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Warfare in the Robotics Age

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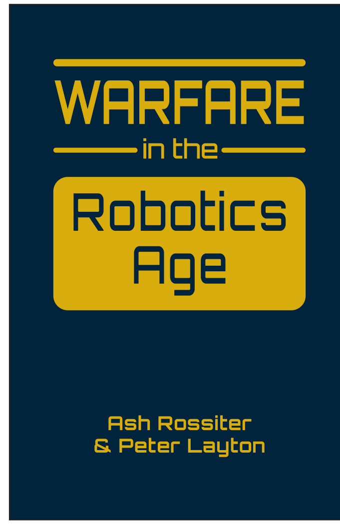

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Revolutionary Technologies, International Politics, and War

For a growing number of policymakers, business leaders, engineers, and scientists, a revolution in robotics is underway that will irreversibly reshape the world as we know it—including how, why, and where wars are fought.

Indeed, there can be few questions more significant for understanding the unfolding international security environment than that of how a suite of technologies commonly associated with the so-called fourth industrial revolution (4IR) will impact strategic affairs. Rapid advances in artificial intelligence (AI) and the capabilities of physical robotic systems—two of the most significant technology areas connected with the 4IR concept—are enabling advanced nations and increasingly others, including non-state actors, to pursue new ways of fighting. These changes, in turn, might spark wider change in strategic interaction between states. Rapid technological development in the field of robotics promises to create a new set of challenges when it comes to identifying new and significant military capabilities and understanding how they will create military advantage and therefore political leverage in years ahead. In short, advances in robotics technology and their increasing real-world application are creating a new set of conditions for the conduct of war and the broader employment of violence in international affairs. Yet, even as robots become an increasing feature of economic and social life, their near-term revolutionary potential across the battlespace is just that—one largely confined to potential at present.

Robots—physical machines typically programmed by a computer that can execute tasks autonomously or automatically—have myriad potential military uses, ranging from casualty evacuation to engaging in lethal combat. Given the uncertainties that pervade forecasting, how can we attempt to anticipate what warfare in the robotics age will entail? This book directly engages with this task by examining the technological development of robotic systems; their past, present, and prospective military employment; and, as a corollary, their implications for international relations. In doing so, it makes several interlinking contributions to the intensifying scholarly and policy debate about the opportunities, challenges, and dangers of warfare in the robotics age.

Technology as Agent of Change

Major powers are doubling down on military robots as competition in international politics intensifies. The navies, armies, and air forces of the world's most advanced militaries are rapidly seeking ways to incorporate increasingly autonomous uncrewed systems into their respective services to generate more battlefield punch. How robots are shaping how militaries prepare for and fight wars—the principal subject of this book—is an unravelling story that necessarily deals with much wider questions about how technology interacts with human affairs, and vice versa.

Scholars charting the chief forces that have shaped human existence accredit the introduction of new technology—both tools *and* ideas about their employment[1]—as critical agents of change. Technology's overall transformational effect on human society is well understood. But more narrowly, many scholars of international politics consider technology to have a pervasive influence on the course of world events, especially in the arena of competition and conflict between states.

The purported revolutionary aspect of emerging technologies spoken about today is not only, of course, how they will transform military affairs; rather, their shaping effect on existing economic practices, the field of medicine, or social interactions grabs as much, if not more, routine attention. But technological change clearly matters at the sharper edges of international politics.

A new technology may alter the perceived existing hierarchy of military power in the international system, providing the possessor with the wherewithal to rise above others—at least until rivals learn to emulate or find ways to offset the initial advantage. New military technology can, according to some research, temporarily, yet decisively, upend a given balance of power, creating conditions conducive to the outbreak of war.[2]

But has technology revolutionized how wars are fought? The belief that a rival is making a technological leap forward with a new weapon may induce sufficient fear to precipitate a crisis.[3] New technology might also shift, in either direction, the balance of power between states on the one hand and nonstate actors—networks, international organizations, private firms, nongovernmental organizations, individuals—on the other.

Not all technologies carry transformative potential, of course. The technologies throughout history that can lay claim to the label "revolutionary" are necessarily few—unless, of course, one's definition of a revolutionary technology is so generous that it robs the term of all utility.[4] Skepticism is surely warranted in the face of annual lists produced by science and technology (S&T) periodicals that compile the ten "game-changing" technologies of that year. Punditry produced from technologists and futurists often claims that we are currently experiencing more radical technological change than at any time in the past. For Klaus Schwab, CEO and founder of the World Economic Forum and propagator of the 4IR concept, the world today stands on the brink of a technological revolution that will fundamentally alter the way we live, work, and relate to one another. "In its scale, scope, and complexity," Schwab expounds, "the transformation will be unlike anything humankind has experienced before."[5]

Most attempts to analyze and forecast the impact of emerging technology on the world, however, look at change through its potential to enhance human existence. The reason for this is straightforward. Many of today's key technological advances are happening within the private sector, made by companies seeking to produce products for consumers. Just as in periods past and gone, technological development has deep implications for international security.[6] International security—and the character of war more specifically—has often been profoundly impacted by the advent of technological developments that occur principally in the civilian world. This point holds true for the field of robotics. Indeed, for many military analysts, it has become axiomatic that robotics will revolutionize warfare, much as the introduction of tanks and airplanes transformed the battlefields of the major wars in the previous century.[7] The anticipated impact of rapid developments in robotics—and, deeply connected to this, in AI—has a decidedly large influence on current issues pertinent to war and peace.

Many changes to our human experience have been driven by one overriding technology, such as the printing press, electricity, or computers. Major change can also be driven by several technologies emerging at roughly the same time. The age of robotics—if an age comes to pass that can be labeled as such—will be realized through a suite of synergistic technologies maturing in a synchronistic manner. Indeed, it is the convergence of several technologies instead of one alone that is propelling such fundamental change in this field. There is nothing new in this. Complementary technologies have in the past produced greater overall change than each individually. This was true, say, of the combinational effects of the railroad and the telegraph. Developments in component technologies of robotics—not least AI—are for many analysts ushering in a new age: the robotics age. "We are in the midst of an ever accelerating and expanding global revolution in [AI] and machine learning, with enormous implications for future economic and military competitiveness," declared former US deputy secretary of defense Robert Work, a prominent advocate for Pentagon utilization of robotics.[8]

Different theories of international politics consider technology's impact on global affairs from a range of perspectives and reach divergent conclusions. This introductory chapter first provides a brief exegesis on how various schools of thought have integrated technological change into theories of peace and war. Later parts of the book draw on these discussions to shed theory-grounded light on the potential implications of rapid developments in robotics for warfare and international politics more broadly. These are not separate matters. Change at the operational and tactical level of war can have higher-level consequences for war's likelihood, relative capabilities between states, and perhaps for the international system as a whole.

The Technology Factor in International Politics

How much weight should we give technology as a source of change in international politics? Geoffrey L. Herrera posits that "technology looms across disciplines as a source of social, economic, and/or political change. It is often the master variable that explains everything."[9] Other prominent theorists are less equivocal about technology's causal properties. Kenneth N. Waltz, for example, noted, "In shaping the behavior of nations, the perennial forces of politics are far more important than the new technology."[10] Between these two bookends, most scholars treat technology as an important independent variable in shaping the world around us. Indeed, new technology informs several key theoretical dispositions in international politics.

