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The technology of war is changing. Remarkable developments are underway in artificial intelligence, cyber technology, autonomous weaponry, hypersonic munitions delivery vehicles, additive manufacturing, remote sensing, stealth, and precision guidance. The ability of forces endowed with state-of-the-art warfighting technologies to see, target, and act efficiently and effectively on the battlefield is arguably greater than it has ever been, and is only likely to continue to improve.[1] Recognizing that no single state is likely to create a monopoly on such technologies, and that it will be even less likely to maintain it if one is established, many observers argue that these advances have the potential to be profoundly destabilizing. The capabilities afforded to the most technologically advanced belligerents in future conflicts will likely spark arms races, create incentives to strike first in crises, and make the conduct of war more costly and painful for both combatants and for civilians on the home front.[2] In short, the developing conventional wisdom suggests that while the capabilities afforded by these emerging technologies may be magnificent, their consequences for strategic stability are likely to be very dangerous.

The collection of essays entitled "Emerging Technologies and Strategic Stability," edited by Todd Sechser, Neil Narang, and Caitlin Talmadge, effectively pushes back against this argument. As the editors argue in their introduction to the special issue, historically "very few technologies fundamentally reshape the dynamics of international conflict," and "even if today's emerging technologies are poised to drive important changes in the international system, they are likely to have variegated and even contradictory effects."[3] It is thus not at all clear, they suggest, that emerging technologies will in fact

[1] See, for example, Peter W. Singer, *Wired for War: The Robotics Revolution and Conflict in the 21st Century* (New York: Penguin Books, 2009); Shawn Brimley, Ben FitzGerald, and Kelley Sayler, "Game Changers: Disruptive Technology and U.S. Defense Strategy" (Washington, D.C.: Center for a New American Security, September 2013).

[2] See, for example, Jesse Ellman, Lisa Samp, and Gabriel Coll, "Assessing the Third Offset Strategy," (Washington, D.C.: Center for Strategic and International Studies, March 2017); James N. Miller and Richard Fontaine, "A New Era in U.S.-Russian Strategic Stability: How Changing Geopolitics and Emerging Technologies Are Reshaping Pathways to Crisis and Conflict," (Washington, D.C.: Center for a New American Security, September 2017); Paul Scharre, *Army of None: Autonomous Weapons and the Future of War* (New York: W.W. Norton & Company, 2018).

[3] Todd S. Sechser, Neil Narang, and Caitlin Talmadge, "Emerging Technologies and Strategic Stability in Peacetime, Crisis, and War," *Journal of Strategic Studies* 42:6 (September 2019) [hereafter *JSS* 42:6]: 727-735, here 728, 729.

be strategically destabilizing. These points, which are developed in the six substantive essays with careful theoretical and historical detail, are a welcome rejoinder to the more common claims frequently made on the matter. The contributors' efforts to ground their thinking about emerging technologies in established theories of the role of technology in war does much to organize their collective analysis and draw out implications and conclusions that are missing from the current debate. Their efforts also highlight just how much more work scholars need to do in order to understand what the continued development of these emerging technologies is likely to mean for the incidence, conduct, and consequences of international conflict.

The essays are eclectic in their substantive focus, which precludes my discussing the theoretical and analytical contributions of each in any meaningful detail in this rather brief review. I would commend each in its own right not only to scholars interested in topics like hypersonic glide weapons and artificial intelligence, but to those concerned with contemporary international security and international relations more generally. Happily, the editors have done their job well and there is a clear overarching structure to the collection which facilitates organization of this review. The essays all examine the relationship between emerging technologies and different components of strategic stability, which the editors suggest is a composite of three subordinate forms of stability: peacetime stability, or the absence of incentives to arms race; crisis stability, or the absence of incentives to strike first when tensions are high; and wartime stability, or the absence of incentives to escalate violence within ongoing conflicts. While no essay in this collection addresses the relationship between emerging technology and all three forms of subordinate stability, together they do suggest some intriguing ways to think about the future of strategic stability in the international system.

