadership in defence production. Globalization and advances in communications are widely believed to enable enemies and adversaries alike to copy NATO countries' state-of-the-art weapon systems, and possibly even surpass them by developing next-generation weapon systems. Moreover, so-called disruptive technologies like artificial intelligence, quantum computing and additive manufacturing are believed to offer cheaper and less technologically demanding options to countries that do not possess the decades' old defence industrial base of NATO countries. These countries could then use such new technologies for weakening NATO force structure.[1]

These concerns are real and deserve close scrutiny. However, adversaries and competitors still face significant challenges which are more insidious than those NATO countries are facing. Because of the complexity of modern technology, imitation, innovation and disruption in armaments production have become increasingly demanding over the past decades – especially for naval and aerial platforms intended to operate in competitive environments. For NATO this implies more targeted defence investments and exploitation of industrial specialisation across the Alliance, as well as experimentation and innovation with new technologies to favour their future integration into the NATO force structure.

Imitation, innovation and disruption: current concerns and past evidence

From an historical perspective, concerns about the demise of NATO's military-industrial leadership seem warranted because in the past, countries like Imperial Germany could catch up and even overtake their adversaries as well as exploit new technologies to strike important tactical, operational and to some extent even strategic successes. This is why many compare, with apprehension, the Anglo-German naval rivalry at the beginning of the past century to the current US-China competition.[2] Moreover, our age and the period between 1870 and 1914, also known as the *Belle Époque*, share many similarities like expanding global communications, booming international trade, unprecedented scientific discoveries and major technological developments.[3] These factors account, to a significant extent, for Imperial Germany's achievements in the Anglo-German naval race: in a relatively short space of time, Germany's naval industry managed to catch up technologically with the Royal Navy's all-big-gun battleships.[4] Building upon British warship design, Germany could also rap-

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1 This debate is summarised in A. Gilli and M. Gilli, "Why China has not caught up yet: military-technological superiority and the limits of imitation, reverse engineering, and cyber espionage", *International Security,* Vol.43, No.3 (Winter 2018/19) and A. Gilli and M. Gilli, "Military Power in the Second Machine Age", paper presented at the US Department of Defense's Joint Artificial Intelligence Center, 30 August 2019.

2 A. L. Friedberg, "The Future of U.S.- China relations: is conflict inevitable?" *International Security*, Vol.30, No.2 (Fall 2005), pp.7-45.

3 M. D. Bordo, B. Eichengreen and D. A. Irwin, "Globalization today really different than globalization a hundred years ago?", *NBER Working Paper* No.7195, June 1999.

4 A. Dodson, *The Kaiser's battlefleet: German capital ships, 1871-1918*, Annapolis, Naval Institute Press, 2016.

idly manage to out-innovate the Royal Navy and quickly deploy more capable warships.[5] Additionally, because of its successes in diesel engines, electric batteries, and optics, Germany could enter and quickly master submarine technology during World War I – to the detriment of Great Britain.[6]

In other words, imitation, innovation and disruption in armaments production seemed relatively accessible options, at least to other Great Powers, during the period 1870-1914. At that time, in fact, the scientific principles underlying military technology could be inferred from simple inspection and observation. Moreover, countries could exploit their civilian industrial base to imitate foreign military platforms – as the machine tools, production facilities and skillsets were very similar, and often about the same, as those of commercial industry.

Adversaries and competitors still face significant challenges which are more insidious than those NATO countries are facing

Second, once Great Powers had sufficient capital and economies of scale, the material and non-material capabilities required to produce and imitate advanced weapon systems were relatively easy to develop. As a result, countries could save time and resources by exploiting the research of their peers and thus move forward with more advanced weapon systems. For instance, by the 1920s, through a policy of acquisition, inspection and reproduction of foreign technology, Japan could deploy some of the most advanced warships in the world, although in the 1905 Battle of Tsushima, all Japanese warships were British-made, as its own naval industry was not sufficiently developed.[7]

Third, since the overall complexity of weapon systems was limited, new technologies could be relatively easily employed in military operations. The modern submarine was invented in 1900 and in just a couple of years represented an important asset for coastal defence, while in World War I it even proved effective in offensive missions. Similarly, heavier-than-air aircraft were invented in 1903 and provided important contributions already during the Great War. Developing these technologies, at least for other Great Powers, was relatively uncomplicated – in fact, in the span of a couple of years all Great Powers produced state-of-the-art submarines and aircraft.[8]

5 N. Friedman, *Naval firepower: battleship guns and gunnery in the dreadnought Era*, Barnsley, UK, Seaforth, 2008.

6 G. Mukunda, "We cannot go on: disruptive innovation and the first World War Royal Navy", *Security Studies* 19, No.1, January 2010, pp.124-59.

7 M. R. Peattie, "Japanese naval construction, 1919-41", in P. Payson O'Brien (ed.), *Technology and naval combat in the twentieth century and beyond*, London, Frank Cass, 2001, pp.93-198.