The broad church of realism gives considerable causal weight to the role of new technology in the relative capabilities of states. Largely treating technology as an exogenous shock, realists, however, differ in the causal processes involved in increasing state power. For some realists, technology is directly relational to the generation of military power. Within this interpretation, the ability to bring into the world new and useful technologies bestows great advantage on the battlefield. Prominent realist Hans Morgenthau, for example, argued, "The fate of nations and civilizations has often been determined by a differential in the technology of warfare that the inferior side was unable to compensate in other ways."[11] In this intuitively plausible line of argument, the possession of cutting-edge military-relevant technologies equates to more effective weapons systems, enhancing military strength, which in turn translates into greater geopolitical power. As Keith Krause once put it, "The possession of modern weapons is a key element in determining the international hierarchy of power."[12] Other realists do see technology as an independent factor in producing some military outcomes but are more equivocal about its role in obtaining desired strategic outcomes.[13]

Technology's importance for other realists is not so much its influence on martial affairs and more the advantages it confers in the economic output from which national power is ultimately derived. Because technology works to determine economic growth, it is therefore *indirectly* responsible for the distribution of power in the international system.[14] This second strand of realist thinking is of less concern to the focus of this study on the impact of military robotics on contemporary and future warfare. Nonetheless, the question of whether those nations that are best able to harness robotic systems for civilian industries will reap economic benefits substantial enough to alter power differentials does loom in the background.

In sum, for many realists, technology, as an independent variable, has a major role in shaping the capabilities of states and thus indirectly the characteristics of the international system. It is possible to conceive how rapid advances in the field of robotics might possess causal properties as an independent variable in both of these realist interpretations. Indeed, the analysis throughout this book aims not just to gauge the potential military gains offered by developing military robots in general; it also considers whether certain states with advanced programs in this area are likely to gain comparative military advantages. In line with realists, this book is unapologetic for treating states as the main unit of analysis. This is not to suggest that states' military organizations will be the only end users of military robots, only that they will be by far the most consequential users. It is also not to say that multinational firms and even individuals are not important in developments related to robotics—they clearly are. Yet, it is still true to say that the vast majority of innovation in robotics occurs within a *national* environment.

Realists are not, of course, the only set of international relations theorists to have something to say about technology and international politics. Liberals do too. But in contrast to realists, liberals believe technological advances have a different causal effect on international politics—effects that might even be conducive to peace. This is especially true of developments in modern communication technologies that have underpinned globalization. In liberal interdependence theory, modern technology has created, so the argument runs, a global economic system of interdependences that dampens the prospects for outright hostilities among the major nations of the world.[15] An associated idea with this supposition is that modern technology generates challenges that can only be addressed at a global level, which in turn incentivizes international cooperation and fosters the notion of an international society.[16] It could be that developments in robotic systems intertwine nations' economies ever more closely, but the opposite may equally be the case.

All the while we have been discussing revolutionary technologies—such as robotic systems—as an independent variable—that is, phenomena with causal properties that shape outcomes in the international realm. But the causal arrow can also run in the other direction. Changes in the international system can also have pronounced effects on technological change—its pace and scale. Conforming to the logic of anarchy, leading states should see superior technology as necessary for remaining ahead of rivals.[17] While this condition of international anarchy is invariant, this "environmental" pressure changes over time; the prospects for cooperation and competition, as well as the probability of war, are often in flux.[18] Holding this thought in mind, it is logical that the level of great power tension in the system has causal significance for states' propensity to innovate—or to try to innovate—and more particularly to develop new military technologies. M. Zachary Taylor, for one, sees external threats as the main impetus for national-level innovation in both the economic and military domains.[19] Barry Posen's study on the interwar period in Europe also indicates that large-scale geopolitical threats increase the urgency with which states respond to the possibility of harnessing new military innovations.[20]

In periods of intense competition, such as during the Cold War, rivals are inclined to believe that not pursuing even outlandish projects to stay ahead might result in a victory for the other side.[21] Under these conditions, governments are probably more concerned about beating opponents to the punch in a technology race.[22] As no one can say for sure which technology will give one side a clear advantage, it makes good strategic sense for those involved in intense competition to compete vigorously. This, in part, explains for some scholars why some states at least have higher rates of innovation than others. "Specifically," as one innovation expert notes, "security concerns affect the willingness of people to accept the heavy costs, risks, and sacrifices necessary to create competitive, national S&T capabilities."[23] To be sure, the rate at which countries are able to technologically innovate varies and is increasingly the domain of fewer and fewer states—a point that can be extended to robotics as well. "Even being generous with the data," Taylor writes, "only a few dozen countries can be said to have much innovation footprint at all. Put simply, the club of innovation nations is very elite."[24]

Both realists and neoclassical economists agree that material incentives to acquire new technologies dominate all other factors. Not all thinking on states' desire to pursue cutting-edge technology is based, however, on a materialist understanding of the world. Other research suggests that the role of prestige has been neglected as an explanatory factor in driving large-scale investments in science and technology.[25] A prime example often cited is the battle for space-power prestige following the Soviet success in putting Sputnik into orbit and the US response with its efforts in manned space flight.[26]

Advances in robotics—and the potential for the pace of development in this field to accelerate in the decades ahead—clearly impinge on the debate about the causal relationship between technology and international politics in important ways. To move beyond the general influence of technology on matters of war and peace to the specific impact of individual technologies, such as robotics, takes us to a consideration of the merits of several mid-level theories. Indeed, while the case of military robotics is sui generis, it will still be possible to derive important inferences about how significant militarily relevant new technology emerges and its implications for war in the world. The following sections provide a brief discussion of the some of the most important mid-level theories—and key questions derived from them—relevant to the case of robotics and warfare that feature prominently in the later analytical parts of this book.

A Robotics-Driven Military Revolution?

That new technology ushers in military revolutions, or what some term *major military innovations*, is a well-established idea.[27] For some, military revolutions do more than just affect outcomes on the battlefield; they can bring about major changes to politics and society. These eras, according to one study of military revolutions, "recast society and the state as well as military organizations. They alter the capacity of states to create and project military power."[28]

There is much truth to the claim that technologies have formed the basis of most, but crucially not all, of the chief military innovations throughout history, including those that significantly altered the capabilities of states vis-à-vis each other and concomitantly the global balance of power.[29] One of the most important issues tackled in these pages is the validity of the oft-made claim that the greater integration of robots into military organizations and their increasing sophistication will unleash an "unmanned revolution in military affairs."[30]

Any adjudication on this matter rests firmly on the wider question of when and if any technology—or collection of synergistic technologies—can be said to result in a military revolution. Technological change varies in scale; the line separating revolutionary change from nonrevolutionary change is an arbitrary one. As a consequence, there is no agreement on what constitutes *revolutionary* change. The threshold for a military revolution is necessarily subjective and depends on one's own interpretation.

To begin with, we must ask whether superiority produced by the possession of any new technology is a predictor of successful military outcomes. Military thinkers—both past and present—differ in the importance they ascribe to technology as an independent variable in bringing about military victory. The Prussian military thinker Carl von Clausewitz, whose intellectual contribution to understanding war casts a longer shadow than that of perhaps any other theorist before or after, had little to say about technological change and its imprint on war.[31] That there was little in the way of technological innovation in the hundred years or so before his time in uniform may partly explain this inattention. Further, the effectiveness of the Napoleonic army in the 1800s—the premier fighting force of its age—was not due to superior mastery of new technology (though the standardization of French artillery in the decades before was significant) but down to organizational, morale, and command factors, such as the employment of mixed-armed units and the massing of firepower at the tactical level.[32]

But it is also true that Clausewitz was more interested in abstractly distilling the governing forces at play in war irrespective of the era under study—or at least those features present in war from the classical era to the period when he was alive. Notwithstanding Clausewitz's inattention, there is a widespread conviction that a causal link exists between technology and fighting abilities. Indeed, in recent decades technology is frequently portrayed as the leading explanation for battlefield success, such as the lopsided victory by US-led forces against the Iraqi military in 1991.[33]

Moving from technology in general, can distinct technologies such as military robotics produce military revolutions? Historians and security studies scholars are divided on the number of technologies thought to have produced military revolutions. There are many candidate technologies that lay claim to having revolutionized warfare, from the pike to the sailing ship, to gunpowder,[34] the telegraph, and the combustion engine, through to nuclear weapons. Technological change is clearly important for scholars concerned with exploring the sources of military revolutions.[35] Yet it is often difficult to isolate a single technology or conglomeration of technologies maturing at the same time as the independent variable in military outcomes—that is, the thing that, above all else, bestowed the critical advantage in any given war. Moreover, technology does not always "appear" as something new. A technology's far-reaching consequences may come from slow advances that eventually simplify or standardize a weapon or from the improvement in manufacturing processes that significantly reduce its cost. This type of long-fuse impact can be hard to isolate at any particular juncture.