Four of the essays in this issue focus on the relationship between emerging technologies and peacetime stability. Ben Garfinkel and Allan Dafoe employ formal modeling to assess the impact of development in cyber weapons on the Offense-Defense Balance.[4] Intriguingly, they find the relationship is non-monotonic; arms racing in the acquisition of cyber capabilities is likely to initially benefit attackers before swinging to the advantage of the defenders. This pattern, which they term "Offense-Defense Scaling," could also arise in arms racing to acquire other emerging technologies like drone swarms, but is not ubiquitous; the advantages of arms racing in precision-guided missiles, for example, are likely to accrue primarily to attackers. The variable relationships between different forms of emerging technologies and the Offense-Defense Balance, and the novel finding of Offense-Defense Scaling, suggest that there may not be a clear relationship between such capabilities and peacetime stability moving forward, especially given the fact that states will not likely possess single-tool arsenals. Multiple systems incorporating several emerging technologies will likely have even more muddled effects on the Offense-Defense Balance.

While Garfinkel and Dafoe suggest that the ultimate effects of the emerging technologies they examine are knowable, if complex, Michael Horowitz, who examines artificial intelligence and Lethal Autonomous Weapons Systems (LAWS), is more circumspect.[5] At present, there is considerable uncertainty about the capabilities of such weapons when they are deployed, how they will perform when used, and, given the dual-use nature of research into artificial intelligence, how much progress others are making in developing such systems. This uncertainty, he notes, makes traditional arms control more challenging, as crafting binding agreements about the capabilities and effects of a technology that is not yet fully understood is exceptionally difficult (772). That uncertainty, too, could lead to arms races, if fear of what others are doing dominates military officers' unease at deploying systems that are not entirely proven or trustworthy. In the short-

[4] Ben Garfinkel and Allan Dafoe, "How Does the Offense-Defense Balance Scale?," *JSS* 42:6: 736-763. For classic statements on the Offense-Defense Balance, see Robert Jervis, "Cooperation Under the Security Dilemma," *World Politics* 30:2 (January 1978): 167-214, https://doi.org/10.2307/2009958; Stephen Van Evera, "Offense, Defense, and the Causes of War," *International Security* 22:4 (Spring 1998): 5-43, https://doi.org/10.2307/2539239; Charles L. Glaser and Chaim Kaufmann, "What Is the Offense-Defense Balance and Can We Measure It?," *International Security* 22:4 (Spring 1998): 44-82, https://doi.org/10.1162/isec.22.4.44.

[5] Michael C. Horowitz, "When Speed Kills: Lethal Autonomous Weapon Systems, Deterrence and Stability," *JSS* 42:6: 764-788

term, he concludes, further development of artificial intelligence and progress toward LAWS is unlikely to disrupt peacetime stability; the picture is less clear over the long-term, however.

Heather Williams and Tristan Volpe separately consider two types of emerging technologies that, in contrast to those examined by Garfinkel and Dafoe and Horowitz, are more amenable arms control and thus unlikely, under specified conditions, to disrupt peacetime stability. Williams examines the issues surrounding the development and proliferation of hypersonic glide vehicles (HGVs) and, drawing on classic works on arms control, develops a number of plausible scenarios in which states working on such systems could come to an agreement on acceptable limits.[6] The key, she argues, is privileging the principles of dynamism, equilibrium, and equanimity in crafting such agreements; static, flat limits are unlikely to address the political realities and incentives driving the pursuit of such weapons in the first place (801). Mitigating the potentially disruptive effects of HGVs on strategic stability is thus possible, but will require more effort than did previous efforts at arms control.

Volpe considers additive manufacturing, or, as it is more commonly known, 3D-printing, particularly with respect to its uses in the production of nuclear weapons.[7] As with artificial intelligence, one of the primary challenges for states using and observing the use of additive manufacturing is that it is a dual-use technology; it has more peaceful uses than military uses. Unlike artificial intelligence, however, the nature of the production of nuclear weapons is well-known. Accordingly, it is more feasible for states using such technologies in the nuclear realm to signal their peaceful motives by, for example, accepting intrusive monitoring, relying primarily on foreign supply of critical components, and having third parties underwrite their non-proliferation intentions (825). The relationship between emerging additive manufacturing capabilities in the nuclear realm and peacetime stability, then, is likely to be driven by the choices states make about whether and how to signal their peaceful intent in using such technologies.