8 B. Brodie and F. M. Brodie, *From the crossbow to H-Bomb: the evolution of the weapons and tactics of warfare*, Bloomington, Indiana University Press, 1973.

Military-technological competition and the complexity of modern weapon systems

Since the *Belle Époque*, however, technology has changed deeply, and this is particularly true for military technology. Scientific and technological progress has opened unprecedented routes and permitted a quantum leap in every known realm. At the same time, military competition has forced countries to pursue ever increasing performance, pushing out further the boundaries of the known and understood. For instance, throughout the 20th century, aircraft and submarines had to fly and cruise increasingly faster as well as higher or deeper, for longer periods, carrying more accurate and more powerful munitions while evading more advanced enemy detection and defence systems – which in turn called for radar-deflecting shapes and radar-absorbing materials for aircraft, and quieting technology and non-magnetic metals for submarines.

As a result of these trends, however, the complexity of weapon systems has increased exponentially. On the one hand, the number of components in military platforms has grown dramatically: in the 1930s, a combat aircraft consisted of hundreds of components, a figure that surged into the tens of thousands in the 1950s and to several hundred thousand in the 2010s.[9] On the other, the components of major weapon systems have become much more sophisticated.[10] Aircraft engines before World War I were "crude" mechanical artefacts that self-taught mechanics could design, assemble, and install in their own workshops.[11] In contrast, the production of today's aircraft engines is so technologically demanding that only a handful of producers around the world possess the necessary technical expertise to develop them.[12]

This increasing complexity of weapon systems has made imitation, innovation and disruption in weapons manufacturing much more difficult. Complexity, in itself, generates incompatibilities and vulnerabilities which, with its rise over the past century, have multiplied and become more severe. Anticipating, detecting, identifying, understanding, and addressing all the possible incompatibilities and vulnerabilities when designing, developing, and manufacturing advanced weapon system pose major challenges. Addressing them without

9 A. S. Milward, *War, economy, and society, 1939-1945*, Berkeley, University of California Press, 1977, p.185; Johnson, "Systems integration and the social solutions of technical problems in complex systems", p.40; and J. Gertler, "F-35 Joint Strike Fighter (JSF) Program", Washington, DC, Congressional Research Service, 29 April 2014.

10 E. Gholz, "Systems integration in the US Defense Industry", *Security Studies*, Vol.16, No.4, October-December 2007, p.281.

11 B. Gunston, *The development of piston aero engines: from the wrights to microlights: a century of evolution and still a power to be reckoned with*, Somerset, UK, Haynes, 1993, p.105.

12 V. Smil, *Prime movers of globalization: the history and impact of diesel engines and gas turbines*, Cambridge, Massachussets, MIT Press, 2013, pp.79-108.

creating new problems is an even more daunting task.[13] All of this becomes even more demanding given the need for weapon producers to design platforms that can incorporate cutting-edge and yet-to-be-developed technologies, that operate in unknown or unfamiliar natural environments such as high altitude or deep water where temperatures are extreme. They must also be able to simultaneously limit their vulnerability to subtle and effective enemy countermeasures and counter-systems.

Imitation and innovation in the present and in the future

Because of the increase in their complexity, modern weapon systems are now much more difficult to imitate and out-innovate than they were in the past. The entry barriers to the production of advanced weapon systems have increased to a point where the most ambitious systems, such as state-of-the-art long-range bombers or ballistic missile submarines, are beyond the reach of most countries. On the one hand, the technological challenges that the most advanced weapon systems pose have become specific and distinctive. Thus, countries that want to produce them need to possess an advanced industrial, scientific, and technological base in the specific technology of their interest (including specialized instruments, laboratories, and testing and production facilities), and they need to master to an unprecedented degree an extremely broad range of disciplinary domains (including extensive experience in weapon systems integration with all the components, systems and subsystems).

On the other hand, the know-how related to the design, development, and production of advanced weapon systems is the product of experience, which in turn is largely tacit — but, tacit knowledge does not spread easily or quickly. Additionally, the production of weapon systems is a collective effort: the resulting know-how and experience is embodied in the corporate knowledge of defence organisations, which further inhibit its diffusion. Designing, developing and manufacturing modern weapon systems requires in-depth knowledge and understanding of a broad range of disciplines, such that it is impossible for any single individual to retain or master. For instance, the production of a jet fighter or a nuclear submarine now requires hundreds, if not thousands, of highly trained scientists, technicians and engineers.

This explains why the couple of years necessary to design, develop and deploy the British *Dreadnought* battleship in the early 20th century are nowadays not even sufficient for developing a new weapon concept and why countries can no longer rely on their commercial industrial base for arms manufacturing as it is not sufficiently specialized.

13 See M. Iansiti, *Technology integration: making critical choices in a dynamic world*, Boston, Harvard Business Review Press, 1997, pp.104-106, 133.

Disruption in the present and in the future

In the view of some observers, military competition in the future will rely less and less on large and expensive weapon systems, and increasingly on artificial intelligence, robotics, 5G networks, quantum computing and other disruptive and emerging technologies. Does this ongoing transition affect NATO?