Military revolutions have played a central role in altering the capabilities of states vis-à-vis each other, but have they radically altered how we fight?[36] Historians such as Williamson Murray are skeptical that war's fundamental nature can be altered by the introduction of a new technology. In reference to the enduring fog and friction of war, Murray argues, "No amount of computing power can anticipate the varied moves and the implications of an enemy's capacity to adapt in unexpected ways."[37] Others posit that technology can bring in new military "eras," upending our sensibilities about appropriate action in war. Reflecting on the use of cruise missiles over three decades ago, Manuel De Landa wrote in *War in the Age of Intelligent Machines* that when we move to the day when "autonomous weapons begin to select their own targets, the moment the responsibility of establishing whether a human is friend or foe is given to the machine, we will have crossed a threshold and a new era will have begun."[38]

Debates about military revolutions and the place of technology as a driver in bringing them about impinge directly on questions about the level of effect that military robotics will have on future warfare. Will they be the "game changer" that many predict they will be? Or will their impact be more gradual and supplementary to existing methods of employing force? A conceptual engagement with different technology types may help us to form answers to these questions.

What *Type* of Technology Are Robots?

Different types of technologies can produce effects quite distinct from each other. Sometimes these effects are more obvious to observers than at other times. Two examples suffice to illustrate this point. The coming of both nuclear weapons and the internet revolutionized international affairs but in markedly different ways.[39] One—nuclear weapons—altered strategic affairs by restraining great power conflict through the specter of mutually assured destruction, which outweighed any perceived gains for engaging in war. To be sure, strategic thinking about the role of nuclear weapons evolved over time, but the revolutionary impact of the introduction of this new technology was understood early on by strategists such Bernard Brodie and leaders of different political hues. In contrast, it has taken longer to appreciate the internet's role in shaping international security and, more particularly, the strategic interaction of states.

One reason for differences in effects is tied up with the intended purpose of each technology—its original raison d'être. This point also bears heavily on the way the technology entered the international system. Nuclear weapons were invented as a military device with one physical purpose: the production of immense destructive force.[40] Though the genesis of the internet can be traced to a US defense program, its development and diffusion through the international system was largely a civilian enterprise. The technology's impact on international security is harder to disaggregate from its influence in the world's economy and the social affairs of groups and individuals.

Perceptions and Usage

The case of military uses for robotics is instructive for understanding this dynamic between a technology's intended purpose and its evolving employment. Technologies, of course, do not just appear; they are developed by humans. They do not exercise an independent force on the world absent their inventors' and harnessers' intentions for them. As later pages of this book illustrate, progress in the field of robotics has at times been heavily shaped by various governments pursuing military programs in this field. Nonetheless, it would be wrong to describe or think about robots by type as a military technology, in their origin or as a consequence of major advances in their development. They are what we, as humans, decide they are. Indeed, their dual-use character has been a constant feature of their backstory, and this fact will undoubtedly endure into the future.

Technologies—their invention, development, and use—cannot be divorced from the social world. Whether military robots ultimately become seen as a type of technology that is destabilizing and threatening depends on how they are socially constructed. Technological artifacts can only be understood in the knowledges, organizations, and institutional frameworks in which they function; they are more than material concretions—the social and the technical are hybridized domains. As Charles Weiss notes, "Science and technology are not independent instruments, but are social processes that respond to a variety of economic, social, cultural and political influences."[41] Indeed, one aim of this book is to give consideration to the way that robots have been imagined and reimagined as to their prospective role in warfare and the shaping influence of this on their past, present, and future development. Our perception of robots as embodiments of violence rather than as benign systems performing economic and domestic functions *for* humans will certainly solidify as they become increasingly utilized as military tools.

Much of the narrative of military robots in popular culture as well as in defense analysis focuses on their kinetic and violent use. Whether robots are created as a weapon primarily for attack rather than for protection is not a preordained matter. How we use military robots could have profound implications for strategic affairs. The introduction of types of past technologies into the world thought to be especially useful for attack—and by extension conquest—has been particularly impactful in world history by dint of encouraging aggression. History reveals some weapons, because of their perceived association with offensive action, can be highly provocative and exacerbate the "security dilemma."[42] States acquiring offensive weaponry, so the predictive theory runs, are more likely to engage in military adventurism, while at the same time other states, judging there to be an increase in the threat environment, will seek to engage in internal or external balancing behavior, exacerbating the security dilemma and raising the prospects of inadvertent war.[43] The importance of any type of new military technology in the international realm results from the ideas, interests, and roles (enmity or friendship) it engenders and helps to support. Alexander Wendt demonstrates that physical artifacts acquire meaning only inside the process of defining foes and friends: "What gives meaning to the forces of destruction are the ‘relations of destruction’ in which they are embedded: the shared ideas, whether cooperative or conflictual, that structure violence between states. These ideas constitute the roles or terms of individuality through which states interact.”[44]

Whether or not some weapons can be said to possess an inherently offensive nature is a long-running debate among scholars of security studies and international law. It has often proved difficult to say in practice where the line between offensive and defensive weapons can be drawn. Defensive weapons, as strategic thinker Thomas Schelling noted, “often embody equipment or technology that is superbly useful in attack and invasion. Moreover, a prerequisite of successful attack is some ability to defend against retaliation or counterattack.”[45] Past qualitative assessments of offensive weapons cite mobility combined with relative capacity to generate firepower as the hallmarks of a technology type that favors attack—a combination that can be termed *striking power*.[46] Based on this schema, many military robots could be classified as offensive. As subsequent analysis will demonstrate, military robots have the potential to fulfil such a wide array of tasks on land, in the skies, and on and below the seas that it is nonsensical to designate them a priori as offensively or otherwise oriented. In the final analysis, it only matters how we decide to use robotic systems.

Placing Robots in a Typology of Technologies

Military robots are difficult to place within a typology of technology. They embody a collection of subtechnologies including the computing power that allows them to act with various degrees of autonomy. No modern weapon is derived from a single technology; it is more apt to think of them as systems that comprise a diversity of technologies that have been brought together. It is therefore useful to think of robotics’ functional constituent parts. Moreover, these “parts” bleed into much of the story that follows.

Simply put, a robot is a physically existing machine built according to the logic of “recognize-think-act,” which must have all three elements: sensors for the apprehension of sensorial stimuli channeled through visible light, the wider electromagnetic spectrum,[47] sound waves, or any other detectable medium; a computer center; and effectors that enable interaction with the environment, including the ability to move. In practice, developments in sensing, thinking, and effectors have been intertwined activities. Indeed, there has been significant complementarity in their operations and the entanglement of their genealogies.