Three of the essays discuss the relationship between emerging technologies and crisis stability. Williams and Horowitz each address incentives for first use alongside incentives for arms racing. Williams argues that, assuming existing arms control agreements do not create particular vulnerabilities for one party, mere possession HGVs is unlikely to create incentives to strike first in moments of high tension (792, 808). Horowitz is more cautious in his consideration of LAWS, arguing that the speed of such weapons could incentivize first strikes, but that uncertainty and fear about the reliability and effects of one's own tools and the programming rules for the adversary's LAWS that might respond could dampen enthusiasm for such attempts (781-783).

Jacqueline Schneider examines the problem of vulnerability at length and argues that, in a crisis, when emerging technologies create new vulnerabilities for their possessors that are exploitable by adversaries, both actors have an incentive to strike first.[8] In the context of the information revolution, this suggests that crises involving heavily networked actors are likely to be particularly unstable when one or both sides rely on centralized information systems that are vulnerable to attack; crises involving such actors are more likely to be stable if both rely on more diffuse networks that are robust to targeted attacks (858). As with, for example, the relationship between additive manufacturing in nuclear production and peacetime stability, whether actors' incentives push toward the early use of violence depends on the choices they make when structuring their new systems.

[6] Heather Williams, "Asymmetric Arms Control and Strategic Stability: Scenarios for Limiting Hypersonic Glide Vehicles," *JSS* 42: 6: 789-813.

[7] Tristan A. Volpe, "Dual-Use Distinguishability: How 3D-Printing Shapes the Security Dilemma for Nuclear Programs," *JSS* 42:6: 814-840.

[8] Jacquelyn Schneider, "The Capability/Vulnerability Paradox and Military Revolutions: Implications for Computing, Cyber, and the Onset of War," *JSS* 42:6: 841-863.

While one could imagine the implications of incentives to arms race and incentives to strike first for the dynamics of escalation once combat ensues, only Caitlin Talmadge's essay directly address the relationship between emerging technologies and wartime stability (864-887).[9] Examining the impact of emerging nuclear, precision targeting, and command-and-control targeting technologies on patterns of escalation during the Cold War, she concludes that such capabilities, on their own, only rarely created incentives to escalate violence in war. Rather, such technologies, which were developed as a result of discrete choices made by political and military elites, are more likely to serve as intervening variables that can accelerate escalatory pressures arising from separate political and military considerations (879-880). As Williams, Thorpe, and Schneider argue in slightly different contexts, it tends to be human choices, rather than emerging technologies, that pose the greatest threat to wartime stability.

These thumbnail sketches cannot adequately capture the theoretical and empirical richness of the collected essays; as noted above, I commend each as an insightful study of the strategic consequences of particular emerging technologies. Reading the pieces as a set, however, reveals a few themes beyond the editors' introductory claims regarding the likely non-revolutionary nature of today's emerging technologies and the many and varied effects such capabilities are likely to have on strategic stability that cry out for further contemplation and research. I will address questions arising from those themes by way of concluding this review.

First, perhaps the preeminent question in my mind after reading these essays is what, precisely, do we mean by strategic stability? Williams, for example, follows Thomas Schelling and Morton Halperin and defines strategic stability "as arms race stability and crisis stability" (790).[10] Volpe similarly defines strategic stability as a function of "(1) arms race incentives in peacetime and (2) conflict initiation during a crisis" (815, note 10). Garfinkel and Dafoe do not seem to define the term. There is similar variation in the other essays. The editors note that there is no consensus on the definition of strategic stability and, for that reason, they take an expansive view of the concept in their special issue (730, note 15). This decision is understandable, but it and the variety of conceptualizations in the individual essays has the functional effect of complicating the aggregation of the findings. Even if Williams is right, and well-crafted arms control treaties can preclude HGVs disrupting peacetime and crisis stability, should we necessarily think that is also the case with respect to wartime stability? If not, and HGVs incentivize escalation during combat, would that increased wartime instability mean a reduction in strategic stability overall? Are peacetime, crisis, and wartime stability jointly necessary for strategic stability, or is one (or two) sufficient? While complete answers to these questions lie well beyond the scope of what the contributors address in their essays, a full understanding of what the implications of emerging technologies may be for strategic stability more generally requires them.