Up to a point. New technologies open many opportunities, but they have not necessarily simplified the process of disruption — especially at the operational and strategic level. New weapon systems and military technologies must in fact survive against an adversary's integrated defense systems to have an operational or strategic effect. Since NATO countries possess the most advanced defense systems in the world, the performance required to offset them calls for performance requirements that in turn leads to vulnerabilities and incompatibilities that can be addressed only through advanced industrial capabilities and extensive expertise. Single component technologies – such as processors or semiconductors – are in fact much more knowledge-intensive than in the past and thus more difficult to develop and to integrate together with other complex technologies.[14]

In the 1930s, a combat aircraft consisted of hundreds of components, a figure that surged into the tens of thousands in the 1950s and to several hundred thousand in the 2010s

Because of the increasing capabilities of single component technologies, moreover, we have observed a migration of complexity from components to systems, and from systems to networks.[15] While this transition yields benefits in terms of effectiveness, it is enormously daunting to handle as it has also further raised the number of vulnerabilities and incompatibilities. New technologies require complex infrastructures to operate that in turn must be resilient to adversarial attack. Cloud computing is the newest frontier in this development and its opportunities as well as its risks are more and more evident: if data, or communication systems, are vulnerable, system

14 N. Thomson and S. Spanuth, "The decline of computers as a general purpose technology: why deep learning and the end of Moore's Law are fragmenting computing", 30 November 2018, available at SSRN: https://ssrn.com/abstract=3287769 or http://dx.doi.org/10.2139/ssrn.3287769

15 A. Mili and F. Tchier, *Software testing: concepts and operations*, Hoboken, NJ, John Wiley and Sons, 2015. D. A. Hounshell, *From the American system to mass production, 1800-1932: the development of manufacturing technology in the United States*, Baltimore, Johns Hopkins University Press, 1985.

performance is at risk.[16]

Finally, newly emerging or disruptive technologies may be very effective for tactical purposes, but they are then unlikely to alter quickly and dramatically the distribution of military power around the world, given NATO countries' advanced air and naval defense systems. For instance, savvy hackers could exploit zero-day vulnerabilities. However writing software code for robust enterprise software – i.e., turn computing into a military advantage – is much more demanding. In fact, the software industry is extremely concentrated: a sign that gaining competitive advantage from software is far from easy.[17] Somehow related, operating advanced technologies often calls for more, not less, skilled personnel – which in turn represents a powerful obstacle to adoption of new or advanced technologies.[18]

The entry barriers to the production of advanced weapon systems have increased to a point where the most ambitious systems are beyond the reach of most countries

Implications for NATO and global security

Our analysis has several implications for NATO. First, NATO's rivals and competitors, such as China and Russia, will not be able to easily and quickly develop state-of-the-art weapon systems, as well as the infrastructural support intended to achieve not only global reach but also localized technological parity with NATO countries.

Second, and connected to this, tackling asymmetrical, hybrid or unconventional challenges is of the utmost importance, but cannot come at the cost of compromising NATO Allies' superiority in military technology – as some analysts, sometimes, recommend. That such competitors have invested in asymmetrical, hybrid or unconventional capabilities seems to suggest that this is a second-best strategy resulting from the technological challenges of developing traditional weapon systems.

Third, NATO countries need to maintain and extend their military-industrial leadership in the years to come. In time, today's state-of-the-art technology will become mature and other countries will develop the capabilities to produce them. Debates about 2 percent expenditure and 20 percent allocations to modernization are helpful – but only up to a point. NATO countries need to increase their defence spending, but a strategy for technological superiority should drive their investments to maximize NATO's competitive advantage. In this respect, NATO benefits from the diversity of its Allies' scientific, technological and industrial capabilities. This generates a broad portfolio of unrivalled weapon systems in almost every possible domain of operations, from jet fighters to nuclear submarines, from satellites to main battle tanks. NATO's breadth puts its competitors and rivals at a key disadvantage. While there are often calls for more integration and cooperation, NATO should actually learn to better appreciate the benefits of industrial specialisation and promote it further.

Finally, new technological domains offer great opportunities. For this reason, it is imperative that NATO leverages its wide and extensive expertise to establish a long-lasting technological primacy in these areas too. Given relatively high entry barriers, NATO countries should work together to consolidate their expertise, as well as experiment and innovate so as to integrate future technologies into their force structures.

16 A. Gilli and M. Gilli, "The diffusion of drone warfare? Industrial, organizational, and infrastructural constraints", *Security Studies*, Vol.25, No.1, 2016.

17 US Department of Defense: defense innovation board: *Software is never done: refactoring the acquisition code for competitive advantage*, Washington, DC, Office of the Secretary of Defense, 2019.

18 A. Asoni, A. Gilli, M. Gilli and T. Sanandaji, "A mercenary army of the poor? Technological change and the demographic composition of the post-9/11 US Military", *Journal of Strategic Studies* (forthcoming). See also A. Gilli (ed.), "The brain and the processor: unpacking the challenges of human-machine interaction", *NDC Research Paper*, No.6, December 2019.

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