Furthermore, many robots put to military use are, like many other contemporary national security technologies, not really defense objects per se. Unlike during the Cold War, spending on research and development (R&D) in many Western nations on national security–relevant technology now occurs as much, if not more, in the private sector as through defense-funded projects. Consequently, defense is no longer thought of as the primary driver of technological innovation in the national security domain. Instead, militaries increasingly look to leverage technologies with dual-use potential primarily developed in the commercial sector. Artificial intelligence, autonomous systems, and advanced supercomputing are seen as powering the next generation of combat systems.[48]

Robots can be an automatic or autonomous type of technology. They may be uncrewed, but that does not mean they are autonomous. Predator uncrewed aerial vehicles flown by human operators, for example, are not fully autonomous.[49] The ability to make decisions and take action independent of humans puts autonomous robots in a particular class of technology. As the authors of one leading report from Harvard's Belfer Center conclude, "AI is often identified as the emerging technology that could most influence military power, whether by automating and improving tasks such as imagery analysis and logistical support functions; assisting decision-making by fusing data from many sources and producing recommended courses of action; or facilitating the development of fully autonomous systems, including weapons that can select and engage targets on their own."[50] For this reason, discussion of robotics and warfare cannot be disentangled from debates about the evolving impact of AI technology on the national security landscape.

Today's AI appears on many levels to be superhuman. Intelligent machines can now outperform the very best human chess and poker players.[51] Moreover, AI increasingly displays the sorts of skills in some areas that we associate with humanlike intelligence, even if this remains limited for now. Even at this stage, AI has progressed sufficiently for some that it is "capable of transforming war, bringing changes more radical than those wrought by earlier technologies, even nuclear weapons."[52]

As potential warfare among the major powers grows increasingly rapid and multidimensional, including in cyberspace and outer space domains, governments and their military commanders may choose to place—or have little choice but to place—ever-greater reliance on intelligent machines for monitoring enemy actions and initiating appropriate countermeasures. This could provide an advantage on the battlefield, where rapid and informed action could prove the key to success, but it also raises numerous concerns, especially regarding nuclear crisis stability. Some of the weapons now in development, such as uncrewed antisubmarine wolfpacks, could theoretically endanger the current equilibrium in nuclear relations among the major powers, which rests on the threat of assured retaliation by invulnerable second-strike forces.

Technologies are characterized not just by their origin and intended purpose but by the ways in which they are employed and, equally, how they are perceived. Their effects throughout the world system are also intrinsically linked to how quickly (or slowly, in some cases) new technology diffuses, who develops it, and who uses it.

Creation, Diffusion, and Adoption of Cutting-Edge Weapons

Who in the international system will take the lead in the employment of robots for military purposes? Will those able to harness the new technology be many or few? As the authors of a recent special issue on the impact of the 4IR on military innovation note, "Technologies and resulting capabilities rarely spread themselves evenly across geopolitical lines. The diffusion of new and potentially powerful militarily relevant technologies—as well as the ability of militaries to exploit their potential—varies widely across the globe."[53] And this point also stands for the originators of technology (and the science behind it). These things will matter a great deal as warfare enters the robotics age.

Who Creates Cutting-Edge Weapons?

Who will produce the most powerful military robots of the future? A progenitor of new technology like advanced robots stands to accrue considerable advantages over less inventive and industrial rivals. Yet, today, not more than a handful of states is capable of producing major breakthroughs in military technology.[54] As M. Zachary Taylor has recently argued, "Despite our heightened respect for innovation and an incredible surge in the supply and demand of everything S&T related, vast differences in national S&T performance abound, even among wealthy, industrialized democracies."[55] Moreover, the ability to create truly novel technology is arguably becoming increasingly concentrated,[56] even if existing technology is diffusing at an accelerating pace.[57] Only a small pack of states is capable of producing novel and significant military technologies, and of these, the United States remains some paces in front of the others. Harvey Sapolsky notes, “The United States takes on a difficult job in seeking true innovation; others generally focus on what is innovative for them but would not produce technology new to the United States. Moreover, the US level of effort creates innovative capability in many technical areas, while other countries focus at most on one or two.”[58]

For decades after the outbreak of World War II, the United States was globally dominant across a range of technology areas (especially computing, telecommunications, software, aerospace, and composite materials), but during the 1970s it began losing market share in many of the technologies originating there to countries such as Germany and Japan, as well as later to Taiwan and South Korea. This decline has arguably continued, and the question remains whether the United States can reverse this trend and remain the world’s technological leader, including in those technologies relevant to robotics.[59] Only the strongest states can maintain the high levels of long-run, risky investment in R&D required to generate major technological innovations in robotics. A partial exception to this rule is perhaps the Republic of Korea—a middle power at best—which has invested heavily in robotics in recent decades.

The US Department of Defense is spending billions of dollars on AI, robotics, and other cutting-edge technologies, contending that the United States must maintain leadership in the development and utilization of those technologies lest its rivals use them to secure a future military advantage. China is assumed to be spending equivalent sums, indicating the initiation of a vigorous arms race in emerging technologies. “Our adversaries are presenting us today with a renewed challenge of a sophisticated, evolving threat,” Michael Griffin, US undersecretary of defense for research and engineering, told Congress in April 2018. “We are in turn preparing to meet that challenge and to restore the technical overmatch of the United States armed forces that we have traditionally held.”[60]

But being a leader in a science and technology field does not automatically translate into innovation. Why are some states more innovative than others? Some scholars have recently attempted to show why international security concerns propel states to create and exploit new technologies. External threat serves to compel states into action. Because domestic S&T capabilities enhance a nation’s military economic security, M. Zachary Taylor writes, “threats to a nation’s military or economic security will tend to increase and broaden support for S&T

progress."[61] This makes sense. Threats to a state's national security raises the benefits of technological advancement while increasing the costs of technological stagnation. If this preposition is credible, we would expect to see a correlation between the level of innovation in the use of military robots and national security threats.

First Movers and Imitators

Because of the long-term financial investment in technology and the required skill levels to perform cutting-edge scientific research, only leading powers are positioned to create the kinds of new military technology that lead to military revolutions.[62] "Great powers," John Mearsheimer notes, "always prefer to be the first to develop new technology."[63] Existing within a competitive environment, states seek to sustain or increase their relative power by improving upon their military capabilities, preferably stealing a march on rivals by being the first to employ a new cutting-edge weapon.[64]

It is questionable whether being the first mover is such an advantage. There are historic examples of greater payoffs from learning from and improving upon the innovations of the first mover.[65] For this discussion, the actual outcomes are less important than the perceived benefits at the time. Though few states produce really novel technology or can make substantial breakthroughs in existing technology areas, other states can ultimately benefit from the innovation and invention of others through emulation.

Although societies differ in regard to capacity to learn and to absorb military and productive technologies, less advanced societies may enjoy what Alexander Gerschenkron called the advantages of backwardness. Imitators, who have lower standards of living and less wasteful habits, can use the imported technology more efficiently. This speaks to Leon Trotsky's idea that backward societies are able to skip historical stages by combining backward forms and more advanced forms in a unique amalgam.[66] Thus, according to Robert Gilpin, "with lower costs, untapped resources, and equivalent technology, backward societies frequently can outcompete the more affluent advanced society economically and militarily."[67] Youthful or rapidly developing states may be able to adopt the most advanced and already proven technologies, whereas prior R&D costs and vested interests deter more advanced economies from substituting the very latest techniques for obsolescent ones. Mature economies also have more vested interests that resist the loss of their privileges.[68]

A key question for the future of warfare is how much advantage leaders in military robots will acquire over others and how long this advantage will last for. Will lesser states be able to quickly imitate demonstrable gains in robotic warfare? Novel technology that is difficult for others to imitate can lead to strategic openings.