Second, the essays in this special issue tend to examine emerging technologies in isolation. As I noted when discussing Garfinkel and Dafoe's essay, however, the technologies considered are not likely to be deployed on their own. What effect might the combination of, for example, effective zero-day cyber-attacks and HGVs have on crisis stability? Or, if artificial intelligence is improved such that LAWS perform in reliable and effective ways, does that increase or decrease the vulnerability associated with centralized information networks? To be sure, the contributors are working through complex logical and practical issues associated with each individual emerging technologies. A central feature of the current era of technological change, though, is the variety of innovations under development. In previous eras of military revolution—for example, when cannon were improved or railroads and telegraphs were deployed in war—the uses of the different technologies tended to converge on the improvement of a particular form of martial activity. Today, by contrast, developments impact a wide range of capabilities operating in multiple domains and lack a clear common denominator. As a result, they are particularly likely to be used in combination and, depending on the features of

[9] Caitlin Talmadge, "Emerging Technology and Intra-War Escalation Risks: Evidence from the Cold War, Implications for Today," *JSS* 42:6: 864-887

[10] For the original formulation of their discussion of strategic stability, see Thomas C. Schelling and Morton H. Halperin, *Strategy and Arms Control* (New York: The Twentieth Century Fund, 1961).

particular combinations, may have variable effects on strategic stability. Understanding more how the additive and interactive properties of emerging technologies impact strategic stability is an important task for future studies.

Finally, the essays in this collection usefully situate our understanding of emerging technologies in established security studies theoretical models like the Offense-Defense Balance and deterrence theory. Such models do much to help us think through the implications of such capabilities for strategic interaction under conditions of perfect information and rational decision making. They remain limited, however, to the extent that they do not account for political dynamics and human shortcomings. A few of the essays—those by Williams and Talmadge, for example—explicitly take note of the way in which political considerations shape actors' approaches to and uses of emergent technologies. It would be useful to apply such frameworks to the other models that are developed in this special issue. For example, how might Offense-Defense Scaling be affected by elites' perceptions of offensive and defensive advantages? What kinds of political systems and incentives are likely to cause actors to adopt measures that allow others to ascertain the peaceful intentions behind additive manufacturing of nuclear components? Other essays, like that by Horowitz, acknowledge that decision makers' uncertainties and fears about emergent technologies can cut in multiple directions and lead to different outcomes with respect to peacetime stability. In what kinds of political settings are the fears of militaries about the performance capabilities of new systems likely to trump the uncertainties of civilian elites about the intentions of similarly equipped adversaries? A more complete understanding of the relationship between emerging technologies and strategic stability requires incorporation of our understandings of human tendencies as well as technical capabilities.

The editors of and contributors to this special issue have performed a service in bringing decades of scholarship and theorizing to the question of the strategic consequences of emerging technologies in the contemporary security environment. The core finding arising from their efforts, that the dire predictions made by those who foresee arms racing, swift resort to war, and potentially inadvertent escalation of violence during conflicts are not justified, is significant. That so many questions remain after reading this collection of essays should be understood as an indicator of the intellectual heft of the endeavor rather than of its weakness. Scholars still have far to go in their quest to better understand how emerging technologies will affect the resort to and conduct of war in the international system; the paths outlined by these authors will provide considerable guidance on that journey.

Ryan Grauer is an Associate Professor of International Affairs in the Graduate School of Public and International Affairs at the University of Pittsburgh. His research examines the sources and use of military power in the international arena. He is the author of *Commanding Military Power* (Cambridge University Press, 2016) and his work has been published in *World Politics*, the *European Journal of International Relations*, and *Security Studies*, among other outlets. At present, he is working on projects examining the creation, organization, and operation of multinational coalitions in battle and the causes and consequences of soldier surrender in war.