Kenneth Waltz has argued that "contending states imitate the military innovations contrived by the country of greatest capability and ingenuity."[69] There is a prescriptive element to this claim: disadvantages arise from not imitating. States may tend toward isomorphism in their military structures, but this may occur after a period has elapsed during which one state has enjoyed certain advantages over others.[70] The US monopoly of nuclear weapons was brief—and far briefer than American policymakers and Soviet watchers believed it would be—but it was significant for a period.[71]

Yet states may want to imitate the success in military robots of the international system's leading state or states, but this desire may not be obtainable.[72] If they cannot build or import cutting-edge military robots, the potential benefits are all but hypothetical.[73] When it comes to relative advantages gained from military robots, much depends on how long first movers—the original creators and exploiters of the technology—hold onto their comparative advantage and how long it takes others to access this technology or imitate it themselves. In short, how rapidly will a technology like advanced military robots diffuse to others?

Diffusion of Technology

To be sure, some technologies diffuse faster than others. Night-vision googles allowed US forces to "own the night" by providing American soldiers with something their adversaries did not possess. These devices, however, soon became ubiquitous across all battlefields and diffused downward to nonstate violent actors also.[74] Similar initial advantages afforded to early European adopters of gunpowder soon equalized—in Europe at least—as the innovation in firearms was emulated by all.

The ability to integrate and exploit new technological advances is one of the primary ways a state can stay ahead of its rivals or close the gap with stronger competitors. The extent to which emerging technologies lead to increases in military power depends on factors that are difficult to anticipate, however.[75] Competitors may not be able to imitate, due to their inability to obtain sensitive technology as a consequence of export controls imposed by the producer.[76] Lack of access to advanced military robots, for example, may propel them to attempt to develop countertechnologies—such as new cyber or electronic warfare capabilities—to offset the perceived advantages of rivals.[77] Attempts at technological military change are often a response to the innovations of others and lead to novel approaches in their own right.

Ceteris paribus, the lower the fixed-cost investments, the greater the number of expected actors who will be able to develop and consume the technology in question. Yet some technologies, even after standardization, still require considerable investments. This could be because the costs of production are high or the disruptive effects of an innovation on organizations are significant enough to make the costs of adaptation equally high.[78] Most countries—including modern European nations—do not possess the specialized personnel needed to effectively operate modern weapon systems.[79] The difficulty the Soviet navy faced in its efforts in aircraft carrier warfare is illustrative of the manifest challenges even great powers face in adopting some innovations.[80] Advanced military robots, as later chapters explicate, will place great demands on states' armed forces, slowing the pace of diffusion through the international system.

Another factor in the rate of diffusion is whether the new technology primarily caters to the public sector or the private sector. Many significant technological innovations qualify as "general-purpose" technologies that both the security and civilian sectors can exploit. Others have circumscribed civilian use. Major technological innovations with low fixed costs and significant private-sector possibilities can be more readily thought of as general-purpose tech. They may have been developed with public-sector purposes in mind, but the commercial applications are so manifest that private-sector activity begins driving the technology. This has already happened to some degree with drones and, as later sections of the book suggest, may also be increasingly the case with robots in other domains.

History should remind us—though it is often underutilized as the teacher it is—that even if a technology has tremendous potential for end users, there are no certainties about who will decide to adopt it or, at the very least, attempt to do so. To be sure, there are often steep hills to climb in the process of incorporating military-related technologies. Adopting new technology is often not easy. Some militaries are better than others at integrating new technology, especially as it increases in complexity and places ever-greater demands on would-be adopters. As Posen reminds us, the United States' "development of new weapons and tactics depends on decades of expensively accumulated technological and tactical experience."[81] It is important to bear in mind that the "ability to conceive of, and implement, organizational and operational means for coordinating new weapon systems as well as new and existing ones should not be assumed."[82]

Yet, even when a new technology seems commonsensical and makes existing equipment or methods outdated, would-be adopters may be resistant to make the necessary organizational changes.[83] As Evan Braden Montgomery notes, "Military organizations are often reluctant to adopt alternative ways of doing business that clash with existing modes of operating, endanger the position of influential warfighting communities, and impose substantial adjustment or opportunity costs."[84] Bureaucracies—and especially militaries—are designed to conduct established tasks with uniformity and regularity. As political scientist Stephen Rosen similarly points out, organizations, and especially military organizations, have difficulty changing because "they are *designed not to change*."[85] This creates a major dilemma: militaries need to innovate but resist innovation due to their inherent bureaucratic attributes. Some scholars posit that it takes civilian leaders facing a national emergency (i.e., when their attention is for a time overwhelmingly focused on military matters) to force such change upon their militaries. When it comes to various types of military robots, much depends on whether the emerging technology supplements existing capabilities or leads to new weapons systems that demand the creation of novel warfighting concepts.

The rate at which advanced and increasingly autonomous military robots are adopted is influenced by whether they are thought of by their existing and prospective end users as a disruptive or sustaining technology. In his groundbreaking work on categorization of technological innovations, Clayton Christensen divided technologies between those that lead to "disruptive" innovations and those that produce "sustaining" ones.[86] Ever since, the idea of disruptive innovation has become indelibly associated with exciting and transformational technology. Some advocates of military transformation in the United States and elsewhere in the West have used "disruptive innovation" as an evocative shorthand to push for major changes they believe are necessary. While that might be the case, organizations are more likely to accept a new technology if innovators situate it within existing paradigms—that is, they demonstrate how it sustains and enhances existing ways of doing things.[87] Indeed, champions of new technology may even downplay the expected disruption caused by introducing a new technology. Early advocate of air power Giulio Douhet acknowledged such duplicity in his initial attempts to convince military leaders about the potential contribution of airplanes. In the 1921 edition of *The Command of the Air*, he called for an auxiliary air arm to support land and sea forces. He later wrote in the preface to the 1927 edition why he presented airpower as a sustaining technology: "At that time [in 1921], in order to accomplish anything practical and useful for my country, I had to be careful not to oppose too strongly certain notions firmly held in high places. Therefore, I was forced to emasculate my thought, confining myself to indispensable fundamentals, and wait for more favorable circumstances before presenting my ideas in full."[88]

Military robots have been and continue to be designed and built to perform multitudinous tasks and thus vary considerably in the scale of change required by militaries to adopt them. Subsequent sections of this book deal directly with how various military organizations are currently attempting—successfully or otherwise—to incorporate robotic systems.

Military robots hold out considerable potential for militaries of different sizes and configurations. As with other useful technologies, it will likely take military organizations longer to integrate such systems into existing doctrine and organizational processes than many analysts anticipate. Even as aspects of the technology become more and more readily available throughout the international system, some actors will be better placed to adopt and efficaciously utilize military robots than others. It may take a major military upset to jolt military organizations and their civilian leaderships into adopting a more radical and accelerated position vis-à-vis the utilization of military robots. Indeed, militaries in particular are arguably more open to innovation if they suffer a serious defeat, such as the energetic reforms of the Prussian army following its complete collapse in 1806.[89]

Hyping Robots

This book seeks to anticipate the unknowable: the role of robots in future war. It therefore has technology—a technology—as its core subject of interest. Isolating one particular technology runs the danger of overplaying its significance in relation to other factors, including other technologies, that will undoubtedly shape the wars of tomorrow. In undertaking this endeavor, care must be taken to not reflexively inflate the potential impact of military robots or take a technologically deterministic approach. Indeed, part of the purpose of this book is to offer an antidote to much of the hype surrounding robotics in warfare that often verges on boosterism.

Technological advances, especially in the area of military systems, are a continuous, dynamic process. Yet the impact of new technology on military effectiveness and the relative comparative advantage that might be gained are hard to predict. Moreover, many important technological innovations have arisen not from a single breakthrough but from a confluence of many individual advances over an extended period. It is therefore difficult to predict when technological developments will coalesce into a revolution in military affairs with all the broader societal and political effects that follow.

Although it is inherently difficult to know in advance which technologies will ultimately leave the biggest imprint on war, there is no shortage of those willing to offer up their predictions. Military commentators, techno-enthusiasts, and literary giants have all joined in the game of predicting what future war will look like and typically give center stage to a favored technology as the key causal variable leading to change. Indeed, military robotics has for a long time fueled imaginations about war over the horizon. This continues today. We are repeatedly told that we are on the cusp of a robotics revolution that will not only shape future war but recast its fundamental nature. A recent British military assessment, for example, asserts, "The increased capability of robots is likely to change the face of warfare." Revolutionary change to war is predicated on the belief that countries will replace large numbers of troops with robots in the decades ahead.[90] Essentially, a future battlefield largely depopulated, bereft of human participants, is often imagined. As a form of extreme remote warfare, robotic warfare will further "de-risk" violence.

Robots, especially those created for military purposes, are not the only technology currently being hailed as a "game changer." But their prospective widespread usage in the near future—not least because of their potential to remove humans from much of the battlefield—is predicted to be the most revolutionary development in warfare since the advent of nuclear weapons. That advances in robotics technology might hold such revolutionary potential chimes with recent thinking about the factors shaping war, which place emerging technology front and center. Indeed, there is a strong case to be made that much analysis of war in the modern era is infused with what can best be termed *technological determinism*. This is best characterized as an ingrained certainty that technology will have an inordinate influence over developments and that its impact will always eventually be felt regardless of any initial or future inhibitors that stand in the way of realizing its potential.

Such technological determinism is true of much of the discussion about robots, especially increasingly autonomous ones, perhaps more so than for any other area of technology today. For many years now, we have been told that we are nearing a robotics revolution in military affairs. This book attempts to take stock of such claims. It interrogates the field of robotics, and autonomous systems more generally, to provide a soberer account of the place of robots in warfare, in the past, present, and future.

It would not be a surprise if the near-term impact of military robotics on war was being exaggerated. International relations scholars and military historians have long observed, albeit episodically, that new technologies often trigger intense enthusiasm among civilian leaders, defense planners, and military officers—or hype.[91] Jeremy Black, for example, has noted the preference among end users and defense analysts for "magic bullet" technology. Such a perspective underplays the incremental character of technological advances.[92]

Hype about any given military technology can raise excessive expectations about the near-term readiness of the technology to perform.[93] This uncertainty about the readiness of any given technology is further complicated because of the three-way interaction between designers, the military (as end user), and policymakers.[94] All have varying motives and needs. Boosters of the technology may underplay the myriad technical hurdles and adoption challenges that lay ahead. The resulting overpromise/underdelivery dynamic holds within it technologist Roy Amara's now famous adage (referred to Amara's law): "We tend to overestimate the effect of a technology in the short run and underestimate the effect in the long run."[95] This could, for instance, lead to the early abandonment of tried and trusted tools or methods in favor of unproven technology whose potential is latent and unproven.

But some level of hype about military robots might prove crucial in the process of their innovation and eventual fielding on the battlefield. Hype might be important in stimulating interest in a cutting-edge robotic system from purse-string holders at a critical stage in its innovation life cycle. As technological innovation expert Sjoerd Bakker posits,

> An innovation may also need a hype to gain legitimacy and credibility in its early stages of development. That is, innovation relies not only on scientific and technological achievements and breakthroughs but also on expectations of future potential. More specifically, expectations of technological progress help to stimulate, steer and coordinate collective action on the sides of researchers, engineers, firms, and funding agencies in order to make the innovation work.[96]

Many technologies have surely benefitted from hype through injections of monies in their early stages of development to get them off the ground. But there are also many examples of technological innovations that were heralded as revolutionary but then gradually fizzled out over the years, such as supersonic air travel or the high-powered lasers of ballistic missile defense.

In some cases, truly technological innovation may go unnoticed, sometimes by its own creator. Rocket propulsion, for example, was dismissed out of hand only to be picked up decades later. Clearly technologies do not have predetermined developmental paths. Recognizing a true innovation or gauging its revolutionary potential is neither simple nor clear-cut. Its ultimate impact on the world is highly contingent on a wide range of material and human factors. Military robots will be no different.

Where Rubber Meets the Road

This introductory chapter has laid out a range of theoretical questions and issues related to technology and warfare to which our examination of the evolving place of military robots has much to contribute.

Before moving on to the analytical chapters ahead, some clarifications on terminology. First, in the English language the term *unmanned* has often been used in relation to robotic vehicles or systems and derives from *manned*. *Manned* comes from the old English *mannian*, "to furnish (a fort, ship, etc.) with a company of men," with the meaning of taking up a specific position on a ship found in use by the 1690s.[97] In 2006, NASA decided to move toward using non-gender specific terms in its space program and began using *crewed* and *uncrewed* (rather than, say, *crewless*). In 2018, the matter as related to aviation was raised by Canada with the need for change then formally recognized by the International Civil Aviation Organization.[98] In the early 2020s, *uncrewed* became more frequently used in place of *unmanned* in any situation, although at times large organizations such as the US Department of Defense used both. *Manned* is now clearly anachronistic. We prefer to use *uncrewed* in this book, but retain *unmanned* as necessary for historical accuracy and when used in the titles of earlier publications.

Second, it must be acknowledged that scholars from different parts of the academy—including the social sciences—interested in science, technology, and innovation mean markedly different things when they use the term *technology*. It is an imprecise concept. Technology can refer to products, to skills, or to the activities undertaken in developing technologies.

Here we largely follow Jeremy Black's view that technology can best be thought of "as a relationship between materials and human ingenuity."[99] In this reading, it is the process of applying scientific knowledge to materials to fabricate an object. This analysis employs the more limited sense of the term *technology* as a process that intends to result in a product (i.e., as a weapon in a military context). Although the phrase "military technology" is used throughout, the origins of any given technology may be either civilian or derived from a military need.[100]

Third, while it is true that increases in scientific knowledge, organized and applied for practical purposes, can lead to advances in technology, science (by which we mean the knowledge obtained by the systematic study of the structure and behavior of the natural world) remains distinct from technology. Scientific progress can be purely theoretical; this book is more interested in change embodied in new *products* that shape military power. However, we recognize that the distinction between the two has become increasingly close with the decrease in time elapsed between laboratory and production line.

Hovering around the term *technology* throughout this book is the word *innovation*. Innovation is thought of here as the introduction or development of a new technology or the adaptation of established technology to a new use.[101] For the purposes of this book, military innovation is limited to improvements in technology and the way this technological change is put to use. Typically, innovation implies gains in effectiveness toward a given pursuit. Understood here, innovation does not include changes or improvements in doctrine, organizations, policies, or institutions that may occur independently of technology.[102] This more circumscribed definition has drawbacks but is a necessary compromise for a more laser-like focus on the impact of robotics on war.

The remainder of this book engages with key theoretical debates but does not lose sight of the goal that conclusions reached have real-world relevance. While the moral, ethical, and legal dimensions of war robots are being hotly debated, scant work addresses operational concepts, organizational and tactical reforms, or verification and validation tests for the emerging systems.[103] To that end, this book is concerned with the designs, material inputs, and operational principles behind military robots as technical objects.

There has been a tendency in international security scholarship to consider a technical understanding of weapons and other national security technologies as edging toward superfluous granularity. Yet, in order to properly evaluate the current and latent potential of any weapon, we must have a keen appreciation of how it functions.[104]

The chapters that follow are intended to fill these gaps and at the same time contribute to higher-order issues in international relations. We do not see these as two separate tasks—far from it. A firmer grasp of the actual ways that military robots have hitherto been used operationally and the likely ways they will be employed in the future is a necessary starting point for any meaningful discussion about their wider shaping effect on the politics of nations.

First, we chart the most critical developments in military robotics—both hardware (i.e., the mechanical platforms and their physical subcomponents) and software, especially artificial intelligence's ability to learn—and explain the persistent challenges inherent in maturing these sophisticated technologies. Second, we offer a comparative study of nations' current strategies in the field of military robotics and their scientific and industrial capabilities for realizing these ambitions. Third, we provide sweeping analysis of evolving military thought about the application of increasingly autonomous robots across various domains. Lastly, we theoretically explore how developments in military robots and their widespread employment might affect higher-order issues in international relations, such as the distribution of power, deterrence, the offense-defense balance, arms race dynamics, and the onset of war.

Notes

1. For how we define technology, see later sections.

2. A number of studies have found that sudden shifts in the military balance between dyads—especially those with a history of animosity—raise the likelihood for war. For synoptic coverage of work on this theory, refer to Daniel S. Geller and J. David Singer, *Nations at War: A Scientific Study of International Conflict* (Cambridge: Cambridge University Press, 1998), 147. See also Robert Gilpin, *War and Change in World Politics* (Cambridge: Cambridge University Press, 1981), 59–62; Robert Powell, *In the Shadow of Power: States and Strategies in International Politics* (Princeton, NJ: Princeton University Press, 1999).

3. Evan Braden Montgomery, "Breaking Out of the Security Dilemma: Realism, Reassurance, and the Problem of Uncertainty," *International Security* 31, no. 2 (2006): 151–185.

4. On this point as it relates to uncrewed aerial systems, see Ash Rossiter, "Military Technology and Revolutions in Warfare: Priming the Drone Debate," *Defense and Security Analysis* 39, no. 2 (2023): 253–255.

5. Klaus Schwab, *The Fourth Industrial Revolution* (New York: Currency, 2017).

6. Schwab, *The Fourth Industrial Revolution*, 80–81.

7. Peter W. Singer, *Wired for War: The Robotics Revolution and Conflict in the 21st Century* (New York: Penguin, 2009), remains an indicative example of this position.

8. Robert O. Work, “Preface,” in *Artificial Intelligence: What Every Policymaker Needs to Know*, ed. Paul Scharre and Michael C. Horowitz (Washington, DC: Center for a New American Security, June 2018), 2.

9. Geoffrey L. Herrera, *Technology and International Transformation: The Railroad, the Atomic Bomb, and the Politics of Technological Change* (New York: State University of New York Press, 2006), 3.

10. Kenneth N. Waltz, *Theory of International Politics* (New York: Random House, 1979).

11. Hans Morgenthau, *Politics Among Nations: The Struggle for Power and Peace* (Beijing: Peking University Press, 1997), 139.

12. Keith Krause, *Arms and the State: Patterns of Military Production and Trade* (Cambridge: Cambridge University Press, 1992), 19.

13. See Colin S. Gray, *Perspectives on Strategy* (Oxford: Oxford University Press, 2013); Jeremy Black, *War and Technology* (Bloomington: Indiana University Press, 2013).

14. See, e.g., Gilpin, *War and Change*.

15. Havard Hegre, “Development and the Liberal Peace: What Does It Take to Be a Trading State?” *Journal of Peace Research* 37, no. 1 (2000): 5–30.

16. Jeremy Youde, *Global Health Governance in International Society* (Oxford: Oxford University Press, 2018).

17. On the idea that business theories may also be fruitful for students of military innovation, see Gautam Mukunda, “We Cannot Go On: Disruptive Innovation and the First World War Royal Navy,” *Security Studies* 19 (2010): 126. See also E. Cefis and O. Marsili, “A Matter of Life and Death: Innovation and Firm Survival,” *Industrial and Corporate Change* 14 (2005): 1167–1192.

18. Charles L. Glaser, “The Security Dilemma Revisited,” *World Politics* 50, no. 1 (1997): 171.

19. Mark Z. Taylor, *The Politics of Innovation: Why Some Countries Are Better Than Others at Science and Technology* (Oxford: Oxford University Press, 2016). See also Vernon W. Ruttan, *Is War Necessary for Economic Growth? Military Procurement and Technology Development* (New York: Oxford University Press, 2006); Merritt Roe Smith, ed., *Military Enterprise and Technological Change: Perspectives on the American Experience* (Cambridge: MIT Press 1985).

20. Barry Posen, *The Sources of Military Doctrine: France, Britain, and Germany Between the World Wars* (Ithaca, NY: Cornell University Press, 1984), 239–240.

21. Mathew Evangelista, *Innovation and the Arms Race: How the United States and the Soviet Union Develop New Military Technologies* (Ithaca, NY: Cornell University Press, 1988).

22. John J. Mearsheimer, *The Tragedy of Great Power Politics*, updated ed. (New York: W. W. Norton and Company, 2014), 231.

23. Taylor, *The Politics of Innovation*, 5.

24. Taylor, *The Politics of Innovation*, 42.

25. Lilach Gilady, *The Price of Prestige: Conspicuous Consumption in International Relations* (Chicago: University of Chicago Press, 2018).

26. Paul Musgrave and Daniel Nexon, “Defending Hierarchy from the Moon to the Indian Ocean: Symbolic Capital and Political Dominance in Early Modern China and the Cold War,” *International Organization* 72, no. 3 (2018): 591–626.

27. Colin S. Gray, *Strategy for Chaos: Revolutions in Military Affairs and the Evidence of History* (London: Frank Cass, 2002); Max Boot, *War Made New: Technology, Warfare, and the Course of History: 1500 to Today* (New York: Gotham Books, 2006); Andrew Krepinevich, “Cavalry to Computer: The Pattern of Military

Revolutions," *National Interest* 37 (1994): 30–43; Martin Van Creveld, *The Transformation of War* (New York: Free Press, 1991); Thomas G. Mahnken, *Technology and the American Way of War Since 1945* (New York: Columbia University Press, 2008).

28. MacGregor Knox and Williamson Murray, eds., *The Dynamics of Military Revolution, 1300–2050* (New York: Cambridge University Press, 2001), 6–7.

29. Revolutions in military affairs or major military innovations can also, of course, be driven by major organizational changes to militaries. See Michael C. Horowitz, *The Diffusion of Military Power: Causes and Consequences* (Princeton, NJ: Princeton University Press, 2010), 22.

30. Adam N. Stulberg, "Managing the Unmanned Revolution in the U.S. Air Force," *Orbis* 51, no. 2 (2007): 251–265.

31. This, for some thinkers, does not make his contribution to understanding war any less enduring. See, e.g., Michael I. Handel, "Clausewitz in the Age of Technology," *Journal of Strategic Studies* 9, no. 2–3 (1986): 51–92.

32. David Gates, *The Napoleonic Wars, 1803–1815* (London: Hodder Education Publishers, 1997).

33. Though the debate on the importance of technology in the war has matured, with other variables now synthesized into the explanation for the overwhelming victory. See Stephen Biddle, "The Gulf War Debate Redux: Why Skill and Technology Are the Right Answer," *International Security* 22, no. 2 (1997): 163–174.

34. Carlo Cipolla, *Guns, Sails and Empires: Technological Innovation and the Early Phases of European Expansion, 1400–1700* (New York: Pantheon Books, 1965); Gilpin, *War and Change*; Herrera, *Technology and International Transformation*.

35. Gray, *Strategy for Chaos*; Boot, *War Made New*; Krepinevich, "Cavalry to Computer," 30–43; Creveld, *The Transformation of War*; Mahnken, *Technology and the American Way of War Since 1945*.

36. See Horowitz, *The Diffusion of Military Power*, 22.

37. Williamson Murray, *America and the Future of War: The Past as Prologue* (Stanford, CA: Hoover Institution Press, 2017), 34–35.

38. Manuel De Landa, *War in the Age of Intelligent Machines* (New York: Zane Books, 1991), 46.

39. Daniel W. Drezner, "Technological Change and International Relations," *International Relations* 33, no. 2 (2019): 287.

40. The expected psychological effects on the recipient of a nuclear explosion were of course also a crucial purpose behind building a nuclear device.

41. Charles Weiss, "Science, Technology and International Relations," *Technology in Society* 27 (2005): 297.

42. Richard Jervis, "Cooperation Under the Security Dilemma," *World Politics* 30 (1978): 188–190.

43. For definitions and discussions of these concepts, see Jervis, "Cooperation Under the Security Dilemma," 186–214; Glaser, "The Security Dilemma Revisited," 185–188; Sean M. Lynn-Jones, "Offense-Defense Theory and Its Critics," *Security Studies* 4, no. 4 (summer 1995): 660–691.

44. Alexander Wendt, *Social Theory of International Politics* (Cambridge: Cambridge University Press, 1999), 225.

45. Thomas C. Schelling, *Arms and Influence*, new ed. (New Haven, CT: Yale University Press, 2008), 249.

46. See Keir Lieber, "Grasping the Technological Peace: The Offense-Defense Balance and International Security," *International Security* 25, no. 1 (2006): 71–104; Stephen Van Evera, *Causes of War* (Ithaca, NY: Cornell University Press, 1999).

47. While all electromagnetic frequencies hold military potential, the lower frequencies of infrared, microwaves, and radio waves are the portions of the spectrum most relevant.

48. Michael Raska et al., "Introduction," in "Defence Innovation and the 4th Industrial Revolution: Security Challenges, Emerging Technologies, and Military Implications," special issue, *Journal of Strategic Studies* 44, no. 4 (2021): 452.

49. On this point, see Brian Dunn, "The Future for Unmanned Surface Vessels in the US Navy," *Georgetown Security Studies Review*, October 28, 2020.

50. Greg Allen and Taniel Chan, "Artificial Intelligence and National Security," Belfer Center, July 2017; Michael C. Horowitz, "Artificial Intelligence, International Competition, and the Balance of Power," *Texas National Security Review* 1, no. 3 (May 2018).

51. Kenneth Payne, *I, Warbot: The Dawn of Artificially Intelligent Conflict* (London: Hurst & Co, 2021), 28.

52. Payne, *I, Warbot*.

53. Raska et al., "Introduction," 452.

54. Jeffrey W. Taliaferro, "State Building for Future Wars: Neoclassical Realism and the Resource Extractive State," *Security Studies* 15, no. 3 (2006): 464–495.

55. Taylor, *The Politics of Innovation*, 4.

56. Mauro Gilli, "The Struggle For Military-Technological Superiority: Complexity, Systems Integration and the Industrial Challenges of Imitation" (PhD diss., Northwestern University, 2015).

57. Horowitz, *The Diffusion of the Military Power*.

58. Harvey M. Sapolsky, "Calm Down, Folks: Enemies Still Fear US Military Tech Innovation," *Defense One*, May 17, 2018.

59. See, e.g., Robert D. Atkinson and Stephen J. Ezell, *Innovation Economics: The Race for Global Advantage* (New Haven, CT: Yale University Press, 2012).

60. Paul McLeary, "USAF Announces Major New Hypersonic Weapon Contract," *Breaking Defense*, April 18, 2018.

61. Taylor, *The Politics of Innovation*, 15.

62. Theo Farrell, Sten Rynning, and Terry Terriff, *Transforming Military Power Since the End of the Cold War* (Cambridge: Cambridge University Press, 2013).

63. Mearsheimer, *The Tragedy of Great Power Politics*, 232.

64. David A. Fastabend and Robert H. Simpson, "Adapt or Die," *Army* 54, no. 2 (February 2004).

65. Japan and the United States accrued greater benefits from carrier warfare even though Britain was the first mover. See Thomas C. Hone, Norman Friedman, and Mark D. Mandeles, *American and British Aircraft Carrier Development, 1919–1941* (Annapolis, MD: Naval Institute Press, 1999).

66. Trotsky quoted by Baruch Knei-Paz, *The Social and Political Thought of Leon Trotsky* (Oxford, UK: Clarendon Press, 1978), 91–92.

67. Gilpin, *War and Change*, 178–179.

68. Anthony Brown, *Inside Bureaucracy* (Boston: Little, Brown and Company, 1967), 158–166.

69. Waltz, *Theory of International Politics*, 127; Colin Elman, "The Logic of Emulation: The Diffusion of Military Practices in the International System" (PhD diss., Columbia University, 1999).

70. Waltz, *Theory of International Politics*, 127.

71. On military emulation, see João Resende-Santos, "Anarchy and the Emulation of Military Systems: Military Organizations and Technology in South America, 1870–1930," in *Realism: Restatement and Renewal*, ed. Benjamin Frankel (London: Frank Cass, 1996).

72. Emily O. Goldman and Andrew L. Ross, "Conclusion: The Diffusion of Military Technology and Ideas—Theory and Practice," in *The Diffusion of Military Technology and Ideas*, ed. Emily O. Goldman and Leslie C. Eliason (Stanford, CA: Stanford University Press, 2003), 371–403. Technology transfer may be more likely if issues of interoperability between the allies' forces are at stake. See Ina Wiesner, *Importing the American Way of War? Network-centric Warfare in the UK and Germany* (Baden Baden: Nomos Verlag, 2013); Theo Farrell, *A Transformation Gap: American Innovations and European Military Change* (Stanford, CA: Stanford University Press, 2010).

73. On the diffusion of military and economic techniques from the dominant state in the system to other states, refer to Gilpin, *War and Change*, 176–177.

74. On the issue of how diffused technologies have benefited nonstate violent actors, see Audrey Kurth Cronin, *Power to the People: How Open Technological Innovation Is Arming Tomorrow's Terrorists* (New York: Oxford University Press, 2020).

75. Evan Braden Montgomery, "Signals of Strength: Capability Demonstrations and Perceptions of Military Power," *Journal of Strategic Studies* 43, no. 2 (2020): 321.

76. J. Reppy, "Dual-Use Technology: Back to the Future?" in *Arming the Future: A Defense Industry for the 21st Century*, ed. A. R. Markusen and S. S. Costigan (New York: Council on Foreign Relations, 1999), 269–284.

77. Taliaferro, "State-Building for Future Wars," 466.

78. Horowitz, *The Diffusion of the Military Innovation*.

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93. See esp., Ash Rossiter, "High-Energy Laser Weapons: Overpromising Readiness," *Parameters* 48, no. 4 (2018): 35–46.

94. On this point, see Black, *War and Technology*, xiii.

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99. Black, *War and Technology*, x.

100. For a fuller discussion on these issues, see W. A. Smit, "Science, Technology and the Military: Relations in Transition," in *Handbook of Science and Technology Studies*, ed. S. Jasanoff et al. (London: Sage, 1995), 598–626.

101. Although military innovation has emerged as one of the most important topics in strategic studies, there is a remarkable lack of consensus about the term. For a recent discussion on this that attempts to develop a common framework, refer to Michael Horowitz and Shira Pindyck, "What Is Military Innovation and Why It Matters," *Journal of Strategic Studies* 46, no. 1 (2023): 85–114.

102. See Taylor, *The Politics of Innovation*, 29.

103. On this point, albeit related more specifically to the military implications of AI, refer to F. G. Hoffman, "Will War's Nature Change in the Seventh Military Revolution?" *Parameters* 47, no. 4 (winter 2017–2018).

104. For example, see, esp., Barton C. Hacker, "Military Institutions, Weapons, and Social Change: Toward a New History of Military Technology," *Technology and Culture* 35 (1994): 768–834.